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FOREWORD FROM THE CONFERENCE CHAIRMAN

As the U.S. begins a major build-up and re-equipment of its Armed Forces, a major challenge facing both the Services and industry is in the area of training, a fact clearly reflected in these Proceedings of the Third Interservice/Industry Training Equipment Conference held in Orlando, Florida, November 30 - December 2.

As you read or refer to this record of the conference, there are several salient thoughts which I would like to share with you.

First, these Proceedings and the rest of the conference program demonstrate the extensive efforts to which both industry and the Services have gone to in order to make this annual event the premier conference in the world on Training and Simulation Equipment.

The need for <u>realistic</u> and <u>dependable</u> methods for training operators of the new weapon systems now being acquired by the Armed Services is increasing, providing new management and technical challenges to industry. Despite advances in automation of prime equipment, and the increased use of built-in training capabilities in that prime equipment, the Department of Defense and the Armed Services continue to have significant and extensive training needs. And these requirements are clearly going to continue to grow throughout the 1980's.

Industry response to these needs, as reflected in these Proceedings and in the more than 50 exhibits at the conference, has been truly innovative. Not only is industry meeting the technical and management challenges, it is again demonstrating the cost effectiveness of training equipment over the use of operational equipment to solve training needs.

In sum, the edge we have on our adversaries is the of high technology in our weapons systems. Only with properly trained personnel can the full benefits of that technology be utilized. We are responding to that challenge.

K. Merl
ADPA Conference Chairman

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THE CHALLENGE OF VISUAL SIMULATION FOR AIR FORCE FLIGHT SIMULATORS

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ABSTRACT

The performance requirements for visual systems to support Air Force flight simulation far exceed the requirements for visual systems which support commercial airline simulators. The difference in requirements stems from the diversity and complexity of military flight missions. While visual systems for airline simulators are generally easily defined and delivered on a predictable schedule, most Air Force visual system procurements are not so straightforward. The difficulty in obtaining visual systems to meet Air Force requirements in a predictable manner arises largely from the fact that current commercially available visual systems have been designed to support airline type missions; The expansion of these systems to meet Air Force training requirements has been less than graceful. This paper examines the differences between airlines and Air Force flight missions, the impact of these differences on system performance requirements and the resultant challenges in Air Force visual system procurement for both the Air Force and the contractor.

INTRODUCTION

The acquisition of visual systems for commercial airline flight simulators (FAA Phase III requirements notwithstanding) is, relatively speaking, a straightforward process. A visual system supporting airline flight training must provide training for taxi, take-off, and landing. The basic cues required to train these tasks are relatively well defined since the training takes place within a definable environment--an airport area. Accordingly, the data base or gaming area requirements are small--on the order of one hundred square miles or less. The data base contents can usually be obtained from several airport blueprints and city street maps. The visual cues for airline tasks normally occur in the pilot's forward field-of-view and, at most, a field-of-view of plus and minus 90 degrees horizontal is required. A narrower field-of-view is usually sufficient. In addition, training of taxi, take-off and landing does not involve the need to recognize or track relatively small features at long ranges from the aircraft. Hence, only a moderate system resolution, on the order of 6 to 10 arc minutes, is required in order to provide adequate visual cues for these tasks. The ability to define the training requirements plus the fact that the resultant system technical requirements are all available within current technology has resulted in the availability of numerous "off-the-shelf" visual systems to provide high fidelity training for the commercial airlines.

For the most part, there is no such thing as "off-the-shelf" when it comes to acquisition of visual systems for Air Force simulators. The current visual system product lines of the various simulator equipment manufacturers are all targeted toward and tailored for the commercial airline market. One reason for this is the fact that the airline training scenario is so well defined and stable; It is easier to optimize a system that addresses a requirement which is not constantly in a state of flux. The second reason is two-fold but is clearly a matter of economics: 1) The commercial market exists for a standard visual product line and 2) Since the airline customer can specify exactly what he needs in a system in order to train pilots, the vendor will not end up in financial jeopardy trying to satisfy the commercial customer.

THE CHALLENGE

The challenge in acquiring simulator visual systems for the Air Force stems from the fact that current visual system technology is oriented toward meeting the needs of the commercial airlines and that Air Force training requirements are far more diverse and demanding in terms of system performance. Although take-off and landing are indeed key flight tasks for the Air Force as well as the airlines, there are a number of additional tasks which must also be trained in the simulator. These tasks are as follows:

-Aerial refueling

-Air combat

-Formation flight

-Air to surface weapons delivery

-Low altitude navigation (terrain avoidance/ terrain following)

With few exceptions, these tasks cannot be satisfied by a visual system which was designed primarily to train take-off and landing. Hence the challenge: Provide the Air Force user a visual system which will provide not only take-off and landing training but also training in various tactical and strategic tasks in between. It will be shown that this challenge belongs to both the Air Force and the visual system contractors.

Defining the Problem

Each of the training tasks listed above requires a unique set of visual cues to be displayed to the aircrew. For example, aerial refueling requires mainly a well defined tanker aircraft to be displayed moving in six degrees of freedom relative to the ownship and little or no terrain surface

CRITICAL SYSTEM REQUIREMENTS

TRAINING TASK	LARGE FOV	HIGH RESOLUTION	SCENE CONTENT
TAKEOFF/LANDING			
INSTRUMENTS			
AIR REFUELING			
AIR COMBAT (HIGH ALT.)	X	X	
FORMATION	X		
TACTICAL FORMATION	X	X	
CONVENTIONAL AIR-TO-SURFACE	X	X	
TACTICAL AIR-TO-SURFACE	X	X	X
LOW ALTITIUDE TACTICAL NAVIGATION	X	X	X*
AIR COMBAT (LOW ALTITIUDE)	X	X	X

*LARGE GEOGRAPHICAL AREA

Figure 1

information. Low-level navigation requires primarily the display of high fidelity terrain and cultural information. In order to provide the cues for a given task in a particular visual system, certain critical performance characteristics are required. The major system characteristics dictated by these cue requirements can be condensed into the following:

1. Large field-of-view
2. High resolution
3. Large gaming area
4. High scene content
5. Special effects/techniques

Figure 1 shows how each of these characteristics are related to the various Air Force training tasks. For the purposes of this paper, "large field-of-view" is taken to mean a horizontal field-of-view of from 130 to 360 degrees and a vertical field-of-view of from 36 to 360 degrees. "High resolution" is regarded as a system resolution in excess of four arc-minutes. "High scene content" implies a displayed scene density throughout most of the gaming area which is greater than that found in an airfield data base. The term "large gaming area" denotes an instantaneous on-line data base covering multiple thousands of square miles in area. "Special effects/techniques" is a catch-all reference to system features such as the depiction of artillery shell tracers, muzzle flashes, surface to air missile launches and so forth. It is important to note that none of these system characteristics are found in standard, off-the-shelf commercial visual systems. It is also important to note that in full mission weapons system trainers (WSTs) the requirement exists to train several of the discrete tasks listed above in a single simulator. As an example, a typical multi-role fighter aircraft mission scenario is depicted in Figure 2. Grouping the various mission segments together, it can be seen that the visual system for a WST for this aircraft must be capable of providing visual cues for take-off, aerial refueling, low-level navigation, terrain avoidance, air to surface weapons delivery, air to air combat and landing. Referring back to Figure 1, it can be seen that such a system must have all four of the critical system characteristics discussed earlier. Since none of these characteristics are available in off-the-shelf visual systems, the result is an acquisition program which is largely a research and development effort.

This example is, to some extent, a "worst-case" situation in which the visual system must satisfy a wide range of task requirements and, therefore, involves all of the major critical system characteristics. The Air Force simulator development program originally aimed at developing a

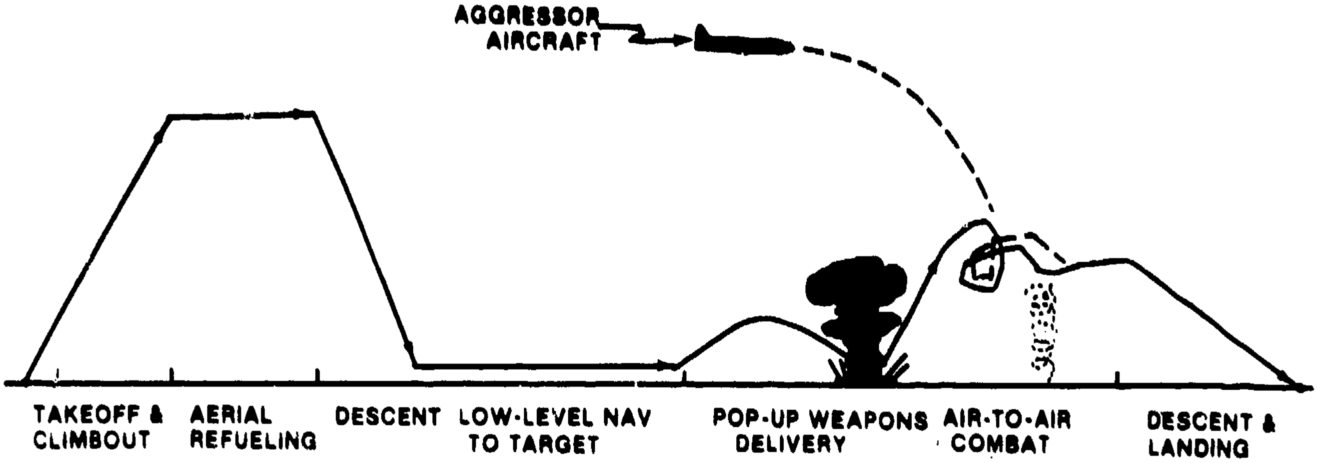

Figure 2

visual system to meet all these requirements (Project 2360, Tactical Combat Trainer) was clearly the most challenging visual system development program ever initiated by the Air Force. The basic thrust of Project 2360 was to develop a single visual system which would provide training in both air to air combat and air to surface weapons delivery. Prior to the program's termination due to funding difficulties, a significant amount of new technology in both the image display and image generation areas was developed. The challenge still remains to integrate this new technology into a complete visual system.

Development Required

The concept of development-oriented visual system acquisition programs cannot be reserved for large scale development efforts like Project 2360. A close inspection of Figure 1 will reveal the fact that only three of the training tasks do not require at least one of the major critical system requirements. Hence, any acquisition program for a visual system which is intended to train other than take-off and landing, instrument/visual transition and air refueling* must be considered a development effort. This leads to the conclusion that "off-the-shelf" procurement of visual systems for Air Force simulators is limited to visual systems for medium range conventional airlift aircraft simulators, trainer aircraft simulators and possibly part-task trainers for air refueling.

In addition to the availability of off-the-shelf visual systems, the commercial airlines also enjoy another advantage not enjoyed by the Air Force. All of their aircraft have the same mission--transport passengers and/or cargo from point A to point B. The Air Force, on the other hand, has some aircraft that drop bombs, some aircraft that shoot at other aircraft; some aircraft that drop cargo at low altitudes; some rotary wing aircraft that fly below tree-top level as well as aircraft that carry passengers and/or cargo from point A to point B. The point to be made here is that virtually every different aircraft type implies a unique set of simulator visual system performance requirements. In terms of the acquisition process, the learning curve ends up being essentially flat; New requirements must be specified for each visual system acquisition and development of new technology or integration of existing technology into a new application must be pursued.

BOUNDING THE PROBLEM

Estimating Cost and Schedule

In terms of acquisition, a prime advantage of off-the-shelf visual systems is cost and schedule predictability. Commercial visual systems are known quantities; Their hardware and software are largely modular. For example, a wide horizontal field-of-view will require multiple display system modules and an equal number of additional image generation channels. The cost of additional airfield data bases will be a multiple of the cost of one airfield data base since the required data base content for any given airfield is defined or readily defineable and obtainable. Since most vendors of commercial visual systems have established price lists, the cost of hardware and software (excluding unique integration requirements) can be readily obtained. Schedule is tied mainly to component part lead times and the complexity of the integration task. When, as in the case of the Air Force, each new visual system has a unique set of requirements and many of those requirements push or clearly exceed the current technical state-of-the-art, arriving at what the cost and schedule should be for a given visual system requires a great deal of creative estimating skill and a few outright guesses. Figures 3 and 4 are an attempt to demonstrate the difficulty in defining how much a particular non-commercial visual system should cost.

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*Recurrent aerial refueling training in a simulator may require a wide horizontal field-of-view, therefore making its acquisition program a development effort as well.

Field-of-View Figure 3 depicts the problem in estimating the cost of a visual display system in terms of field-of-view. The commercial hardware values are predicated on using standard CRT/mirror/beamsplitter type display modules. Disregarding the cost of the ancillary mounting hardware and keeping resolution a constant, the cost of the commercial hardware is simply the desired field-of-view in number of displays (units of about 44°) horizontally multiplied by the desired field-of-view in number of displays (units of about 32°) vertically (maximum vertical multiplier is 2 for a total of 64°). Once the horizontal field-of-view reaches about 200° and the vertical field-of-view reaches about 64° the ability to readily estimate display cost diminishes rapidly. "Standard" CRT/mirror/beamsplitter type displays can no longer be used and hence the solid, known cost estimating base disappears. This is not to say that a system cannot be costed, but the problem does indeed become multivariate. Once the bounds of modular display systems are exceeded, horizontal field-of-view can be traded off against vertical field-of-view and vice versa. Resolution also becomes a tradeoff against field-of-view. While there are available cost figures for a few large field-of-view displays, each display represents a unique level of performance and successful interpolation and extrapolation of those cost figures to displays with different characteristics is impossible. Given a set of state-of-the-art display components (e.g., projectors, screens, etc.) and a particular set of performance requirements, it is a relatively straightforward process to determine the number of components required and hence produce a fairly reliable cost estimate. Changing any one variable, i.e., horizontal or vertical field-of-view , projector type or resolution will require a new estimate.

If one attempts to meet a given set of performance requirements using display components which are not proven, state-of-the-art devices, cost and schedule risks increase significantly. The completion date for the display subsystem becomes intimately tied to the availability dates of the various R & D components. The cost of the display subsystem is at the mercy of the final production cost of these components as well.

Resolution. Attempting to cost out a high resolution visual system is very much akin to the large field-of-view problem. Per the previous discussion on field-of-view, once the field-of-view capability of juxtaposed standard display units is exceeded, resolution becomes a dependent variable in the resolution/field-of-view equation. Figure 4 demonstrates this concept. For standard display modules, increasing display resolution can be thought of as a linearly increasing variable. For a given resolution, the variable becomes a constant regardless of the chosen total field-of-view. For fields-of-view that exceed the capability of the modular display approach, arriving at a system cost requires a great deal more analysis. Due to the inverse relationship between field-of-view and resolution and the resultant available design trade-offs, the question of the cost of higher resolution must always take into account the field-of-view. This discussion has conveniently ignored the impact of image generation on system resolution. However, the relationship between resolution and field-of-view follows essentially the same rules as the displays.

Gaming Area (Data Base). As mentioned earlier, the gaming areas or data bases for airline simulators are oriented to the airfield itself and a very small geographical area surrounding it. The required contents of the data base are fairly well understood by the contractor and hence a "cookbook" pricing scheme can be adopted for pricing one or more airfield data bases. The work required to create each different airfield data base is, plus or minus ten percent for unique significant features, the same. Also, since the quantity of work required to create a data base is fairly well known, the amount of time it takes to create the data base is largely a function of the manpower applied to the task. Schedule confidence is enhanced by the fact that the techniques used to build small area airfield oriented data bases (eg., digitizing from maps) are completely understood.

The cost and schedule requirements for creating large data bases for Air Force systems, cannot be arrived at with anywhere near equal ease. There are several reasons for this: 1) First and foremost, the data base content required for any given mission task (i.e., low-level navigation, tactical air to surface weapons delivery, etc.) is not well understood. For the take-off landing task we know that most of the visual cues occur on or in direct proximity to the runway. Scene complexity (except for textural information in the area immediately adjacent to the landing zone) is not a significant factor in building an airfield data base. The fidelity of the representation of the runway environment is known, by experience, to be paramount. With little, if any, experience with the creation and training use of data bases for low-level navigation, for instance, it is difficult to estimate the per-square-mile manpower required to build the data base. 2) Availability of source data also places a question mark on the creation of large data bases. For a given airfield, civil engineering blueprints are normally available and augmenting that data with photographs is a manageable task. If one considers the problem of creating a data base which represents a large area of the real world, the acquisition of source data becomes a tenuous proposition.(1) Given that a large part of the continental U.S. is now available in digital format, the current cultural information in that data is not sufficient to do a credible job of visual data base generation. There are numerous characteristics of the visual world which are not currently portrayed in the data, not the least of which are color, roads, railroads, etc. Additional features like roads must be digitized from charts. Color information must either be inferred from feature descriptors or a sampling of photography. 3) Conventional techniques used in creating small area data bases, such as hand digitizing of features, are impractical when producing a data base covering multiple thousands of square nautical miles. If, for example, it takes five data base modellers a total of six months to create a single airfield area covering 50 square miles, simple arithmetic reveals that it would take 2,500 man-years to create a 50,000 square mile data base using the same technique.** The obvious answer is some type of automated data base generation

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**Creation includes collection of source data, digitization and debug on the real-time visual system.

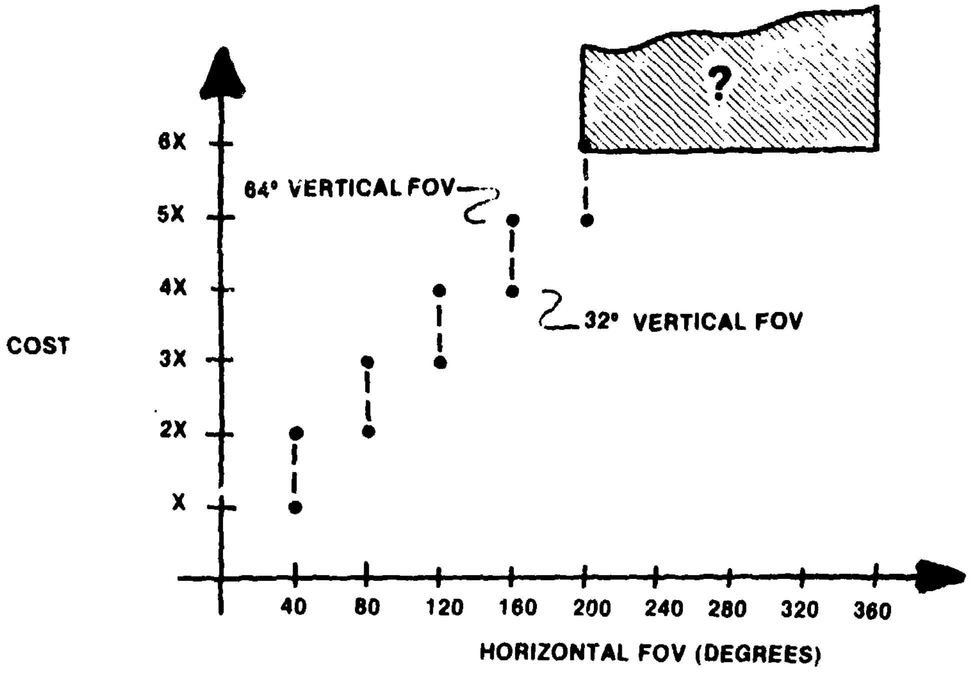

Figure 3

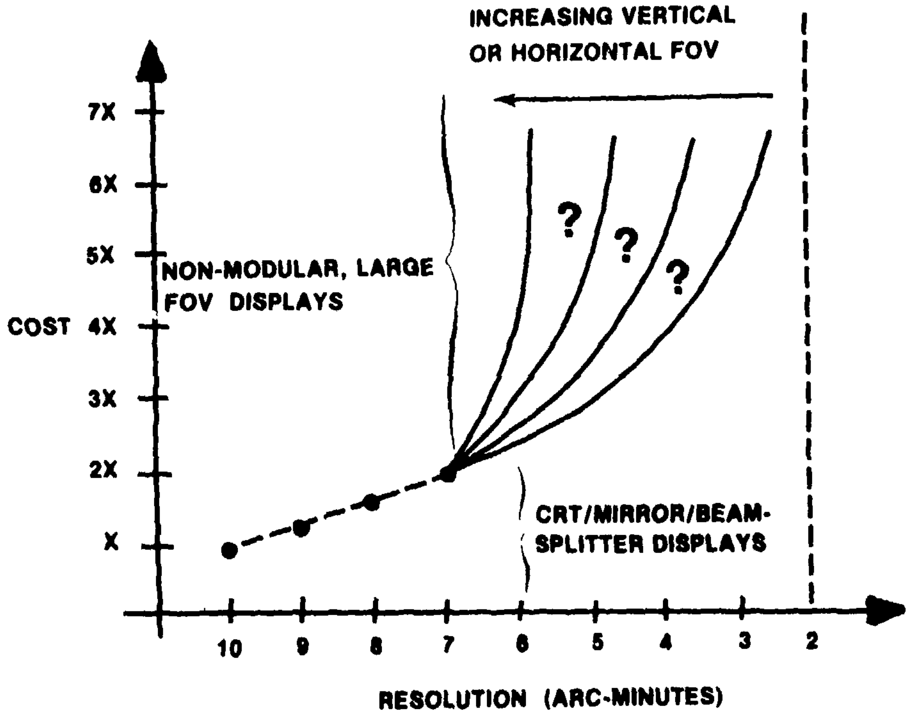

Figure 4

system employing a computer transformation of the digital data base. This, however, requires the development of additional software to perform this work. The estimation of the amount of software needed to do the job is difficult because the end product (the on-line data base) must be compatible with the host image generator. The image generator is normally in the initial stages of design when the data base software needs to be developed, thereby making this estimation task more difficult.

Scene Content. Perhaps the most overlooked area in the discussion of visual system performance is that of scene content--What visual information needs to be displayed to the aircrew? What does the aircrew need to see on the visual displays in order to receive some measure of training? The answers to the questions are different for each of the different tasks that need to be trained, and hence virtually every different visual system procured by the Air Force. The diversity of the various tasks and the quest for the answers to the above questions represent a significant challenge in the Air Force's acquisition of visual systems.

The solution to the scene content problem is shared between two system design areas: 1) The data base content and 2) The image generator power. Both of these areas are intimately related to each other. Too little data base content will result in insufficient image density (clutter) to provide suitable training. Too much data base content can overload the image generator and product image anomalies which result in reduced training effectiveness.

In the final analysis, it is largely by the overall scene content that the "goodness" or adequacy of a visual system is evaluated. If an aircrew attempts to train in a simulator with a visual system which does not provide cues which are analogous to actual aircraft flight experience, the visual system will be judged as unacceptable or unuseable for training. One arc-minute resolution and a 360^o field-of-view will not compensate for incoherent scene content. It is in this area that the visual system contractor gets an opportunity to share the visual system acquisition challenge with the Air Force.

Achieving an optimal scene content can make or break an entire visual system program in terms of cost and schedule as well. Making the assumption that the image generator can generate sufficient scene density (total number of faces, edges, light points, etc.) the only scene density variable is the data base content. The contractor, in concert with the eventual users (aircrews), must begin early on in a program to try and determine the optimal, useable scene content. Failure to do an adequate job of data base definition on the front-end runs the risk of generating an entire multi-thousand mile data base with incorrect or improperly portrayed features. The cost and schedule impact of regenerating an entire large area data base is staggering.

Special Effects/Techniques. Since most visual systems are designed to satisfy commercial training requirements, the special effects required for some Air Force training tasks (i.e. depiction of flares, tracers, weapons impacts, etc.) present challenges in image generator design. In the course of the visual system program, the inclusion of special effects can have a significant impact on the image generator hardware and the development schedule. In many cases, an image generator must be designed from the ground up in order to accommodate special effects. In some cases, the system designer may believe that a particular special feature can be produced in a system by simply modifying or augmenting an existing standard feature (e.g., using the landing light subsystem to do simulation of flare illumination effects). Unfortunately, it usually isn't until the hardware is designed, built and operating before it is determined that the simple modification approach will not satisfy the special effect requirements. The result is usually a large hardware redesign effort, hardware and software growth, along with the attendant schedule impacts.

MEETING THE CHALLENGES

At this point, it should be clear that acquiring visual systems which meet Air Force training requirements is anything but a straightforward, "place your order" process. The challenges are significant. It should also be clear that the challenges are shared by the Air Force and the contractor. Achieving success--producing a usable visual system for the user--MAC, SAC, TAC, or ATC, requires initiatives on the part of both the Air Force and the contractor. Some of these initiatives may require a departure from the way things are usually done. Here are some places to start:

Fire The Artist

Step one in bringing order to the chaos of visual system development belongs to the contractor. A picture may be worth a thousand words, but the words often end up being lies when the final system doesn't produce scenes anywhere near the 8 x 10 "artist concept" photographs. Describing the performance of a system which doesn't even exist on paper by means of a colorful picture is a heinous act. The user will expect the system output to look just like the pictures. Why shouldn't he? When it doesn't, he'll think you've deceived him and that you can't be trusted. Why shouldn't he? Regaining the user's confidence and convincing him that he likes your system will be most difficult.

Understand The Requirements

This initiative belongs to both the Air Force program team and the contractor. It is impossible, solely by means of a technical performance specification, to convey to the contractor all of the information regarding what the user needs to see in the visual system in order to train. The Air Force needs to do a better job of describing the various training tasks to the contractor. The technical specification ends up being the objective criteria for visual system acceptance, but the subjective criteria (scene content, lack of distracting artifacts, etc.) are equally important in achieving a successful program. The contractor needs to investigate the actual training tasks long before system design begins; The proposal preparation period is not too early to begin.

Gaining the initial understanding is important, but the task continues throughout the life of the program. Continuous interaction between the designers and the eventual users is essential. As discussed earlier, one set of bad assumptions made early-on in a program can spell disaster. Getting the user's subjective comments as soon as they can see something displayed on the system can help to avert problems down the line on both sides. The Air Force must make a serious effort to try and ensure that the same people who evaluate and critique the system this month will be available next month as well. Failure to do this will result in conflicting comments and frustration on the part of the contractor's personnel.

Systems Engineering

The requirement for "systems engineering" appears in every Air Force solicitation for simulators. Contractor proposals always contain detailed descriptions of how systems engineering will be pursued in the candidate program. If there is one area of simulation that demands the application of a systems oriented design approach, it is surely visual simulation. But for some reason, visual systems traditionally suffer from a gross lack of systems engineering discipline.

There appear to be several reasons why this is true. One reason is certainly the fact that the technology of visual simulation is growing so fast that subsystem designs never stabilize long enough to be totally quantified. This phenomenon is aggravated by the fact that military simulation requirements always seem to press the state-of-the-art to its limits. When the characteristics of a given subsystem are not well understood, the impact and interaction of that subsystem with the rest of the system and the resultant requirements it places on the design of adjacent subsystems cannot be understood either. The result is a system composed of subsystems which may not function together as a unit or, at best, operate well below system specification requirements.

The second reason for marginal systems engineering stems from the attempt to force existing designs to do things they were never intended to do. Rather than starting from the ground up in systems design, a decision is made, before the requirements are fully understood, to use a specific existing subsystem design. The number of successes using this approach are few. While the decision to use this approach is based on a motive of front-end cost avoidance, the long term result is often one of false economy. It often costs more to redesign a system once it is built than it would have to do the job carefully and correctly from the start.

Systems engineering is not merely ensuring that the various subsystems will fit together, or interface properly. The various components must, when brought together, form a totally integrated system. In the world of visual systems, this means that the data base people, the image generation people and the displays people all fully understand each other's design objectives. The data base designers may create a beautiful set of data base files, but if those files contain too much data for the image generator to process in a given frame time when the two are integrated, the choice is either to regenerate the data base or redesign the image generator. Either option is costly.

CONCLUSIONS

The business of acquiring visual systems for Air Force simulators has been shown to be dramatically different from the same task for the commercial airlines. Accordingly, the acquisition process must be pursued differently by both the Air Force and the contractors. The key to success on the part of both parties is continuous, open interaction throughout the life of the program. The Air Force needs to do a better job of conveying to the contractor exactly what the training requirements are. But the Air Force must continue to rely on the contractor community to dilligently and innovatively convert those training requirements into the integrated visual system that will do the job required.

REFERENCE

1. R.W. Beck and M.R. Nicol, "CIG Data Bases; Where Are We Headed?", Proceedings of the 2nd Interservice/Industry Training Equipment Conference, November, 1980.

ABOUT THE AUTHOR

Robert W. Beck is a Senior Systems Engineer at Aeronautical Systems Division (ASD), Wright-Patterson AFB, Ohio. He is currently responsible for analysis and development of requirements for U.S. Air Force visual systems programs. He holds a Bachelor of Electrical Engineering degree from the University of Detroit and a MS degree in Systems Engineering from Wright State University.

HELMET MOUNTED LASER PROJECTOR

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ABSTRACT

A visual simulation system design is described which provides an observer seated in a cockpit with an apparent high resolution display over a wide field of view limited only by cockpit structure. The system utilizes a Helmet Mounted Opto-mechanical Laser Projector to produce a composite display on a high gain screen surrounding the cockpit. The display consists of two full color laser rasters comprising an inset and a surround. One raster is dedicated to a relatively narrow, high resolution area of interest which tracks the observer's look direction. The other raster provides a wide, low resolution instantaneous field of view in the surrounding area corresponding to the observer's peripheral field. The other major system components are a head attitude sensor, an eye attitude sensor and a two channel computer image generation system whose performance is tailored to the display requirements.

INTRODUCTION

Simulators are utilized in military flight training to provide the pilot or other aircrew with an interactive environment within which he can learn and exercise the skills required to operate his weapon system. Tasks such as low altitude flight, navigation, target acquisition and weapon delivery, threat avoidance, and confined area maneuvering are performed in a large complex, dynamic visual environment. The cost/training effective simulation of such an environment in a ground based training system is a goal of visual simulation technology.

The historic approach to providing a wide field of view, high resolution display has been to mosaic a large number of display windows around the trainee. The number of display windows or channels required for such an approach is a function of the size of the desired field of view, the desired resolution, and the number of picture elements (pixels) which can be provided by a window. The state-of-the-art for typical display window capability is approximately one million pixels. A field of view requirement of two thirds of a complete sphere combined with a resolution requirement for pixels to subtend two arc minutes implies more than thirty display windows. The image generator for such a display system would also have thirty channels. It is obvious that the mosaic approach becomes more and more impractical as the field of view increases and the desired resolution improves. But what are the alternatives?

An alternative approach is to take advantage of the perceptual limitations of the observer. The observer does not see the entire available field at any instant in time. His instantaneous field of view is a fraction, albeit a large fraction, of the total field available to him through head and body movements. Nor does the observer see his entire instantaneous field at high resolution. His high resolution seeing is confined to a relatively small area of interest surrounding his look direction. The Helmet Mounted Laser Projector visual simulation system is designed to provide a display which efficiently matches the observer's capabilities.

The basic system concept has been reported (1). However, it will be briefly summarized so that the analyses and experimental results reported in this paper can be understood in proper context.

SYSTEM CONCEPT

The visual simulation concept is based on the premise that a composite display consisting of an eye tracked area of interest (AOI) surrounded by a head directed instantaneous field of view (IFOV) would be perceived by the observer as having high resolution throughout his available field of view.

The technical approach chosen to implement this concept is the Helmet Mounted Laser Projector Visual Simulation System. The AOI and the IFOV are each produced by a full color laser raster. The composite display is projected from the observer's helmet through a single projection lens onto a retroreflective spherical screen. The lasers, modulators, and line scanner are located remote from the observer. The modulated laser lines are relayed to the observer's helmet by a flexible, lightweight fiber optic link. The helmet mounted optical system performs several functions; it converts the two line scans into two rasters, combines the two rasters into a single composite frame, offsets the composite frame to follow eye movements and to compensate for computational lag in the computer image generator (CIG), and projects the composite display onto the screen. Figure 1 shows a schematic diagram of the display optical system. The remaining major components of the visual simulation system include a head attitude sensor, an eye attitude sensor, and a CIG.

The reasons for choosing this technical approach are discussed in a previous paper (1) and will not be repeated here. They may be summarized by stating that the potential advantages outweighed the risks.

A summary of the Helmet Mounted Laser Projector Visual Simulation System performance goals is given in Table I.

TABLE I SYSTEM PERFORMANCE GOALS

Apparent Field of View -	Limited Only by Cockpit Structure
Apparent Resolution -	1.7 Arc Minute/Pixel
Displayed Instantaneous Field of View -	145° Diagonal
Displayed Area of Interest -	36° Diagonal
AOI Resolution -	1.7 Arc Minute/Pixel on - Axis
IFOV Resolution -	6.5 Arc Minute/Pixel on - Axis
Apparent Luminance -	10 Foot-Lamberts (Highlight)
Color -	Full
Contrast Ratio -	30:1

An artist's concept of the system is in Figure 2. Note that the view is that of someone looking over the observer's shoulder. The observer, himself, would not be aware of the composite nature of the display. Nor would he be aware of the absence of display outside his instantaneous field of view.

VISION MODELS

Before proceeding with the design and fabrication of the visual simulation system based on the helmet mounted laser projector, several questions needed answers. How large should the AOI be? What kind of blending is required between the AOI and the IFOV? How large should the IFOV be? How should the IFOV be blended to the background? How accurately should head attitude be measured? How accurately should eye attitude be measured? How quickly should the display stabilize following a head or eye movement? The answers to these questions were, generally not available in the literature. Information regarding perception thresholds could be found but did not give acceptability thresholds. Accordingly, several experiments were devised to, at least, give some guidance in designing the visual simulation system hardware.

Area of Interest

Experiments were performed to get an idea of how large the Area of Interest (AOI) had to be in order to be subjectively acceptable as a function of the delay between an eye movement and the movement of the AOI. Note that the movement of the AOI consisted of a movement of the borders of the high resolution inset with no change in the apparent location of image features. The experimental apparatus consisted of annular projection lens, a variable resolution mask, a servo system to rotate the mask, a variable delay system, and an eye tracker. The apparatus, test procedure, and results are described in Reference 2, and pictured in Figure 3. In carrying out these experiments it was quickly determined that hard edges (abrupt resolution changes) between the AOI and IFOV were very objectionable and distracting to most observers. Consequently, the masks were fabricated to cause a gradual transition of resolution rather than an abrupt change. Since the transition region would require both levels of resolution the size of the AOI must include the transition region. The results of the eye tracked experiments indicate that an AOI width of 25° within which is a 5° wide smoothly varying transition region combined with a delay of 80 milliseconds and an eye tracker accuracy of ± 2.5° would cause noticeable, but not objectionable, perception of the borders of the AOI.

Instantaneous Field of View

Instantaneous field of view requirements were determined by using the apparatus pictured in Figure 3 in a different configuration. The eye attitude sensor was removed and a horizontal head angle sensor substituted. The variable resolution masks were replaced with servo controlled masks which were capable of providing a constant resolution over a limited field angle. Subjective evaluations indicated that an instantaneous field of view of 130° with a delay of 80 milliseconds would be noticeable but not objectionable. Experiments using a head slaved instantaneous field of view performed on ASPT (3) indicated that a field width of 90° was adequate for certain tasks. Since the optical design of the display was not greatly influenced by the difference between 90° and 130°, it was decided to go with the wider field to provide peripheral cues for those tasks for which a 90° field might not suffice. The blending of the IFOV to the background was not found to be a significant problem. Hard edges of the IFOV at 130° were just noticeable and not objectionable. This indicates that a smaller field with some blending may suffice but this has not been experimentally verified.

Image Stability

The most critical performance requirement of a helmet mounted display is to provide imagery which is acceptably stable against head movements. Experiments were performed utilizing a head attitude sensing system manufactured by Polhemus Model SHMS IIIA to provide head pointing information to the Visual Technology Research Simulator (VTRS) Computer Image Generator (CIG)(4) which then provided a single, monochrome video signal to a helmet mounted miniature projection CRT, manufactured by Systems Research Laboratories. The projected CRT raster was reflected from a 1 meter radius spherical screen coated with Scotchlite #7615 high gain screen material manufactured by 3M. The following problems were noted:

Image Lag

The thruput delay caused by the head attitude sensor (16ms) combined with the CIG computational thruput delay (50 milliseconds) produced a lag in proper image positioning perceived as an angular image displacement equal to the angular difference between current head angle and the head angle used to compute the current scene. This was considered to be highly unacceptable and led to a display design which incorporated a feature to compensate for image lag in pitch and yaw. Head roll rates were found to be sufficiently slow to allow an acceptable lag without compensation for thrupur delay.

Image Jitter

Although the specified anglular accuracy (less than 1^{o}) of the SHMS IIIA was adequate, the precision of the digital signal was found to produce an image jitter of approximately 0.1^{o}. This value of jitter would probably be acceptable for a wide field display whose resolution is poorer than 0.1^{o}, but since the resolution goal of the display system is about four times better than 0.1^{o} a head attitude sensor having a precision of 0.025^{o} would be required if system resolution is to be maintained.

Image Luminance and Contrast

Luminance values usually specified for outside-the-cockpit daylight visual simulation displays are typically in the range of one to ten foot-lamberts. Accordingly, a display brightness of ten foot-lamberts was chosen as a goal. The helmet mounted laser projector configuration combined with a retroreflective screen could provide this brightness. The retroflective screen also minimizes cross reflectance problems allowing a designed contrast ratio of thirty to one. However, a more critical problem is the contrast between the displayed image as seen on the screen and the apparent brightness of ghost imagery reflected from inside the cockpit surfaces. This effect was noticeable in that the observer had the feeling that he was wearing a miner's lamp on his helmet. This problem was noted and attempt has been made to resolve it by designing the screen and cockpit surfaces such that the maximum luminance of ghost images would be less than the minimum luminance (dark level) of the displayed imagery on the screen.

Shadows

Although the helmet mounted projector was designed to cause minimum shadow effects the separation of the projector from the observer's eyes will produce residual shadows on the screen which are in the observer's field. Although the magnitude of this effect was computed, its acceptability had to be evaluated. Accordingly a display configuration was assembled which produced the same type of shadows as would be apparent in the helmet mounted laser prcjector configuration. The subjective evaluation using this apparatus indicated that a static (head not moving) situation the shadows of struts were acceptable, but that head motion caused objectionable shadow. Thus, it was decided to utilize a cockpit configuration with no struts within the available field of view. Shadows caused by the cockpit structure itself generally lie below the observer's line of sight and are not visible.

Resolution

The resolution capability of the eye peaks at approximately one arc minute per optical line pair for foveated high contrast targets displayed at a luminance of 10 foot-lamberts. This corresponds to an acuity of 2.0 or capability to read the 20/10 line on a Snellen Eye Chart. However, the specified resolution of a display for visual simulation seldom requires this demanding performance. Typical specifications usually correspond to an acuity of 0.2 or less. An acuity of 0.2 corresponds to a limiting resolution of 10 arc minutes/optical line pair. The resolution goal for the helmet mounted laser projector system was not determined by eye capabilities but by a computation of the expected resolution obtainable with a nominal 1000 line/frame raster filling the AOI. Since the required size of the AOI was roughly 25^{o} the resolution capability is approximately 1.6 arc minutes/TV line which corresponds to 3.3 arc minutes/TV line pair or five minutes per optical pair. This resolution is twice as good as the resolution being specified in some visual simulation systems today. To fill an available field of view 240^{o}H x 180^{o}V with a non-head/eye coupled display having equivalent resolution would require a nominal 1000 line raster display for each 25^{o} x 25^{o} segment or 40 channels of display/image generator.

COMPUTER IMAGE GENERATOR

Since the primary objective of the helmet mounted projector project was to demonstrate feasibility of the concept, the effort devoted to the image generator was limited to a study performed by General Electric (5) to investigate modifications to the existing VTRS CIG which would be required to demonstrate and evaluate the concept. The results of this study indicated that the following modifications would be required.

Channel Specific Level of Detail

Although the current VTRS CIG has the capability to portray a given feature at different levels of detail, the system does not have the capability to provide different levels of detail in the two display channels. This capability is essential to the AOI-IFOV concept if an increase in apparent image detail is to be demonstrated, and its effect evaluated.

Channel Specific Distortion Correction

The existing VTRS CIG has the capability to provide distortion correction whose parameters can be varied in real time through a segmentation and remapping process (6). Modifications would be required to expand this capability from single channel to both channels.

Inset Blending

The current VTRS CIG does not have the capability to provide an inset AOI which smoothly transitions to the IFOV. A scheme for accomplishing a blended inset capability is currently being developed for AFHRL at Williams AFB for evaluation of a dual projector concept (7). Such a scheme would be required for the helmet mounted laser projector to avoid unacceptable transition between regions.

Systems Performance

The existing VTRS CIG with appropriate modification and interfaces to a head attitude sensor and an eye attitude sensor would have the capability of providing a displayed scene content of 1,000 potentially visible edges in the IFOV and 1,000 edges in the AOI. The apparent edge density of the entire available field should be equivalent to the edge density observed in the AOI which is equivalent to a perceived total of 40,000 edges although the verification of this assumption has not been accomplished.

HEAD ATTITUDE SENSOR

The function of the head attitude sensing system is to provide a head pointing direction in pitch, roll and yaw. The attitude information should be as current as possible and precise to 0.025° or better. A head attitude sensing system which meets the precision requirement and has a thruput delay of 10 milliseconds has been developed for the Aerospace Medical Research Laboratory at Wright-Patterson AFB by Polhemus. The Polhemus system employs a magnetic field radiator mounted on the cockpit structure and a magnetic sensor mounted on the helmet. The principle of operation is discussed in Reference 8.

Since the Polhemus system is the most likely candidate for implementation in the helmet mounted laser projector, a feasibility experiment utilizing a single channel, monochrome helmet mounted laser projector together with the VTRS CIG and the retroflective screen was assembled and evaluated. The feasibility model differed from the final design in several respects. Only one frame scan galvanometer was mounted on the helmet as opposed to three galvanometers in the helmet mounted laser projector design. An off-the-shelf fiber optics array was utilized to relay a line scan to the helmet rather than a custom made fiber optics ribbon. A narrow field (40°) off-the-shelf projection lens was used rather than the 140° lens called for in the design. The results of this experiment indicated that the galvanometer caused no noticeable noise in the head attitude sensor as long as no metallic structure got between the radiator and the sensor and measurement samples were synchronized to occur during the relatively quiescent time of the frame scanner (not during flyback). Although the magnetic sensor approach appears to be viable, alternative head attitude sensing systems were also considered. The best alternative approach studied would utilize three automatic polarimeters capable of slewing at head angular rates mounted behind small holes in the screen structure and polarized suitably coded, light sources on the helmet. Automatic polarimeters are available off-the-shelf with precision to 0.001°. Unfortunately slew rates are on the order of 1°/second rather than the 100°/second required for head motions. The concept of utilizing automatic polarimetry will be pursued if required.

EYE ATTITUDE SENSOR

Many techniques for monitoring eye movements have been developed (9). Unfortunately no technique incorporates all of the desired features of an eye tracker for the helmet mounted laser projector. Electroculagraphy (EOG) has the desired measurement range (to the limit of eyeball rotation) and causes no obstruction of the field of view. But EOG is noisy and highly sensitive to electrode contact, facial muscle activity, and light adaptation level. Remote oculometers are limited in measurement range to approximately $\underline{+}30^\circ$, have relatively slow response (due to frame rate of sensor), and require the observer to keep his head pointed toward the oculometer. Helmet mounted oculometer configurations are possible but the advantage of free head movement is offset by the requirement for a beamsplitter and supporting structure within the observer's field of view. A limbus tracking system is restricted to a measurement range of $\underline{+}20^\circ$ and is also obtrusive into the observer's field of view. However the limbus tracker has relatively fast response and is relatively inexpensive. A limbus tracker was utilized in the eye tracker AOI experiments described above.

Relative Head-Helmet Motion

The question of relative movement between the observer's head and his helmet is not critical to the stability of the display since the helmet is tracked and the projector is mounted on the helmet. However, any eye tracking system which measures eye attitude in relation to a monitoring device fixed on the helmet will be affected by this relative movement. An experiment was designed and carried out to measure this relative motion. The apparatus consisted of a custom molded bite fixture and a Navy aviator's helmet Model APH-6. A rigid conducting bar extended from the bite fixture to the brow area on the subject's head. The bar was centered in an adjustable gap between two contact points and wired such that contact between the bar and either one of the sides of the gap would cause a battery powered lamp to light. The results of this experiment indicated that head rotations in yaw at rates less than 60°/second caused relative movements of less than 0.010 inches. Higher head rates or head roll caused relative movements of less than 0.025 inches. These values can be realted to eye movement accuracies. The movement of the limbus of the eye is approximately 0.010 inches per degree of eye rotation. Corneal relfex motion is approximately 0.003 inches per degree of eye rotation. Although no attempt was made to custom fit the helmet or otherwise stabilize it beyond the normal chin strap the relative motion was within an acceptable range for a helmet mounted limbus tracker but not acceptable for a helmet mounted corneal reflex tracker. However, oculometers have been developed which utilize the pupil location as a reference (10). Such systems are limited to frame rate response since the whole image of the eye must be processed to determine the location of the corneal reflex as well as the eye pupil.

Eye Position Prediction

Rapid eye movements (called saccades) have a characteristic motion which allows prediction of the endpoint when the movement is only halfway completed (11). Although such prediction (in order to get a head start on generating the imagery for the new AOI) has not been determined to be required it certainly would be desirable if it could be efficiently implemented. Figure 4. shows three plots. The top plot shows the output of an analog eye tracker, such as a limbus tracker. The first part of the curve contains a 20° saccade having a duration of 60 milliseconds. The last part of the curve shows the effect of a blink. The middle curve shows the velocity as a function of time obtained by differentiating the angle curve. Note that the saccade shows a peak velocity halfway through the saccade. The velocity profile for the blink is also depicted. The lower curve represents the output of a predictor device developed under a contract with Carnegie-Mellon University. The predictor is capable of predicting the final eye position by measuring the time at which velocity peaks and then doubling the angle. The predictor can also discriminate against eye blinks by utilizing an algorithm which contains velocity thresholds and eye movement monitor characteristics. The net time savings in this example is 30 milliseconds. Longer saccades would result in greater time savings. Indications are that prediction accuracies of 2° are obtainable for saccades of 20°.

DISPLAY SYSTEM

A description of the design and operation of the display system has been presented previously (1) and will not be repeated here. What was not discussed in the previous paper were some of the design issues and tradeoff analyses which led to the system design. A large part of this effort was performed by Dan Lobb under a contract with the University of Central Florida.

Line Image Generator

The functions of the line image generator are to provide sufficient three color laser light, to provide two - three color modulated beams, to provide scanning for both beams. The issues were: What laser or laser mix would be optimum in terms of available colors, power, and reliability? What type of optics would be most desirable for the color separation and recombination? What type of modulators should be used? What type of scanners should be used? Figure 5 shows a schematic diagram of the line image generator. The answers to these questions were primarily based on our laboratory's experience with laser display systems.

Lasers

Our experience with a multi-laser display system and the problems associated with reliability and maintainability led to a requirement to use as few lasers as possible. A colorimetric analysis indicated that a single 10 watt Argon Ion Laser would provide sufficient luminance in blue and green plus enough excess light to pump a red dye laser. Based on desired display luminance and computed losses between the laser and the screen, the analysis concluded that the latest light required is approximately 1,000 lumens in wavelengths actually used after any necessary loss from some wavelengths to achieve a good white. The composition of the laser white is: Red primary (from the Rhodamine 6-G dye cell) having a wavelength of 610 nanometers and power of 1,300 milliwatts; a green primary of 514.5 nanometers and power of 1,500 milliwatts (about half of the green line power directly from the 10 watt Argon Laser); and a blue primary having a dominant wavelength of 470 nanometers and power of 1,400 milliwatts (composed of the short wavelength outputs of the Argon Laser from 454 nanometers to 476 nanometers). The remaining Argon power is utilized to pump the dye cell. Thus the problems associated with multiple lasers can be avoided.

Color Splitting

There are two practical options for separating the Argon Laser output into the various colors required: Dispersive prisms and dichroics. The problems of specifying and manufacturing dichroics to separate wavelengths as close as the 488 nanometer Argon Laser line (used to pump the dye) from the 476 nanometer Argon line (which provides a large fraction of the blue primary). On the other hand, dichroic splitting is simple and straightforward. After a careful weighing of advantages and disadvantages the prism dispersion method was chosen as the preferred technique.

Modulation

At the video bandwidths of interest, acousto optic modulators offer the most efficient, cost effective method for intensity modulating the six beams of laser light resulting from the color splitting components (2 channels of 3 primaries each).

Color Combination

Since the six modulated beams must be recombined prior to line scanning as two beams the choice of combining technique must be made. In this case there is significant separation between the primaries (the closest being the 514.5 green and 476 blue) allowing the simplicity of dichroics to be preferred.

Line Scanner

The choice of a line scanning system was almost forced. Acousto-optic techniques would have required six independent line scanning channels with obvious problems of balancing and registration. On the other hand a rotating polygon system could scan both three color beams simultaneously.

Fiber Optics Relay

The function of the fiber optics relay is to transmit the two three color laser scan lines to the helmet. The basic problem associated with this arrangement is avoiding image artifacts caused by broken fibers or different transmission through different fibers. Several experiments were performed to evaluate the effect of broken fibers and to minimize the effect of different transmissions. The conclusion was that even a single broken fiber was immediately obvious in the display but its effect on training performance could not be predicted. A specification for a fiber bundle containing no broken fibers was prepared. As of this writing two manufacturers are under contract to provide such bundles for test and evaluation with delivery expected in August 1981. The apparent transmission of different fibers was found to be strongly influenced by the collecting aperture used to gather light at the output of the bundle. For the specific fiber array tested, it appeared that a collecting aperture of f/5 would suffice.

Helmet Mounted Projector

The functions of the helmet mounted projector are: To offset the line scans in the line direction to follow eye movements and compensate for rapid head yaw motion; provide frame scanning for both rasters; provide offset capability in the cross line direction; provide composite frame from two independent images; and project the composite frame onto the screen. A schematic diagram of the helmet mounted optics is pictured in Figure 6. The design was developed under the rather severe constraint of having to be head supported and, at the same time, composed of components which were either off-the-shelf or represented low risk development. All of the above requirements were met by this design.

Screen

The requirements for the display screen parameters are driven by two constraints; the contrast between images observed on the screen surface and reflected off inside-the-cockpit surfaces should be high, and the screen structure should be an existing 10 foot radius dome. By painting all inside - the - cockpit surfaces flat black and tilting all specular surfaces such that no specular reflections can be directed toward the observer's head the interior of the cockpit can be assumed to be a screen having a gain of 0.1 or less located approximately two feet from the observer. This implies that the screen gain required to keep inside the cockpit imagery luminance below the dark level of the display (nominally 3% of peak brightness) must be greater than 75. Off-the-shelf retroreflective screen materials were experimentally evaluated with the results indicated in Figure 7. The three sets of data represent gain measurements of Avery International Retroreflector (embossed corner cubes); 3M Scotchlite Type 7615 and 3M Scotchlite Type 8910. The results of the evaluation of the embossed corner cube material are somewhat misleading since this material was not uniform and since it displayed a six-lobed retroreflective return pattern when illuminated with laser light. The conclusion was that Scotchlite coating 8910 performed adequately well over the range of angles required by the helmet mounted laser projector (approximately 0.5° to 1.5° projection point eye point separation). However, a more uniform gain characteristic could be obtained by modifying the index of refraction of the glass beads utilized to manufacture the screen. A contract study with the Optical Sciences Center at the University of Arizona resulted in the conclusion that an index of refraction of approximately 1.87 would result in a more uniform distribution over the desired range. Preliminary discussions were held with 3M which indicated that such a specification was feasible within the constraints of the manufacturing processes utilized for their standard products.

SUMMARY

The design and feasibility analysis process described in this paper represents an overview of an exploratory development effort which has culminated in a specification for a visual simulation system which offers great potential for improved performance at low cost when compared to conventional mosaic approaches to the wide field high resolution display problem. Based on this effort an advanced development program has been initiated which will result in the fabrication of a research tool incorporating the design concepts outlined in this paper. The research tool will be integrated into the Visual Technology Research Simulator Facility at NAVTRAEQUIPCEN for evaluation of technical performance and training effectiveness.

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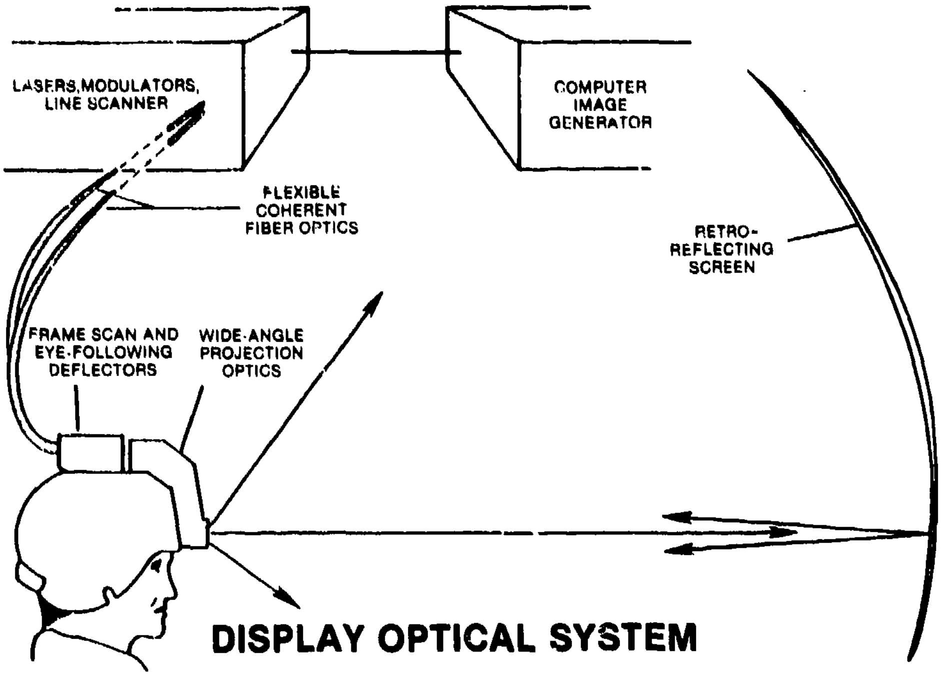


Figure 1. Display Optical System

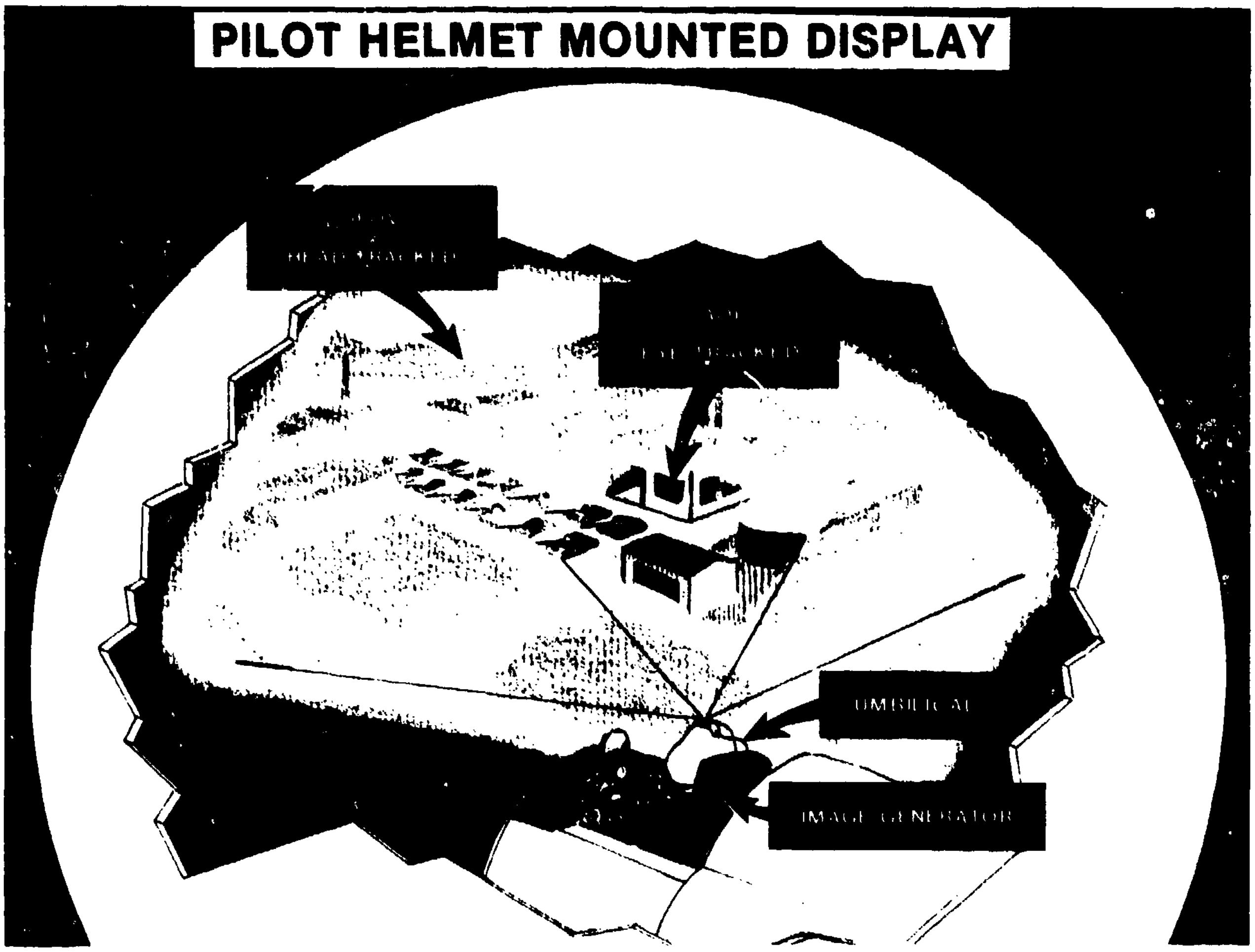


Figure 2. Artist's Concept

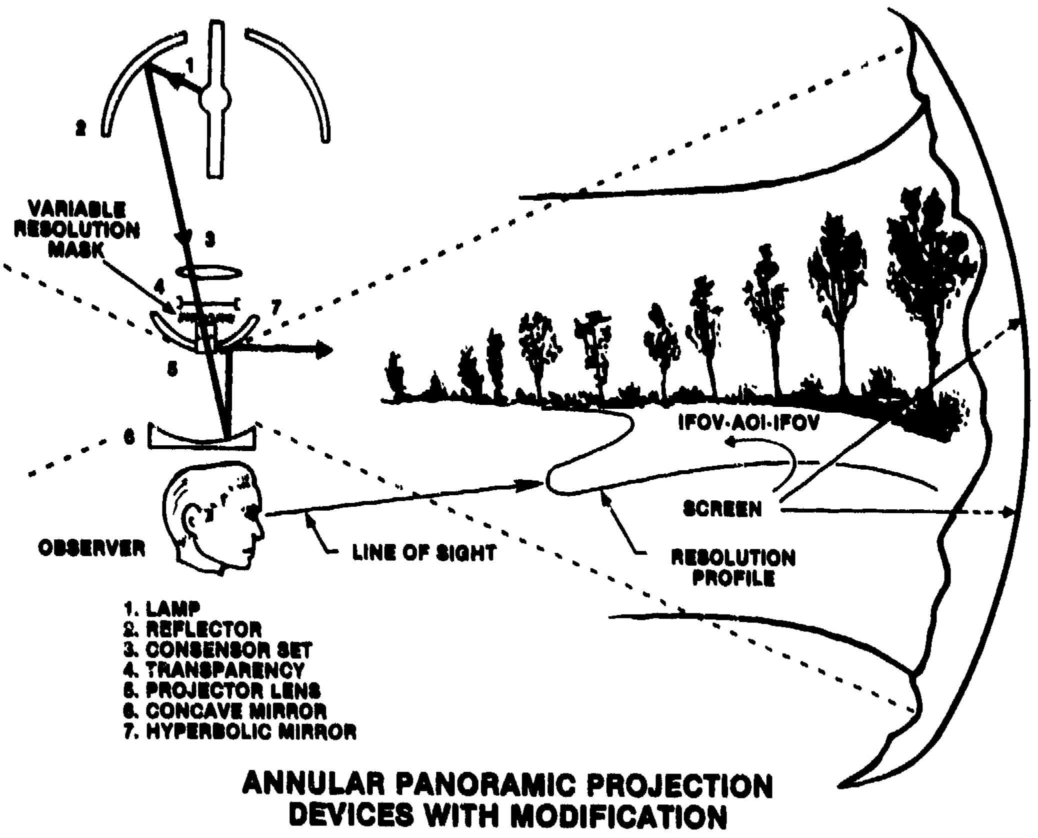


Figure 3. Area of Interest Test Apparatus

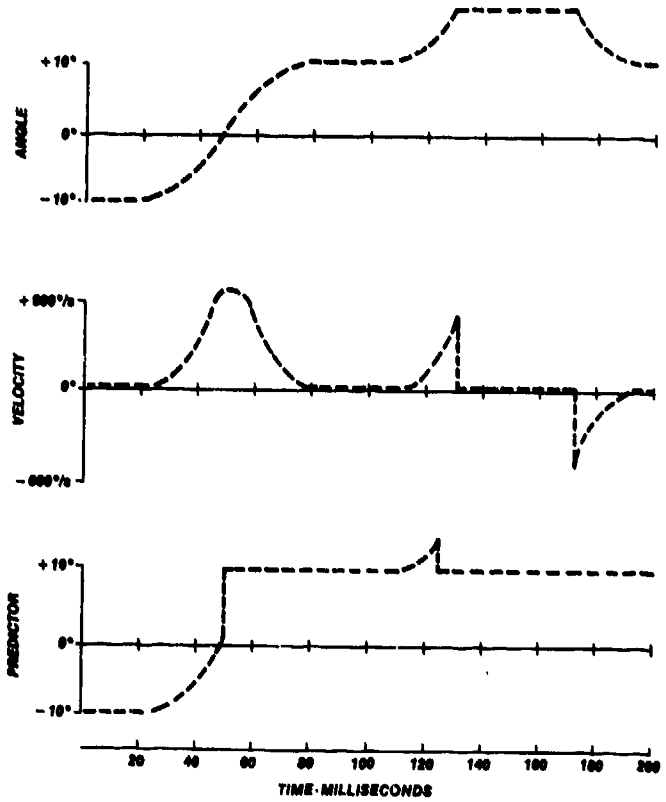
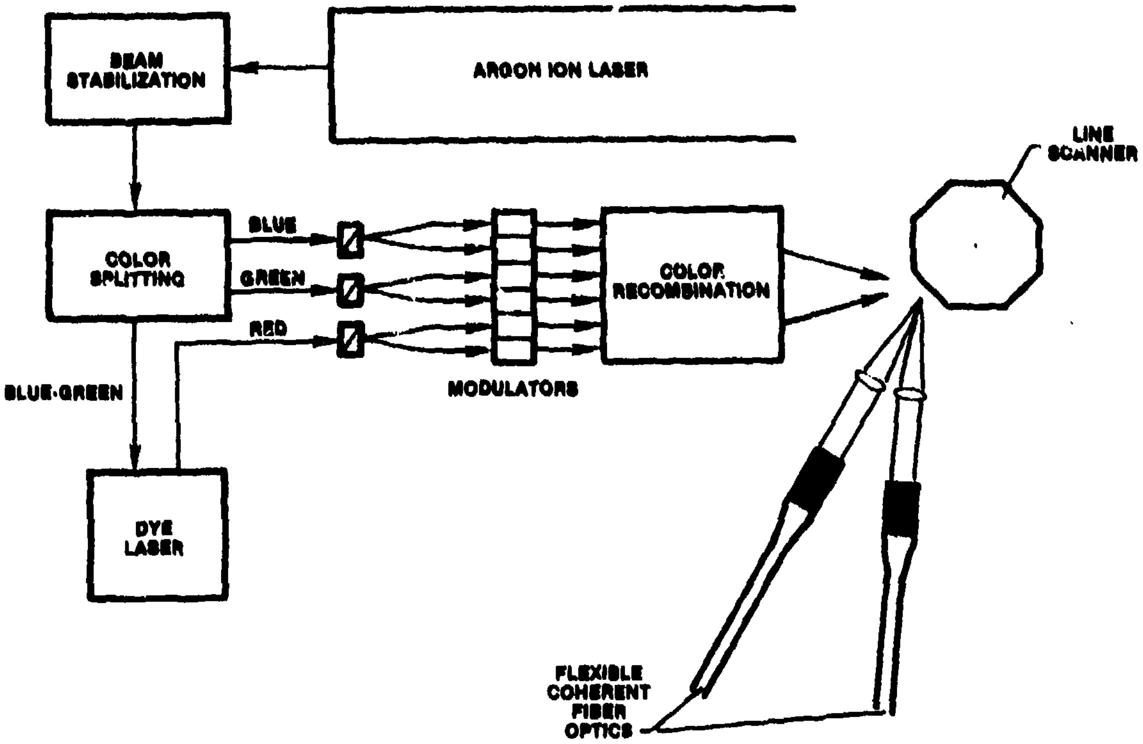
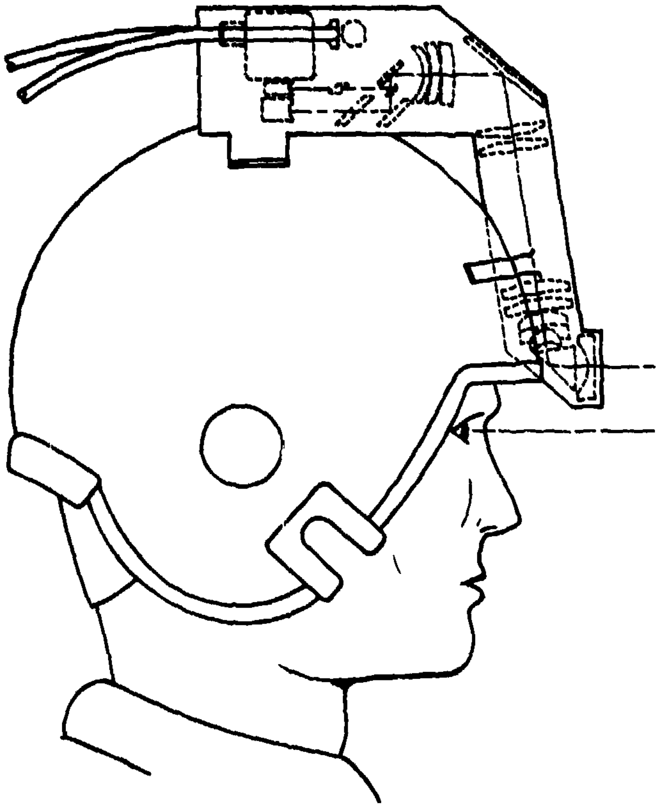


Figure 4. Eye Angle,Velocity,and Predictor Angle vs. Time



OFF-HELMET OPTICAL SYSTEM

Figure 5. Line Image Generator



HELMET-MOUNTED OPTICS

Figure 6. Helmet Mounted Optics

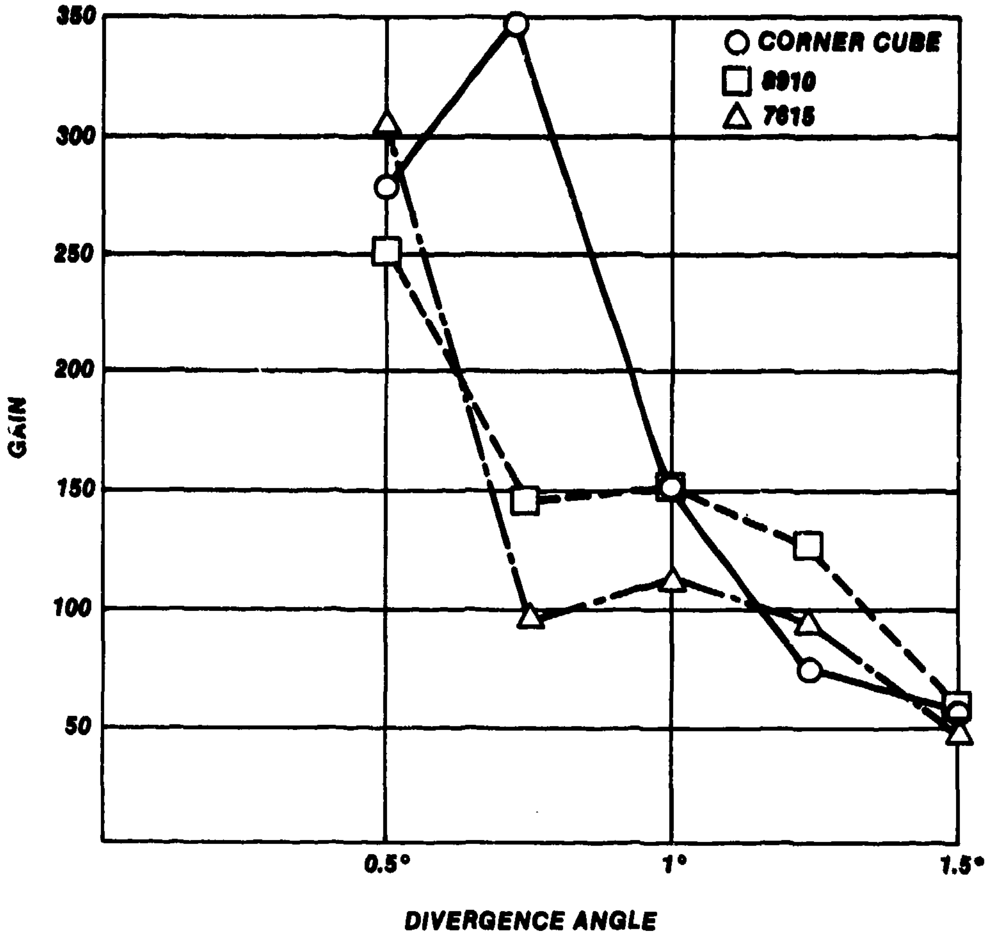


Figure 7. Screen Gain Measurements

COMPUTER PROGRAM FOR DISTORTION ANALYSIS IN SPHERICAL SCREEN DISPLAYS

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ABSTRACT

In visual simulation, the distortion of imagery in wide-angle display systems is a major concern. Effective flight training requires that imagery presented to a trainee provide a proper perspective view of his simulated environment without distortion. Use of spherical screens (domes) introduces both perspective and geometrical distortion into the wide-angle displays. Use of video projection systems with Computer Image Generation (CGI) offers the options of raster shaping or computer re-mapping of raster pixels for distortion correction. The goal in distortion correction is to provide proper perspective of imagery to a trainee. The basic causes for distortion and a computer program for analysis of spherical screen distortion will be discussed.

INTRODUCTION

Visual Flight Simulation

Visual flight simulators are being developed into an important part of the training that pilots, both commercial and military, are receiving for development and upkeep of their flight skills. The ultimate goal in visual simulation is to provide a realistic view of the environment about a simulated aircraft to increase the effectiveness of training exercises. (1) A trainee's view of this environment, in conjunction with mechanical simulation of the aircraft dynamics and structure, can induce many physical/psychological effects of actual flight. (2) Imagery is often provided via computer image generation (CIG) and displayed by video projection systems. Generally, the CIG system takes account of viewpoint and heading direction within a mathematically modeled landscape (database) to generate a view of this database during a simulated flight. (3) The effectiveness of the visual simulation depends on many factors, including the Field Of View (FOV), detail in the database, resolution capability, display brightness and contrast, and relative distortion of the imagery.

Wide-Angle Visual Displays

The goal of realism in visual simulation has led to the use of very wide-angle displays filling a horizontal FOV of 90° or more at the pilots viewpoint. Increasing the FOV to greater than 180° has led to the use of spherical screens (domes) with a number of projectors filling different parts of the pilot's available FOV to form a wide-angle scene. (4) Ideally, the projectors and viewpoint should be located at the center of the dome, or at least at the same point, to reduce distortions for the viewer. Unfortunately, physical restrictions do not allow a number of projectors and the viewer to occupy the same position in space, thus forcing the oblique projection of imagery onto the dome. This fact results in distortion of the imagery.

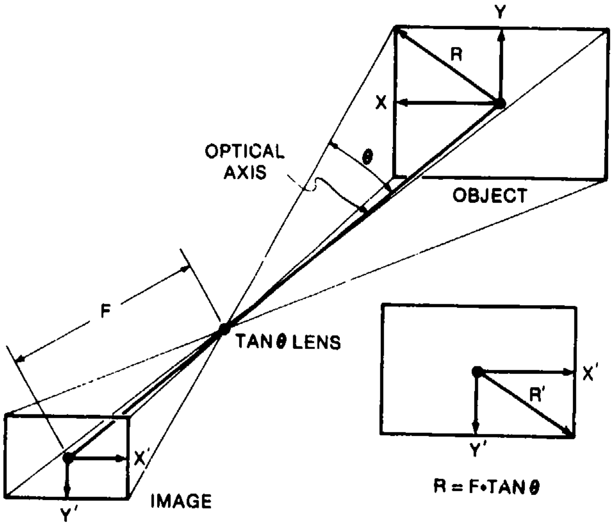


Figure 1. Mapping via Tangent θ Lens, Non-Distorted

Distortion

Distortion refers to the geometry of an image as compared to the actual geometry of the objects involved. Perhaps the best way to describe the concept of distortion as related to optical systems is to first consider the concept of a distortionless lens mapping. Figure 1 shows the mapping process of a well corrected F-Tan θ lens as a rectangular object is mapped through the lens. The resulting image formed is again a rectangular figure. The radial distance, R, to an image point is determined by the tangent of the angle, θ, that an object point subtends from the optical axis of the lens system. Hence the lens mapping equation, R = F-Tan θ, where F is the focal length of the lens. If the direction of the mapping process is reversed, we then have the case of the lens being used as a projection lens versus use as a taking lens. For this case, any imagery placed on the plane denoted as the image plane will be transferred to the object plane without distortion. This is the concept of a distortionless lens mapping.

Next, we should consider the concept of distortionless viewing of a projected image. If it were possible to place the eye of a viewer at the exit pupil of a projection lens which has an F-Tan θ mapping function, as in figure 2, then the viewer would perceive no distortion of the imagery projected from the image plane. However, if the viewer is removed from the exit pupil location, then the shape of a rectangular object would no longer appear rectangular. This removal of the viewpoint from the exit pupil results in a form of distortion known as Perspective Distortion, which usually results in rectangular objects exhibiting a keystone shape. The key to reducing perspective distortion is to place the exit pupil of the projector as close as possible to the viewer's eyepoint.

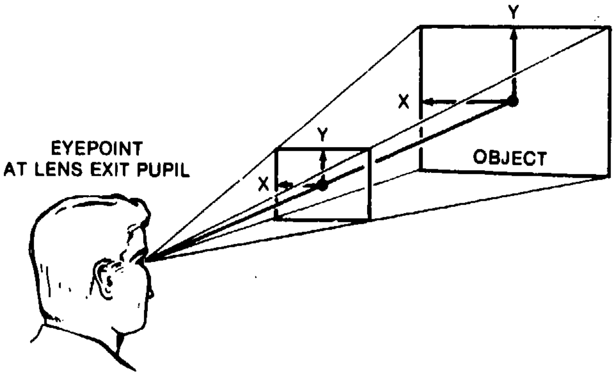


Figure 2. Distortionless Viewing

In a dome display system, their exists another form of distortion. This form is referred to as Geometric Distortion, which involves the oblique projection of imagery onto screen surfaces which are not flat display planes. The result is that the projection of straight lines onto the screen surface are viewed as curved lines by the observer. It should be noted, that if the viewpoint and exit pupil of a F-Tan θ lens are coincident, then the shape of the screen cannot contribute to distortion. (7)

Therefore, the amount of distortion depends on the size and shape of the screen, as well as projector/viewpoint positioning. As the projector and viewpoint are displaced from each other the apparent size and shape of the projected imagery, as well as the angular subtense and position, will vary accordingly. It is the purpose of the computer program to be described to consider these two forms of distortion, that is Perspective and Geometric Distortion, in spherical screen display systems.

Distortion definitions vary according to the type of projection system involved. The method of calculating distortion in this paper is based on the Institute of Radio Engineers (IRE) Standards for Television. (5) This method defines the Geometric Position Error (GPE) for any point in the field as the magnitude of the distance from the point to its ideal location. This implies a radial distance measurement from the ideal location of a point to its actual position. The percentage of distortion is then found by dividing the GPE by the full field height of the image. Figure 3 shows the linearity chart given in the IRE standards for distortion measurements. This chart is placed over a video monitor which has an alignment pattern generated by a test signal generator and qualitative measurements are made by observing the position of the pattern with reference to calibrated circles.

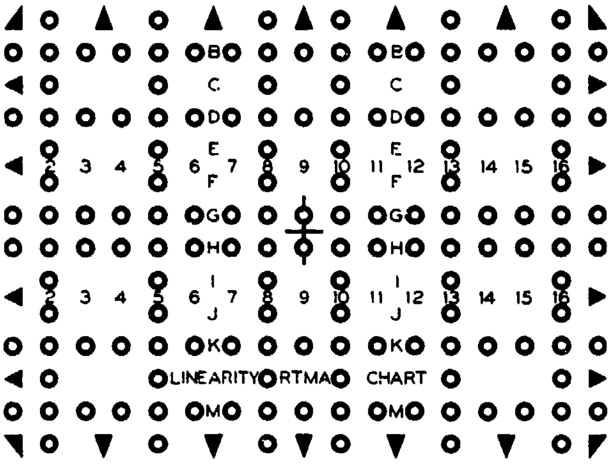


Figure 3. IRE Linearity Chart

Distortion Correction

The first attempts at correcting distortion primarily involved the use of optical elements to pre-distort the image upon projection, resulting in an image that appeared non-distorted to the viewer. This method, although successful, required the correction to be physically set at the time of lens design for the display system. The capability to easily change the correction factor was lost along with the ability to use off-the-shelf standard lenses.

With the use of video projection systems, the option of correcting distortion by altering the scanning geometry of the video raster (raster shaping) became available. In this way the image can be pre-distorted before the projection lens in order to produce a non-distorted view. (6) The advent of Computer Image Generators brought an alternate method for corrections. The objects to be projected are remapped in the CIG computation to provide the required object pre-distortion before being placed on the video raster for projection. (7) Raster shaping and CIG remapping may be combined to reduce the complexity of the individual corrections. Both raster shaping and CIG remapping will allow changes in corrective action to some degree and may also allow dynamic correction.

Lens Mapping

In the computer program developed for analysis of distortion, there are four types of lens mappings considered for the projection lens. These four lenses allow the analysis to include consideration of the effects of the lens mappings on the final net distortion. The lens must be included in the analysis for it is an integral part of the system. The four lenses are:

1. F-Tan θ (distortionless lens)
2. F-Tan θ with primary distortion
3. F-θ (θ in radians)
4. F-Sin θ

All these lens mappings imply a radially symmetric mapping with the center of the mapping plane on the optical axis of the system. The F-Tan θ lens places an image point on the image plane according to the tangent of the angle (θ) between the optical axis and the object point. The mapping equation is:

$$Rt = F \cdot Tan(\theta),$$

where Rt is the image point radial distance from the center of the image plane, F is the lens focal length, and θ is the angle.

The F-Tan θ with primary distortion (F-Tan $\theta \cdot$ P) lens is defined as a departure from the F-Tan θ mapping due to an approximation of Tan-θ by only two terms of a power series. The resulting equation is:

$$Rp = Rt\,(1 + (DFACTOR * Rt^2)),$$

where Rp is the image point radial distance for the F-Tan $\theta \cdot$ P mapping, Rt is the radial distance for the F-Tan θ mapping, and DFACTOR is the primary distortion factor.

An F-θ lens maps object space to image space according to the angle in radians to the object point, resulting in the radial position of the image (R_θ) being defined as:

$$R_\theta = F\theta.$$

The F-Sin θ lens implies a mapping according to the sine of the optical axis, yielding the mapping equation:

$$Rs = F\,Sin(\theta).$$

Figure 4 shows the relative distortions of a rectangular object by the lenses previously mentioned.

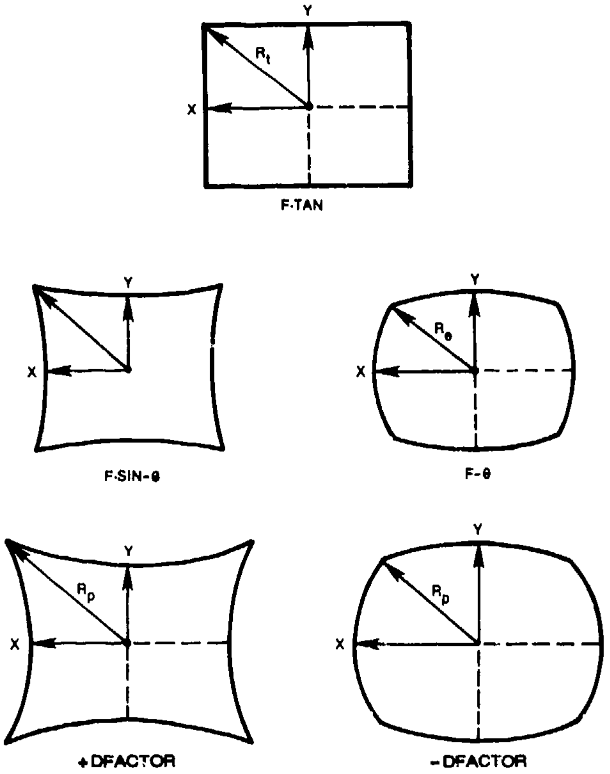


Figure 4. Relative Distortions of a Rectangular Object by Various Lens Mappings

THE PROGRAM - MAPTAG

Introduction

MAPTAG is an acronym for Mapping Tables and Graphs, a program written in FORTRAN for distortion analysis. The facilities for development and operation of the program are part of the NAVTRAEQUIPCEN's Computer Simulation Laboratory. The computer system utilized is a VAX-11/780 with graphics provided via a Tektronix graphic terminal model 4014-11.

The program is designed to find the required distorted raster shape for projection onto a dome from a particular projection point. This projected raster is to be viewed at a viewpoint as a non-distorted raster. The location of the viewpoint and projector can be located inside or outisde the dome of radius R. The raster is placed on a View Window of variable height and width in degrees, and can be centered at any location on the dome.

In order to describe the projection/viewing system, the location of the projector, viewpoint, and image points are referenced to a 3-D coordinate system located at the center of the dome (Figure 5). In this system, the Z-axis is positive upwards, the X-axis is positive forward, and the Y-axis is positive to the left. Additionally, the angles for projection and viewing are spherical angles referenced to the positive X-axis. Vertical angles are positive above the dome horizon and negative below the horizon with a maximum magnitude of 90°. Horizontal angles are positive for a counter-clockwise rotation (positive X-axis into the positive Y-axis) when viewed from a point on the positive Z-axis. The hoiizontal angles have a maximum magnitude of 180°.

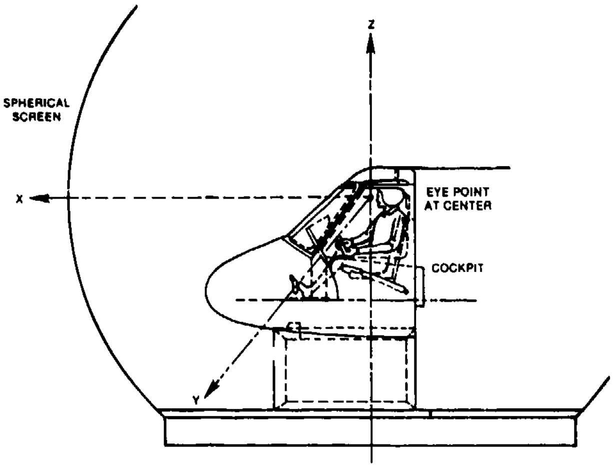


Figure 5. 3-D Coordinate System For Spherical Screen

There are three other coordinate systems involved in the program. These are two 3-D coordinate systems, located at the viewpoint and projection point, and a 2-D coordinate system used to define the Input Plane.Each of the 3-D systems are parallel to the other, with the 2-D system transformed to the sphere-centered 3-D system as the Input Plane becomes the View Window.

View Window

The View Window is defined as that part of the available FOV that is being filled by one projector. Ideally, the viewer will see objects projected onto this window as non-distorted. If a video projection system is used, then the viewer will want to see a raster plane that has pixels at equal increments across the raster lines and equally spaced raster lines on the window. This is the Input Plane and is constructed by considering the desired angular height and width as well as the position of the center of the view window (PCTR) relative to the viewpoint. These values are used to find the height and width of the raster plane in dimensional units that are fixed with respect to dimensional units used for all 3-D locations.

The Input Plane has a 2-D coordinate system with its origin set at the center of the plane (Figure 6). In this coordinate system the Y-axis is positive upward and the X-axis is positive to the left. Once the height and width of the Input Plane are known, then the first point on the plane is found by dividing the height and width in half. This first point is defined as the top left point on the plane. Subsequent points on the plane are found by considering the number of points across the horizontal raster lines (NHORIZ) and the number of vertical raster lines (NVERT) on the plane. The width of the plane is divided by (NHORIZ-1) to find the linear increments along the raster (HINCRFMENT), while the height is divided by (NVERT-1) to find the linear increments between raster lines (VINCREMENT). To find the next point along a raster line on the plane, the HINCREMENT is subtracted from the previous points' X-coordinate with the Y-coordinate remaining the same. At the end of a raster line, the VINCREMENT is subtracted from the previous points' Y-coordinate, and the X-coordinate is reset to the X-coordinate of the first point. In this way, raster lines are drawn from left to right and top to bottom on the Input Plane.

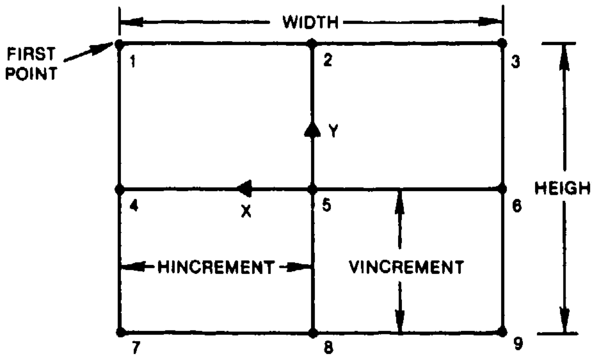


Figure 6. 3x3 Input Plane

After a point on the Input Plane is found, the Input Plane is aligned to be normal to the viewer's Line of Sight (LOS) and translated to the desired View Window center (Figure 7). At this point, the View Window is projected onto the surface of the spherical screen but still appears to be a flat non-distorted raster from the viewpoint.

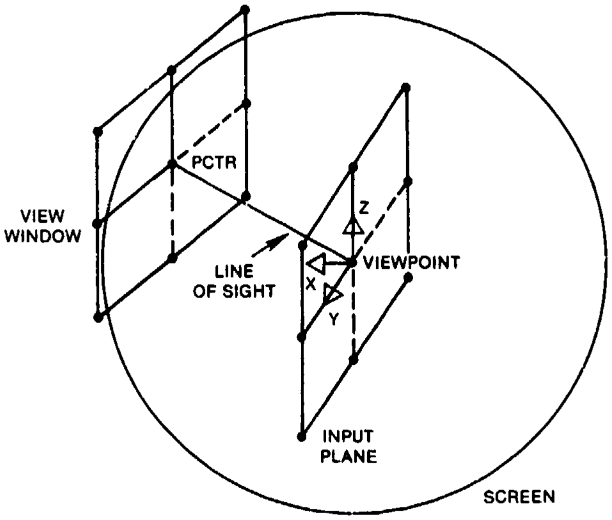


Figure 7. View Window Generation

Spherical Screen Projection

To find the intersection of a ray projected from the viewpoint towards the spherical screen, the subroutine Sphere Point from Angles (SPTFANG) is used. This subroutine uses spherical angles of projection to define the direction of individual rays at the viewpoint. This distance from the viewpoint to the screen is calculated and used to find the terminus of the ray in 3-D coordinates.

The angles to points on the View Window plane from the viewpoint are found by subroutine Spherical Angles from Points (SANGFPT) and then are input to SPTFANG. The View Window is then mapped onto the screen surface and we are now ready to find a perspective view of the View Window from the projection point.

Perspective View

Another subroutine, PSPECTIVE, is used to find the perspective view of the View Window from the projection point. Initially the subroutine translates the origin of the 3-D coordinates for the View Window to the projection point. Then, the View Window is rotated about the projector to align the center of the View Window (PCTR) with the projector's X-axis. (8) Having accomplished these operations, the tangents to points on the View Window can be found relative to PCTR.

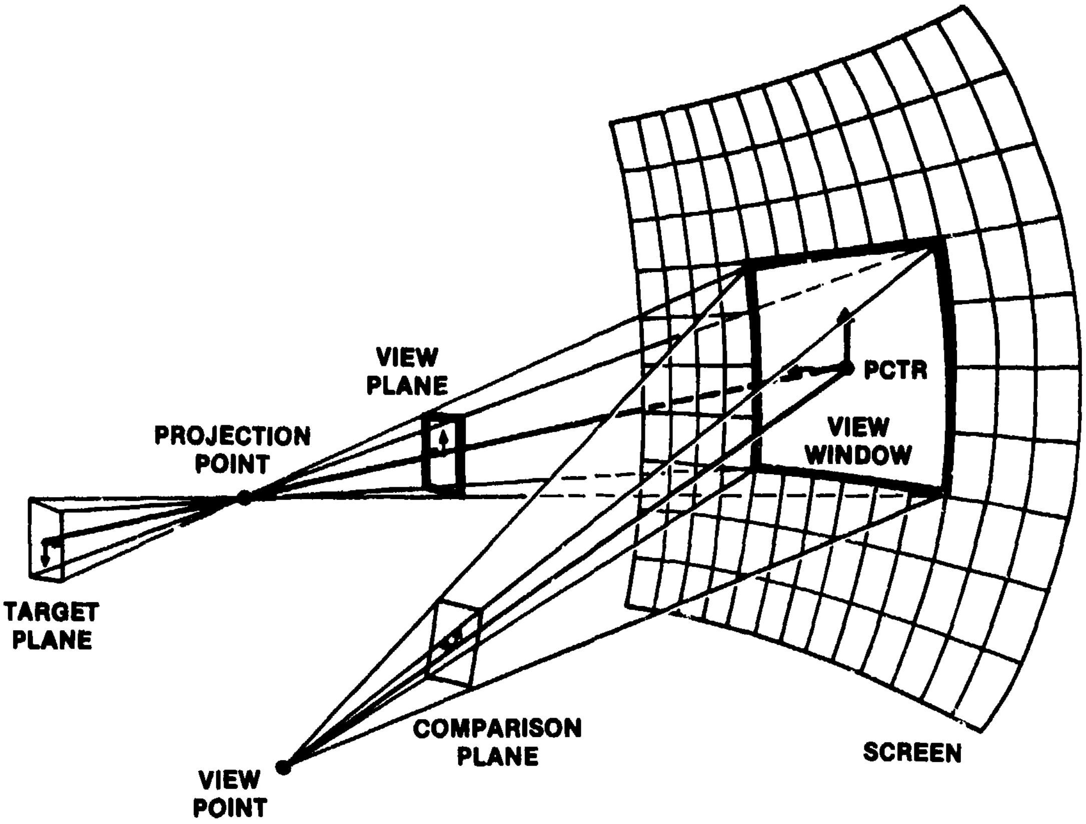


Figure 8. Projection/Viewing Diagram

PSPECTIVE allows this tangent mapping to be altered by a remapping through one of three other lens mappings listed previously. Only the tangent mappings will give a correct perspective from the projection point, with the three additional mapping choices distorting the view according to their mapping functions. These mapping coordinates are sent to plotting programs which draw the View Plane on a graphic terminal with hard-copy available.

Reference circles, indicating total FOV's of 90° and 110°, are included on the output mappings. These FOV's are generated by subroutine FOV and are dependent on the type of lens mapping specified. These reference circles can be used to determine the location of object points relative to the optical axis of the lens. Points that lie on a circle are defined as being located at the half-angle of the total FOV. For example, if a point is on the 90° FOV circle, then the angle between the optical axis and the ray to that point is 45°. Points outside the FOV reference circle are at greater angles, while points inside the FOV reference angles are at an angle less than the FOV half-angle. The FOV reference circles give an excellent way to approximate the total FOV required for a particular projection arrangement.

Mapping Output

Figure 8 shows the basic mapping processes for MAPTAG containing two mappings. The first maps the input plane on to the surface of the dome to provide a non-distorted raster to the viewer. This raster pattern on the dome is the View Window. In the process of creating the View Window, a Comparison Plane is also formed which is a mapping of the Input Plane calculated by considering the eye as a F-Tan lens with a focal length of unity. In all output mappings, the value of the focal length is taken as unity, allowing mappings for a lens of another focal length to be represented by multiplying the mapping coordinates by the desired focal length.

The second mapping is from the dome surface through the view plane and onto the target plane. The mappings produced by MAPTAG are mappings at the view plane, which provide a perspective view of the object points on the dome from the projection point. A perspective view of the target plane from the projection point (a view of the required raster pattern) may be obtained by a rotation of the output mapping about its center by 180° and observing the pattern through the reverse side of the mapping.

The coordinates for the view plane output mapping can also be placed in table form. Each table contains specific information on the projection/viewing system and the type of mapping used. The coordinates are printed in the table according to their relative position on the raster plane. Also placed in the table output are the coordinates of the Comparison Plane, allowing distortion calculations to be made from the table. Use of the Comparison Plane coordinates for calculations requires the scaling of the coordinates to reduce the Comparison Plane height to the height of the View Plane. The scaling factor is defined as the ratio of the View Plane height to the height of the Comparison Plane. For purposes of distortion calculations, the GPE is then found by effectively overlaying the View Plane on the Comparison Plane via the coordinate tables.

Subroutine TBLDIST uses the coordinates sent to the mapping tables to calculate distortion percentages for nine points in the field. These nine points, assuming an odd number of points on the plane, are the four corner points, the central point, and the four points at the midpoint of each edge of the plane. The percentages found are included on the mapping table output.

PROGRAM OPERATION

Running the Program

In order to operate the program, variables describing the projection/viewing system must be entered. Upon instructing the computer to execute the program (RUN MAPTAG), the user is prompted to enter the necessary values. Definition of the view window starts with the location of the center of the view window (PCTR). This location is in 3-D coordinates relative to the screen center and must be on the screen surface. Next, the height and width in degrees and the number of points across and down the window are entered. The maximum height or width of any window is less than 180° due to the method of creating the input plane. Additionally, the number of points should be odd for use in the distortion calculation subroutine.

Describing the rest of the system requires entering the radius of the screen, R, the projector location EX(FX, FY, FZ), and the viewpoint, EN(XE, YE, ZE). The units for these coordinates are arbitrary, but must be the same for all 3-D coordinates. As an option, the projector axis can be offset from PCTR during operation of the program by entering degree offsets other than zero for VOFFP and HOFFP.

The rest of the values to be entered are concerned with the type of output mapping and table. The type of lens mapping is chosen by entering a value from 1 to 4 corresponding to the four lens mappings available. If a Tan θ mapping with a primary distortion is desired, then the user is prompted to enter a distortion factor (DFACTOR). Additionally the user is instructed to enter a graphic scaling factor (FSCALE), screen magnification factor (SMAG), and offsetting values for the origin of the screen (XBIAS, YBIAS) in inches. Finally, the user can decide if table output is wanted during the present run of the program.

After the program has completed the graphics, the user is instructed to enter "C" to continue execution. The user is then offered the option of changing the projection axis offset, graphic scaling, screen magnification, and table output option. If a change is desired, the program again prompts the user to enter values and the graphic screen is cleared in order to draw a new perspective view according to the new values. If no changes are desired, the program will clear the graphic screen and execution is stopped.

SAMPLE PROJECTION SYSTEMS

As examples, the results of two sample projection/viewer systems are included. The first sample is a simple projector/viewer arrangement where the viewer is placed at the center of a 20 foot radius dome and the projector is located at the 3-D location (0.0,0.0,12.0) inches. This results in a 12 inch displacement of the projector directly above the viewer. In this case the projected View Window subtends angles of 70°vertical by 90° horizontal from the viewpoint. On this View Window, there is an 11 by 11 raster pattern which forms one hundred rectangular blocks as depicted on figure 9. The window is centered on the surface of the dome at the 3-D location (240.0,0.0,0.0) inches, or at the intersection of the X-axis with the dome surface. Table 1 shows the program prompts and user inputs to describe the above system. Figures 10, 11, and 12 show the required raster shapes to be projected from the defined projector location for the use of projection lenses with mapping functions of Tan θ , Sin θ , and θ , respectively.

The second projection/viewer arrangement is a projector arrangement with the View Window and projector located on opposing sides of the dome surface. In this system the viewpoint is again coincident with the center of a 20 foot radius dome. However, the projector is located behind the viewer on the surface of the dome at the 3-D location (-218.0,0.0,101.0) inches, and the View Window is placed at the 3-D location (218.0,0.0,-101.0) inches. This arrangement directs the optical axis of the projector to pass through the center of the dome on its way to the center of the View Window, and provides a for a symmetrical projection onto the window at a distance of twice the dome radius, or 40 feet. The View Window contains an 11 by 11 raster pattern and subtends angles of 160° by 160° from the viewpoint as shown in figure 13. Figures 14, 15, and 16, with tables 5, 6, and 7, describe the required raster shapes for example 2.

ANALYSIS OF THE SAMPLE SYSTEMS

Analysis of the required raster shapes for a projection system involves looking at the graphic mapping outputs and their corresponding table outputs. From these a visualization of the raster shapes is obtained, along with the distortion percentages related to each mapping.

Examining the coordinate tables 2, 3, and 4, which are for the first example, specific information for each type of lens in this projection arrangement is revealed. The tables are labeled as to the type of lens mapping function considered along with identification of the projector, viewer, and view window locations. The tables contain the coordinates of the intersection points for the distorted raster shape and the coordinates of the non-distorted Comparison Plane. Notice that the coordinates are preceeded by the labels (X, Y) and (XC, YC) which denote the coordinates of the View Plane and Comparison Plane in turn. These coordinates are included in the tables in the same manner that the raster lines are drawn on the View Window, that is, left to right and top to bottom. The tables provide only the coordinates of the points used in the distortion calculation routine, and not all the points of the 11 by 11 pattern. The coordinates of all the points are available, but are not included here due to the size of the tables.

The first output mapping for example 1, figure 9, is a tangent mapping of the View Window, or equivalently, the Comparison Plane. This is the raster shape that the viewer should see for the condition of no distortion. The tangent mapping for this projection system, figure 10, shows a maximum distortion of 2.6%, with symmetrical distortion about the center vertical line of the raster pattern. All the distortion percentages for this mapping are low and reflect the close proximity to the viewpoint of a projector with a F Tanθ mapping function. Looking at the F-θ and F-Sin θ outputs, the maximum distortion percentages jump to 28.6% and 20.3%. These percentaghes are large and reflect the departure of the individual lens mapping functions from a distortionless, or F-Tan θ , lens. In this system, a lens with a F-Tan θ mapping would be preferred due to the closeness of the projector and viewer, and the less than 90° projection angles required.

The second example is offered as an extreme case compared to the preceeding case. The separation of the projector and viewer is increased to 20 feet and the View Window is required to fill a FOV of 160 ° by 160° at the viewpoint. Examining the mappings and tables for this second system, it can be seen that the distorted raster shapes for all the mapping functions fall within the 90° reference circle. In fact, the maximum projection angle for any of the lenses is approximately 80°. This angle is appropriate considering the View Window to fill a 160 by 160° FOV at the viewpoint with projection from a distance of twice the dome radius. A projection lens with the TFOV of 90° would provide more than enough of the projection field required to fill the View Window.

The distortion percentages for all three lens types are quite large and are approximately equal. Examining tables 5, 6, and 7, the maximum distortion required for the F-θ mapping is slightly greater than the Tangent mapping (18.09% vs. 18.90%), while the F-Sin θ mapping requires the most raster shaping at 19.22%. These raster shapes may be hard to implement by raster shaping alone as can be seen in figures 14, 15, and 16.

Other information to be gained from the program output concerns the redistribution of the raster points on the projection lens target plane. In the second system, the points are crowded together near the edges of the target plane with only a few points in the center of the target plane. The effect of this distribution depends on the projection lens in use, but would tend to reduce the resolution capacity of the imaging system. This is due to the crowding of resolution elements (Resels) on the target plane where most lenses lose resolution capability, and lack of resels where most lenses have their greatest resolution.

SUMMARY

The program MAPTAG is a very useful tool for determining the required raster shape to be projected which provides for distortionless viewing. The graphic output provides visualization of the distortions encountered in dome displays. The table allows distortion calculations to be performed and can also provide for equations that describe the raster distortion, line by line.

The subroutines utilized by MAPTAG have been written in a general form to allow their use in building other specific distortion routines. The flowcharts and program coding have been documented and are available to the general public. (9) Extension of the program, to provide more information about projection systems, is being investigated. These programs provide an excellent basis for distortion analysis of video projection systems and efforts are being taken to include projection of generalized imagery.

EXAMPLE 1

```
  RUN MAPTAG

   DESCRIBE PLANAR INPUT SCREEN

   ENTER DESIRED COORDINATES FOR PLACEMENT OF CENTER
   OF PLANE IN SPHERE COORDINATE SYSTEM, THE X-AXIS IS POSITIVE
   FORWARD WITH THE Y-AXIS POSITIVE TO THE LEFT, AND THE Z-AXIS
   IS POSITIVE UPWARDS
240,0,0

    ENTER VERTICAL AND HORIZONTAL FOV'S IN DEGREES
70,90

   ENTER NUMBER OF POINTS ALONG VERTICAL AND HORIZONTAL
   AXES
11,11

   DESCRIBE SPHERICAL SCREEN DISPLAY SYSTEM

   ENTER SPHERICAL SCREEN RADIUS
240
   ENTER PROJECTOR POSITION (FX,FY,FZ)
0,0,12
  ENTER VIEWPOINT POSITION (XE,YE,ZE)
0,0,0
   ENTER VERTICAL AND HORIZONTAL OFFSET FOR PROJECTION
   DIRECTION (DEGREES)
0,0
  ENTER SCALE FACTOR , SCREEN MAS , YBIAS, XBIAS NORMALLY
   SCREEN MAG = 1, XBIAS = 0, YBIAS = 0, THE SCALE FACTOR
   DETERMINES THE TFOV (FSCALE * 90)
1.5,1,1,0,0
  PICK WHICH TYPE OF MAPPING DESIRED, FOR A TANGENT MAPPING
  ENTER "1", FOR AN IDEAL R-THEATA MAPPING ENTER "2", FOR
  TANTHETA MAPPING WITH PRIMARY DISTORTION , ENTER "3",
  FOR SIN THETA MAPPING, ENTER "4"
1
  IF TABLE OUTPUT IS DESIRED TYPE TRUE ; IF NOT FALSE
T

  TYPE C TO CONTINUE EXECUTION
1
$ C
 TO CHANGE VOFF,HOFF,MAG,FSCALE,LIABLE,TYPE OF MAPPING
  ENTER "T", IF NOT ENTER "F"
F
  TO CHANGE SCREEN MAGNIFICATION,ENTER T ,TO STOP ENTER F
F
FORTRAN STOP
$
```

TABLE 1

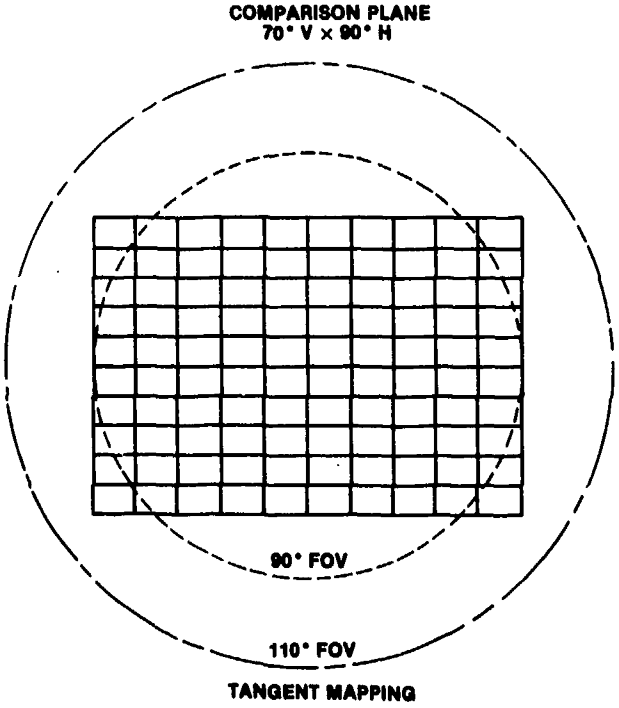


Figure 9.

TAN THETA MAPPING COORDINATES

```
   THE VIEWPOINT IS AT :
 X =     0.0000   Y =     0.000   Z =     0.000
   OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN
   FILLING A FIELD OF      70.000 DEGREES VERTICALLY, AND
   90.000 DEGREES HORIZONTALLY ABOUT A POINT X=
   240.000  Y=       0.000  Z=      0.000  DEFINED  AS
   CENTER OF "FOV".

   THE PROJECTOR IS AT :
 X =     0.0000   Y =     0.000   Z =     12.000

THE RADIUS OF THE SPHERICAL SCREEN IS    240.000

X               1.033            0.000            -1.033
Y               0.693            0.712             0.693

XC              1.000            0.000            -1.000
YC              0.700            0.700             0.700

X               0.998            0.000            -0.998
Y              -0.021            0.000            -0.021

XC              1.000            0.000            -1.000
YC              0.000            0.000             0.000

X               0.964            0.000            -0.964
Y              -0.702           -0.685            -0.702

XC              1.000            0.000            -1.000
XC             -0.700           -0.700            -0.700

                  DISTORTION PERCENTAGES

  THE TARGET PLANE HEIGHT IS          1.397

          1            2            3
           2.44%          0.84%          2.44%
          4            5            6
           1.49%          0.00%          1.49%
          7            8            9
           2.60%          1.08%          2.60%
```

TABLE 2

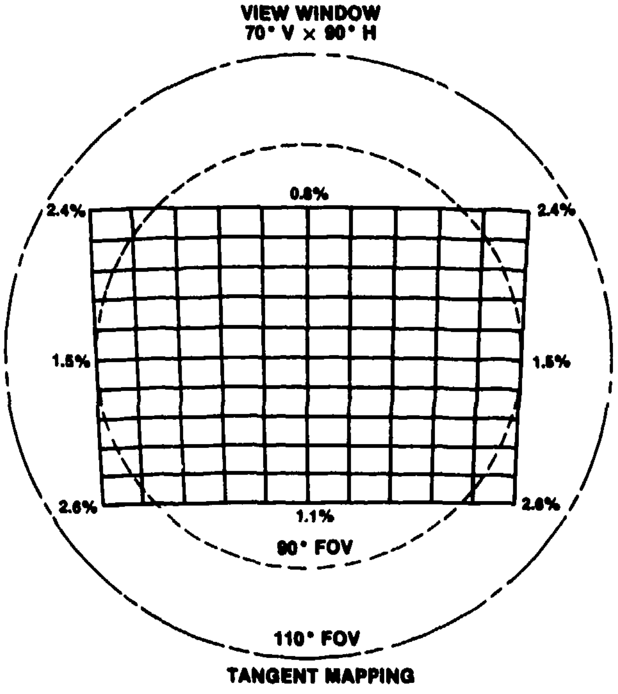


Figure 10.

R-THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :
X = 0.0000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING A FIELD OF 70.000 DEGREES VERTICALLY, AND 90.000 DEGREES HORIZONTALLY ABOUT A POINT X= 240.000 Y=0.000 Z= 0.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :
X = 0.0000 Y = 0.000 Z = 12.000

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

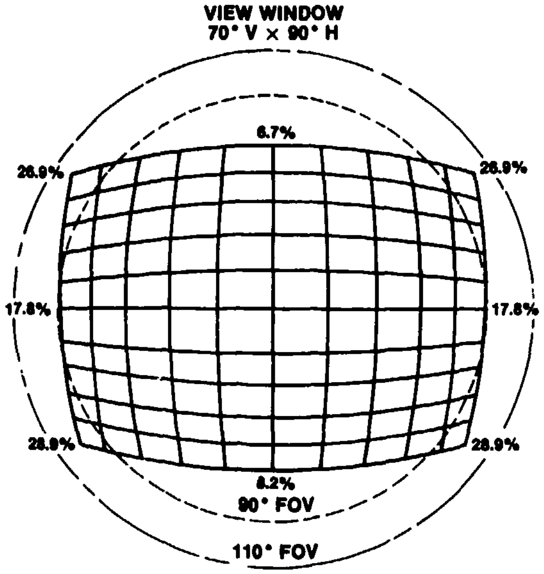
X	0.742	0.000	-0.742
Y	0.498	0.618	0.498
XC	1.000	0.000	-1.000
YC	0.700	0.900	0.700
X	0.784	0.000	-0.784
Y	-0.015	0.000	-0.016
XC	1.000	0.000	-1.000
YC	0.000	0.000	0.000
X	0.706	0.000	-0.706
Y	-0.514	-0.601	-0.514
XC	1.000	1.000	-1.000
YC	-0.700		-0.700

DISTORTION PERCENTAGES

THE TARGET PLANE HEIGHT IS 1.219

1	2	3
26.87%	6.69%	26.87%
4	5	6
17.75%	0.00%	17.75%
7	8	9
26.58%	8.16%	28.58%

TABLE 3



R-THETA MAPPING

Figure 11.

SIN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :
X = 0.000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING A FIELD OF 70.000 DEGREES VERTICALLY, AND 90.000 DEGREES HORIZONTALLY ABOUT A POINT X= 240.000 Y= 0.000 Z= 0.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :
X = 0.0000 Y = 0.000 Z = 12.000

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

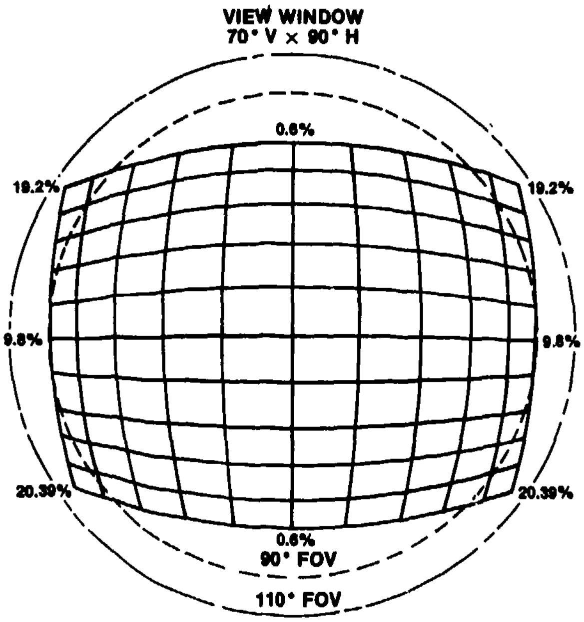
X	0.647	0.000	-0.647
Y	0.434	0.580	0.434
XC	1.000	0.000	-1.000
YC	0.700	0.700	0.700
X	0.706	0.000	-0.706
Y	-0.015	0.000	-0.015
XC	1.000	0.000	-1.000
YC	0.000	0.000	0.000
X	0.619	0.000	-0.619
Y	-0.451	-0.565	-0.451
XC	1.000	0.000	-1.000
YC	-0.700	-0.700	-0.700

DISTORTION PERCENTAGES

THE TARGET PLANE HEIGHT IS 1.145

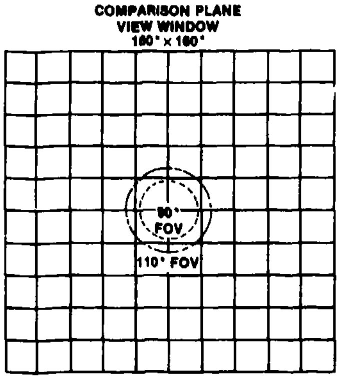
1	.2	3
19.17%	0.64%	19.17%
4	6	6
9.82%	0.00%	9.82%
7	8	9
20.32%	0.64%	20.32%

TABLE 4



SIN THETA MAPPING

Figure 12.



TANGENT MAPPING

Figure 13.

TAN THETA MAPPING COORDINATES

```
   THE VIEWPOINT IS AT :
 X  =     0.0000   Y  =     0.000   Z  =     0.000
   OBSERVING A LINEAR RASTER PATTERN ON THESCREEN
   FILLING A FIELD OF   160.000 DEGREES VERTICALLY,
   AND    160.000 DEGREES HORIZONTALLY ABOUT A POINT
   X=   218.000  Y=     0.000  Z=   -101.000    DEFINED
   AS CENTER OF "FOV".

   THE PROJECTOR IS AT :
 X  =  -218.0000   Y  =     0.000   Z  =     101.000

THE RADIUS OF THE SPHERICAL SCREEN IS     240.000
X              0.624            0.000           -0.624
Y              0.624            0.838            0.624

XC             5.671            0.000           -5.671
YC             5.671            5.671            5.671

X              0.838            0.000           -0.838
Y              0.000            0.000            0.000

XC             5.671            0.000           -5.671
YC             0.000            0.000            0.000

X              0.624            0.000           -0.624
Y             -0.624           -0.838           -0.624

XC             5.671            0.000           -5.671
YC            -5.671           -5.671           -5.671

                   DISTORTION PERCENTAGES

           1             2             3
           18.09%        0.00%         18.09%

           4             5             6
           0.00%         0.00%         0.00%

           7             8             9
           18.09%        0.00%         18.09%
```

TABLE 5

R-THETA MAPPING COORDINATES

```
   THE VIEWPOINT IS AT :
 X  =     0.000   Y  =     0.0000   Z  =     0.000
   OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILL-
   ING A FIELD OF 160.000 DEGREES VERTICALLY,
   AND   160.000 DEGREES HORIZONTALLY ABOUT A POINT
   X=   218.000  Y=   0.000    Z=  -101.000  DEFINED AS
   CENTER OF "FOV".

   THE PROJECTOR IS AT :
 X  =  -218.0000   Y  =     0.000   Z  =     101.000

THE RADIUS OF THE SPHERICAL SCREEN IS     240.000
X              0.511            0.000           -0.511
Y              0.511            0.698            0.511

XC             5.671            0.000           -5.671
YC             5.671            5.671            5.671

X              0.698            0.000           -0.698
Y              0.000            0.000            0.000

XC             5.671            0.000           -5.671
YC             0.000            0.000            0.000

X              0.511            0.000           -0.511
Y             -0.511           -0.698           -0.511

XC             5.671            0.000           -5.671
YC            -5.671           -5.671           -5.671

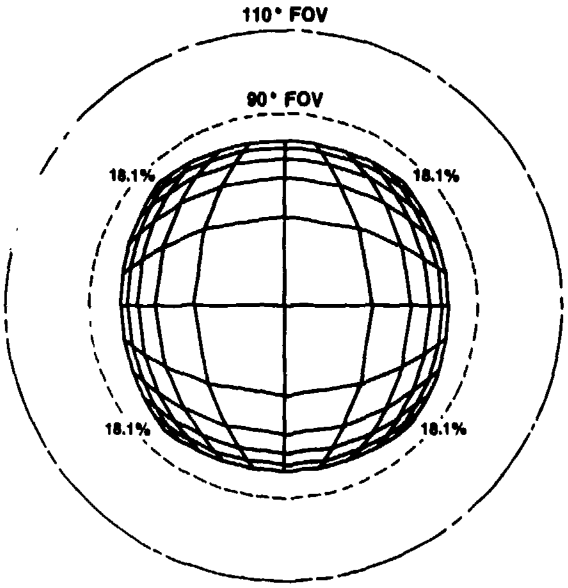
                   DISTORTION PERCENTAGES

           1             2             3
           18.90%        0.00%         18.90%

           4             5             6
           0.00%         0.00%         0.00%

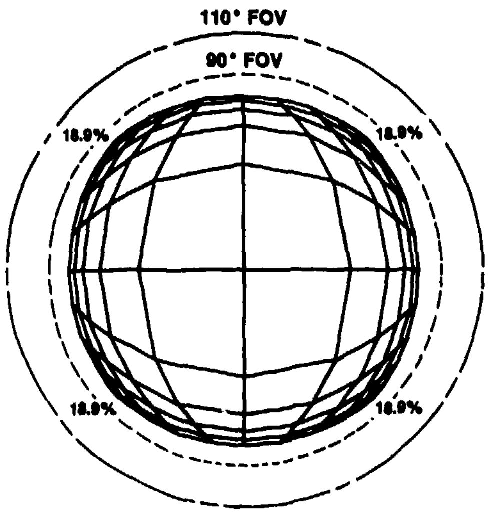
           7             8             9
           18.90%        0.00%         18.90%
```

TABLE 6



TANGENT MAPPING

Figure 14.



R-THETA MAPPING

Figure 15.

```
                    SIN THETA MAPPING COORDINATES

   THE VIEWPOINT IS AT :
 X =     0.0000  Y =     0.000  Z =     0.000
   OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING
   A  FIELD  OF      160.000   DEGREES  VERTICALLY,  AND
   160.000  DEGREES  HORIZONTALLY  ABOUT  A  POINT
   X=   218.000  Y=   0.000   Z=  -101.000  DEFINED AS
   CENTER OF "FOV".

   THE PROJECTOR IS AT :
 X =  -218.0000  Y =    0.000  Z =    101.000

THE RADIUS OF THE SPHERICAL SCREEN IS    240.000
X           0.468          0.000          -0.468
Y           0.468          0.642           0.468

XC          5.671          0.000          -5.671
YC          5.671          5.671           5.671

X           0.642          0.000          -0.642
Y           0.000          0.000           0.000

XC          5.671          0.000          -5.671
YC          0.000          0.000           0.000

X           0.468          0.000          -0.468
Y          -0.468         -0.642          -0.468

XC          5.671          0.000          -5.671
YC         -5.671         -5.671          -5.671

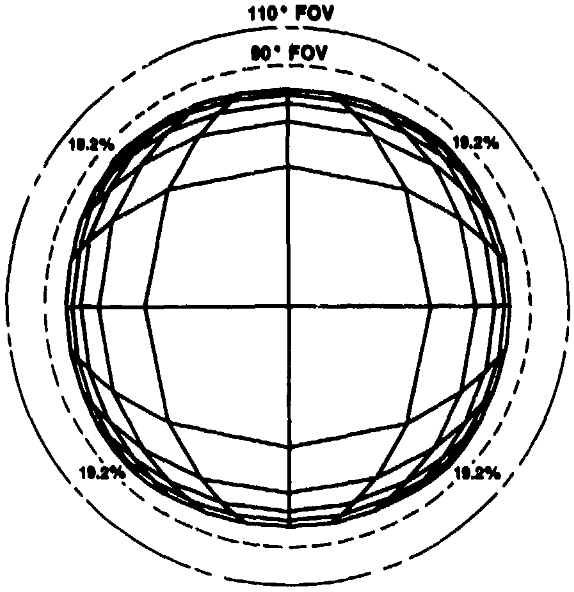
                 DISTORTION PERCENTAGES

          1          2          3
          19.22%     0.00%      19.22%

          4          5          6
           0.00%     0.00%       0.00%

          7          8          9
          19.22%     0.00%      19.22%
```

TABLE 7



SIN THETA MAPPING

Figure 16.

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ABOUT THE AUTHOR

Mr. Richard C. Hebb is a Physicist in the Simulation Technology Branch of the Advanced Concepts Simulation Laboratory at the Naval Training Equipment Center, Orlando, Florida. He is engaged in research on visual display systems, primarily on the Helmet Mounted Display project. He holds a B.S. in Math and Physics from Jacksonville University in Florida.

TARGET TV PROJECTOR WITH DYNAMIC RASTER SHAPING FOR USE IN DOME SIMULATORS

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ABSTRACT

Large dome simulators for air-to-air and air-to-ground aircraft weapons tactics trainers are coming into prominence. In such devices, the training objective is to improve pilot proficiency and coordination by allowing the pilot to train in the use of weapons in realistic operational and threat environments. Typically, the pilot will fight against a TV projected image that is slewed across the field of view. Sometimes neither the pilot's eyes nor the TV projector lens is located at the center of the dome screen. From geometrical considerations, a standard rectangular or square TV image looks distorted to the pilot. The degree and shape of the distortion changes with the shift in location of the "target" on the screen relative to the pilot as it is slewed either by servo pointing the entire projector or by optical means.

This paper describes the design and development of a TV projector that is capable of predistorting the TV raster such that from the pilot's viewpoint the image will look rectilinear at all times. This dynamic raster shaping can be updated at the TV field rate (typically 60 times per second) so that there is no perceptible jumpiness in the image as the shape is varied. In addition, the raster can be zoomed to create the appearance of distance change to the target and rotated to compensate the effects caused by the mirror steering of the target image across the dome.

INTRODUCTION

The layout of a typical aircraft weapons tactics trainer such as presently being developed for the U.S. Navy as Training Device 2E7 is shown in Figure 1. Each of two 40-ft diameter domes houses a simulated cockpit of a high performance jet fighter aircraft--an F/A-18 in the case of Device 2E7. The images from three background TV projectors and four target TV projectors are projected on the inside of the dome to present an all-encompassing dynamic scene to the pilot. The images are generated by digital techniques and the dynamics of the system are controlled by a large central computer. With this arrangement each of two pilots can either engage in simulated combat with each other or each can engage simultaneously in battle against the computer.

Each of the three background projectors is dedicated to a 120-degree segment of the dome and presents the image of the earth and sky environment surrounding the aircraft. Each of the four target projectors provides means to slew the image of a target or friendly aircraft across the field of view of the pilot. Since neither the pilot's eye point nor the target projectors are necessarily located on the geometrical center of the dome, standard rectilinear TV images may look distorted to the pilot. The degree and shape of the distortion changes with the location of the projected target on the dome screen relative to the pilot as it is slewed across his field of view.

DYNAMIC RASTER SHAPING

Systems Research Laboratories, Inc. (SRL) has provided TV projectors for simulation and training where either the whole projector head is mechanically slewed under servomechanism control (as shown in Figure 2) or the projector head remains stationary and the image is slewed across the domed screen by use of articulated optics (as shown in Figure 3a and 3b). In either case, computer controlled servomechanisms are used to keep the images in focus as the distance to the screen changes with pointing angle. The gimbaling of the whole projector head is better when using wide field-of-view lens, while the articulated lens is more practical with narrow field-of-view lens.

We are familiar with how a slide projector image becomes distorted if the slide projector is not placed squarely to the screen. If it is too low, the image is distorted such that the image of a square looks more like a trapezoid with a larger top than bottom. We also know that a projected picture that is square on the screen can look distorted when viewed off axis. These effects are compounded in the case of the target projectors where the image on the TV projection cathode ray tube is flat and rectilinear and the screen is concave and off-axis to the projected image. The answer to the problem created by such geometrical distortions is to predistort the TV image before it is projected such that it looks correct to the viewer.

Several approaches to predistorting the images can be taken. The digital image generator can be programmed to predistort the video. This requires a large increase in computing power. Likewise, a double ended, optically coupled scan converter such as the SRL Model 342A (effectively a TV camera viewing rectilinear video displayed on a predistorted CRT raster; therefore, generating a predistorted video at the TV camera output, can be used. This method has a built-in time delay of one field time and requires extremely good (but achievable) electro-optics in order not to degrade resolution. The method described in this paper uses an approach where rectilinear video is displayed on a CRT projector which provides dynamic raster shaping.

The development of the predistortion algorithm, though straightforward, is still moderately complex. Fortunately, the predistortion can be implemented in a practical system by modifying the TV horizontal and vertical sweep signals with a series of linear and nonlinear mathematical expressions in the analog domain. The functions that need to be implemented are:

- position
- size
- linearity
- trapezoidal
- pincushion/barrel
- curvature
- rotation
- orthogonality

The effect of these functions on a rectilinear raster is shown in Figure 4. All terms except for rotation can be solved using linear analog computational techniques. Rotation requires sine/cosine coordinate transformation.

In the case of the Navy's F/A-18 weapons tactics trainer Device 2E7, the central computer, either from canned programs or from the responses of the two adversary pilots, keeps track of the position of the target aircraft and generates the pointing angles of the respective target projectors. This information is translated to servomechanism information which is transmitted to the projector focus servo and to the articulated lens azimuth and elevation mirrors. It also generates at a TV field rate (60 fields/second) the coefficients for all the linear predistortion functions and both the sine and cosine of the rotation function in a digital format. Within the control unit of the TV projector electronics, this digital data is converted to analog and the remainder of the computation is accomplished in the analog domain. Figure 4 is a series of drawings showing the components of the various raster distortion terms that can be applied to the sweep circuits. These predistortion terms are shown only for the horizontal axis for ease in visualizing the effect. In actuality, a portion of each of these corrections in both the horizontal and vertical axis as well as rotation would be present, creating a very complex raster such as shown in Figure 5.

OTHER CONSIDERATIONS

Dynamic raster shaping places several other major requirements upon the projector. Normal TV displays and projectors use resonant horizontal deflection amplifiers due to their power conserving characteristics and due to their relative simplicity. Though some raster correction can be accomplished in resonant deflection amplifiers, only those corrections which are symmetrical about the center of sweep can be implemented simply. This eliminates curvature correction which is needed anytime the projector's optical axis is not colinear with a line drawn from the center of the dome to the dome itself--a situation that occurs at only one pointing angle with each projector. Also, raster rotation is not possible since the rapid TV retrace can be made in only one direction with resonant circuits. For continuous raster rotation, both the vertical and horizontal amplifiers must be equally as fast in both directions and as fast as each other. With these restraints on the system, it is necessary to use identical linear current feedback amplifiers for both the horizontal and vertical deflection amplifiers.

To conserve power, an SRL patented smooth actuating voltage boost is used whenever the deflection amplifiers sense it is in a flyback mode--independent of direction of flyback. (1) In practice, in each dome the four projectors are used in two pairs allowing the projection of two independent targets in order that one projector can take over from the other when it is slewed to a position such that the image would be obstructed by the simulated aircraft fuselage. Again, in order to conserve power, which would require an additional load on the dome's air conditioning system, the SRL projectors have a deflection amplifier powerdown feature which is used whenever the projector is not selected by the computer.

Up to 250:1 raster zooming is also available in the projector to create the effect of variable distance to the target. However, small rasters on a TV projector operating at up to 60 watts screen dissipation are potential problems due to phosphor burning. The SRL projector calculates the actual raster area and limits the video drive to a safe short-term value. This allows the display of bright objects for short periods of time, but long-term protection is up to the central computer.

CONCLUSIONS

Dome simulators are proving to be effective training aids. Steerable TV projectors are also proving to be practical means of providing the image of the target. As more realism and precision are required to keep airmen proficient in weapon tactics, more emphasis needs to be given to image fidelity. This requires not only higher resolution, but higher geometrical fidelity. The concept of providing dynamic raster shaping in the TV projector instead of in the digital image generator or an intermediary black box is both technically superior and cost effective and should find its place in more advanced visual systems. I visualize its use spreading to air-to-ground as well as present air-to-air weapons tactics trainers.

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ABOUT THE AUTHOR

Mr. Richard E. Holmes, Chief Scientist, Electro-Optical Systems, Training Systems Group, Systems Research Laboratories, Inc. Responsible for conceptual development of techniques for visual image pickup, processing and display. Registered Professional Engineer in State of Ohio, Mr. Holmes holds several patents, EE degree from University of Cincinnati and MSEE from University of Connecticut.

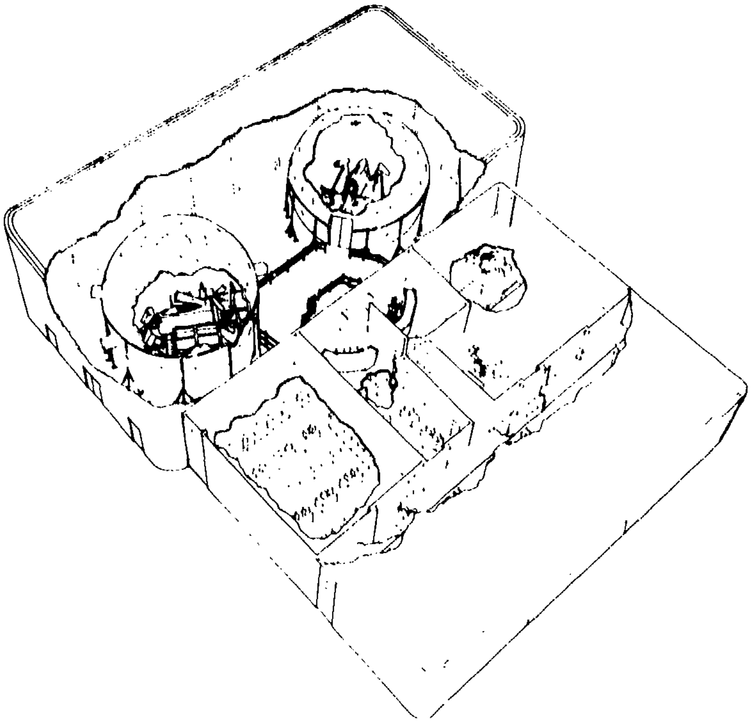

Figure 1. Typical Dome Weapons Tactics Trainer

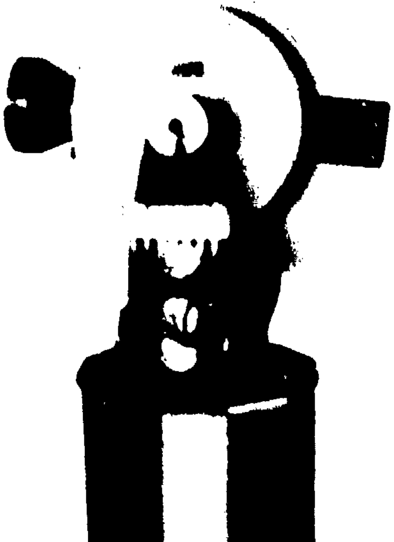

Figure 2. Steerable TV Projector Head with Servo Azimuth and Elevation

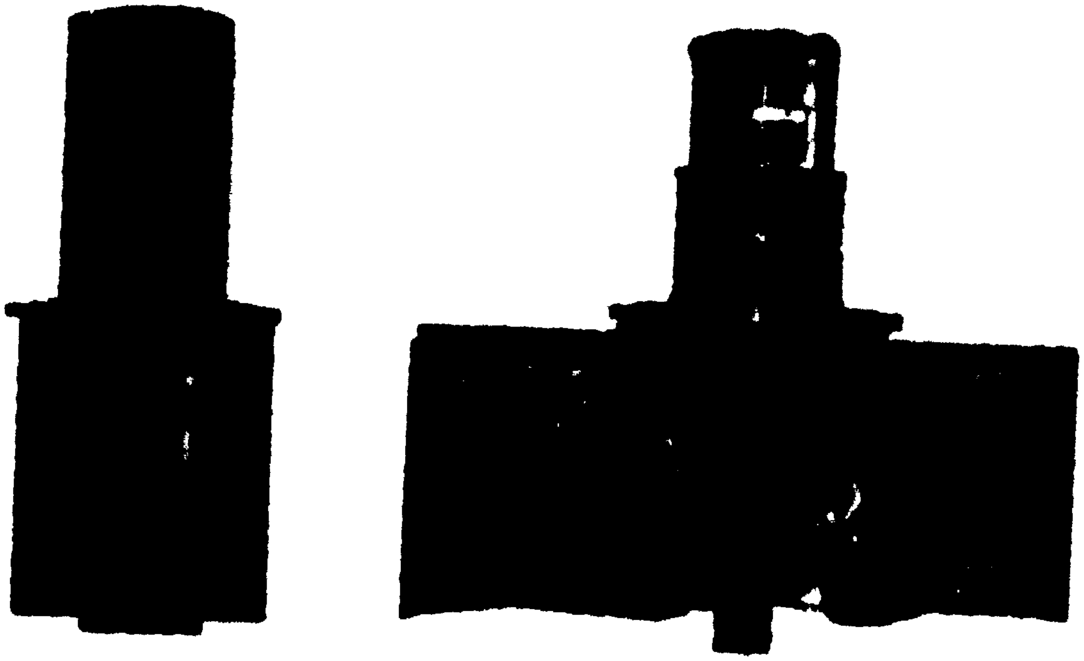

Figure 3a. Projector Head (without optics) Used with Device 2E7 Target Projector

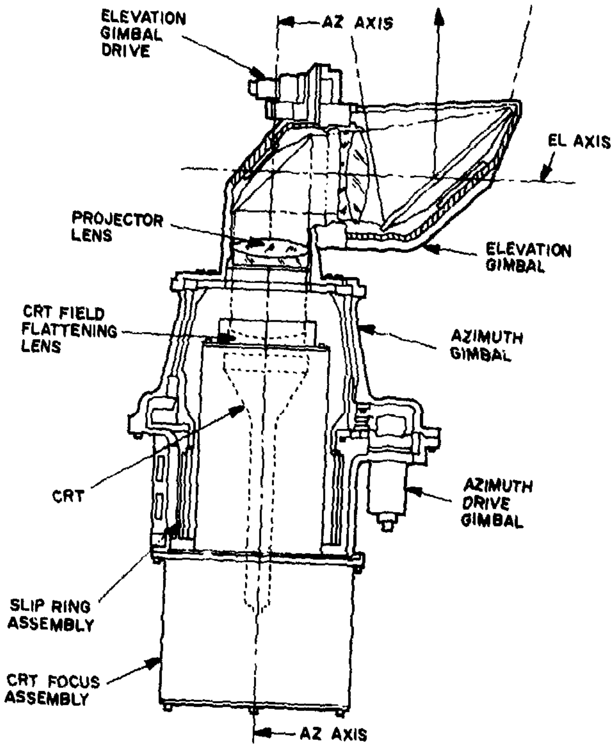

Figure 3b. Outline Drawing of Projector Head Showing Typical Steering Optics

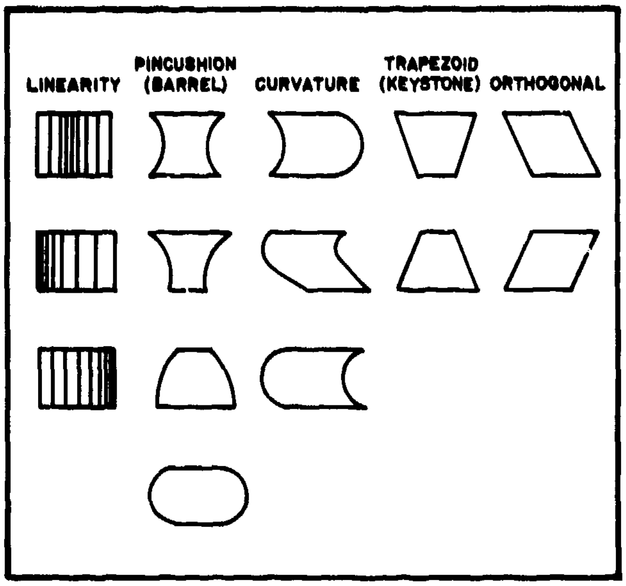

Figure 4. Photograph of Predistorted Rectilinear Raster

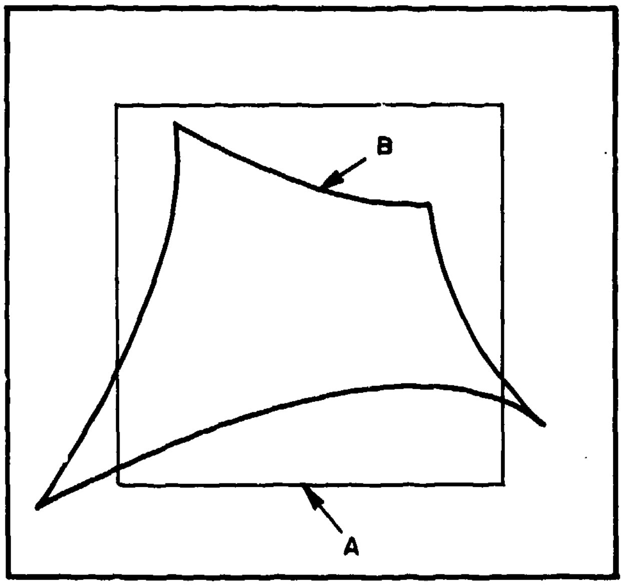

Figure 5. Typical Raster

A - Uncorrected

B - With Dynamic Raster Shaping

VISUAL DISPLAY RESOLUTION AND CONTRAST REQUIREMENTS FOR AIR COMBAT SIMULATION: AN APPLICATION OF COMPUTER MODELING

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ABSTRACT

A study on the effects of target resolution and contrast in air combat engagements was conducted to determine the potential impact of visual display characteristics on the effectiveness of air combat simulation training. A large-scale computer model of air combat engagements was used to investigate the effects of 2 and 4 arc min. of target resolution and target/background contrast ratios of 0.5 and 9.0. The study results are discussed in the context of the benefits of enhanced visual display characteristics in practicing the skills required in air combat.

INTRODUCTION

The requirement for a high degree of realism in the generation of visual scenes in the displays of manned flight simulators has been a major factor in increasing the unit cost of simulators used in aircrew training. The training benefits that result from each successive advance in visual display technology must be weighed against the cost increase associated with that technology if simulation is to remain a viable option for aircrew training. Agencies tasked with the procurement of aircrew training systems are repeatedly tasked with the problem of cost-benefit trade-offs but have little or no objective means by which to assess the extent to which training will be affected by a given improvement in a device's fidelity with actual aircraft operations.

An area where flight simulation is likely to play an increasing role in training is in air-to-air combat. Success in air-to-air combat depends on the skilled execution of basic fighter maneuvers and on the awareness and understanding of the tactical situation.

Simulation training has, to date, stressed basic fighter maneuvering, that is, instruction in the limits of an aircraft's flight envelope, weapons envelope recognition and pre-planned offensive and defensive fighter maneuvers. The Air Force's Simulator for Air-to-Air Combat (SAAC) is an example of this kind of simulation training for air combat. However, the type of training that is likely to have the greatest benefit for real-world combat success involves flight vs flight force-level engagements where many aircraft are simultaneously involved in the same gaming area. Only exercises involving large numbers of operational aircraft can currently provide realistic training in these force-level combat environments. The costs of such exercises in fuel consumed, airframe and engine wear, and potential for aircraft and aircrew losses make it difficult to conduct this training. The alternative to providing training in combat environments likely to be encountered by pilots is through ground-based simulators. In addition to reducing costs, simulation would provide virtually unlimited flexibility in preparing pilots for performance with and against different numbers and types of aircraft and, therefore, permit training in key areas such as situation awareness, communication and control, and energy management. However, simulation technology has not achieved the state where visual scene generation of this type of environment can provide the necessary degree of realism within the practical limits of cost. For example, the brightness requirements for presenting a full field of view, daylight scene is 1000 ft-L or greater but dome visual displays such as the Navy's VTRS and F-14 Wide Angle Visual Systems (WAVS) provide a brightness of only about 4 ft-L and 0.4 ft-L, respectively.

Display resolution limits are of even greater concern since even a realistic brightness level will be of little value if the display resolution is not sufficient to provide target acquisition and identification of target attitude changes at realistic ranges. Ideally, visual perception of targets in simulators should be limited only by the optics of eye and not by the simulator display. Unfortunately, the optimal resolution of current displays is in the range of 6-8 arc min. compared to 1-2 arc min resolution capacity of the eye. Producing displays with very high resolution is technically feasible(1) but the cost associated with very high resolution systems is substantial. More important from the viewpoint of training management is the degree to which training effectiveness of the simulator is improved by advances in display quality. In the majority of cases, the real training value of a simulator is only known well after the device is procured and an operational test conducted. Design specifications for successful training of certain tasks can, of course, be done to a limited extent on research devices. But even these devices are constrained by available technology as well as the considerable difficulty in conducting controlled transfer-of-training studies to determine the cost-effectiveness of even one of a variety of display improvements.

This paper will describe an alternative method for determining the potential impact of visual display characteristics on air combat simulation training effectiveness as well as presenting initial data from this ongoing research. Our objective is to provide reliable data on the kinds of training that will be possible under specific visual display conditions for a tactical air combat simulator training system. For the sake of simplicity and brevity we have focused on resolution and contrast characteristics. Investigations into other display characteristics such as field-of-view/area-of-interest are in the planning stage.

METHOD

The method employed in this study had to meet the requirements of any useful applied research, i.e., control of the variables of interest and valid generalizability of the results to the operational environment. Additional constraints of time to conduct the needed studies also were considered. Data must be available at the time in which decisions on a systems training value are being made if such data are to have any impact on design specifications.

The advances in the field of computer simulation modeling in the last two decades are of such a scope that the utility of using such models in addressing manned flight simulator design issues deserved investigation. A computer model as a research tool has the potential to meet all of the criteria previously mentioned.

TAC BRAWLER

A key element in utilizing a computer model to investigate the general problem of simulation fidelity and the specific problem of visual display requirements is that the model accurately depict the human component of the task at hand. Few tasks in the flight regime depend more on pilot perception and decision-making than air-to-air combat. The engagement model that was ultimately chosen met the need to simulate this human component of realistic force-level air combat engagements. The model chosen for this research, TAC BRAWLER, is a cooperative air combat engagement model developed under the auspices of the Assistant Chief of Staff, Studies and Analyses, HQ USAF. BRAWLER was designed to model flight vs flight engagements for a variety of fighter aircraft types and weapons systems. Continual interaction with experienced air combat pilots in the model's development assured that the simulated pilot responses in each of the aircraft involved in the engagement accurately depicted skilled, but not perfect, pilot combat performance. Further validation of BRAWLER has been carried out in conjunction with AIMVAL/ACEVAL exercise.

A detailed description of BRAWLER is beyond the scope of this paper. However, a brief discussion of the model architecture of BRAWLER (Figure 1) emphasizing the visual modeling will aid in understanding the procedures and results that follow. The architecture of BRAWLER is divided into two major information arrays, a Central Status Array which describes the physical parameters of the engagement and a Mental Status Array which describes each pilot's perception of the engagement. The Central Status Array maintains information on each aircraft's position and velocity, missile launches, etc. for all aircraft in the engagement. The Mental Status Array maintains only the information available to a pilot based upon that pilot's (imperfect) knowledge of the situation. A pilot's awareness of the actions of other aircraft in the engagement is based upon information available visually (either directly or by radar) and information from flight members or ground control. The decisions trade by each pilot in the engagement are, therefore, based on information that would be available to that pilot in a real-life engagement. This approach to the modeling of pilot behavior in BRAWLER allows for the simulation of air combat skill expected of experience, but not perfect, pilots.

Pilot Visual Perception.

Since this report addresses the issue of visual display effects in a manned flight simulator, a detailed description of how BRAWLER models the visual perception of pilots in air combat engagements is necessary. The visual processes of the simulated pilot in BRAWLER were systematically varied to emulate the effects of differing display characteristics of resolution and contrast. Target inherent contrast values of 0.5 and 9.0 were used in this study where inherent contrast is computed by the formula:

$$C = |L_t - L_b| / L_b$$

where: L_t = target luminance,
L_b = background luminance.

The effect of target contrast on the likelihood of detection depends on the position of the target in the pilot's visual field. As a consequence, BRAWLER models the effect of target contrast utilizing a visual detection lobe.(4) The lobe delineates the threshold contrast values that a target must meet in order to be detectable. The equation used to describe the detection lobe for foveal vision is:

$$C_t = 1.55 + 15.2/\beta^2, \quad (\theta < 0.8 \text{ deg})$$

The equation for parafoveal vision is:

$$C_t = 1.75\, \theta^{1/2} + 19\theta/\beta^2, \quad (\theta > 0.8 \text{ deg})$$

where β is the angle subtended by the target (arc min.), θ is the off-axis angle, and C_t is percent contrast at threshold. It is clear from these formulae that the effects of target contrast depend to a great extent on the position within the pilot's visual field. However, atmospheric visibility will markedly affect the level of target contrast that is actually perceived by the pilot. The level of target contrast that actually reaches the pilot's eyes is the effective, as opposed to the inherent, contrast of the target. Effective contrast in BRAWLER is modeled as an exponential function of inherent target contrast as follows:

$$c = c_0\, e^{-3.912\, R/V}$$

where: c = effective target contrast,
c_0 = inherent target contrast,
R = range of target,
V = atmospheric visibility.

Inherent target contrast values of 0.5 and 9.0

were used in this study. Atmospheric visibility was set at 20 nm for all engagements. Given that the effective contrast of the target is sufficient for detection to occur, BRAWLER estimates the probability of detection in a single glimpse to be a normal ogive function of the ratio of effective to threshold contrast for targets subtending any given visual angle.(5)

Simulation of resolution effects in BRAWLER is based on the apparent size of the target derived from the angle subtended by the target at a given range. If the total surface area of the target is not sufficient to subtend the minimum visual angle (resolution values) used, the target would remain undetected. Note that the value β (angle subtended) in the formula for contrast threshold will have an inverse effect on threshold detection probability. The higher the visual angle subtended by the target, the lower the contrast threshold required for target detection.

Visual search characteristics will also affect the likelihood that a target within visual range will be detected. BRAWLER models the pilot's visual search pattern by dividing the total visual field (excluding areas masked by the cockpit) into eight sectors. Sectors are searched essentially at random with the constraint that the same sector is not searched again until at least one other sector is sampled. The simulated pilot searches each sector for 2.5 sec. with no more than 150 msec. per fixation. Once the target is detected, a visual tracking algorithm based upon the optimum control model(6) is initiated while the target is in view.

Procedure

The purpose of using BRAWLER was to determine the kinds of effects display resolution might have on engagements in a manned flight simulator and, therefore, the kinds of skills that could be trained. Since display resolution in effect limits what the pilots will see in an engagement, the visual acuity of the "pilots" in BRAWLER was altered to simulate resolution acuities of 2 and 4 arc min. These values were chosen to permit comparison of resolution effects for display systems of the future where 2 arc min. may be considered the ultimate goal of a system designer. Target inherent contrast values of 0.5 and 9.0 were also simulated in this study. The contrast value of 0.5 approximates the expected contrast of targets in the real-life engagements. A high contrast of 9.0 was chosen to investigate potential trade-offs between resolution and contrast in display design. All engagements were run as within visual range (WVR) scenarios, i.e., radar intercept was not possible.

Engagement Scenarios

For the sake of simplicity, only BRAWLER data on a one vs one engagement will be presented here. The aircraft simulated were Air Force F-15 fighters equipped with radar and infrared guided missiles and guns. At the start of each engagement the aircraft were situated with reciprocal headings (head-on approach) and offset by 1 nm, with a slant range of 8 nm. Visual acuity values for a given engagement scenario were either 2 or 4 arc min. for both pilots. All scenarios assumed daylight, unlimited visibility conditions. As with real life engagements, some variability in performance is expected from one engagement to the next. To assure reliability of the results, 25 engagements were run for each factorial combination of resolution and contrast under each of the two (Head-On or Right-Angle) intercept conditions.

RESULTS

Results of the BRAWLER engagement runs were analyzed for effects of differences in simulated system resolution and target inherent contrast on average detection range, opportunities for early shots, advantage of first sighter, and the type of weapons used. These measurements were chosen because they would reflect the general nature of the engagements and are reasonably accurate indicators of the types of skills that would be excercised. The results were analyzed separately for the Head-On and Right-Angle engagement scenarios.

Detection Range

The average range at which an opponent was detected under the four conditions of system resolution and target contrast are shown in Figure 2 for the two engagement scenarios. The average Head-On detection range for the 2 arc min. case is 14,800 ft. (S.D. = 3,200 ft.) and for the 4 arc min. case it is 11,100 ft. (S.D. = 1,300 ft.) with a target contrast at 0.5. When the target contrast is very high (9.0), the average detection increases to 20,300 ft. (S.D. = 1,200 ft.) for the 2 arc min. resolution case but has little effect on the 4 arc min. case. A similar pattern of results occurs in the Right-Angle engagement scenarios. The increase in target contrast did not, as might be expected, improve initial target detection in the poor resolution runs. A doubling of resolution from 2 to 4 arc min. improves detection but only by an average of 3,700 ft. in the low contrast conditions. The effects of resolution and contrast on detection range are reflected in the opportunity for early shots.

Early Shots

The proportion of engagements in which weapons were fired in the first phase of the engagement is shown in Figure 3. The improvement in detection range within increased acuity accounts for an increase of only 12% in shots fired during the initial phase of the Head-On engagement with low contrast. With increased target contrast from 0.5 to 9.0, early shots rise dramatically from 16% to 80% of the engagements in the 2 arc min. case. As expected from the data on detection range, improved contrast had no significant effect on early shot opportunities in the Head-On engagements. The pattern of results for early shots as with detection range data is similar for both scenario types run.

The relatively small effects on detection range and early shot opportunities resulting from a doubling of target resolution suggest that only a small gain in training utility is achieved for this critical phase of air combat engagements. Attaining positional and energy advantage over an opponent aircraft early in an engagement are often the most important factors in determining the outcome of an engagement. The increases in the range of target detection in this study which resulted from improved target resolution were not of sufficient magnitude to markedly affect the positional advantage of either combatant. As a result, the opportunities to fire weapons early in the engagement are roughly equivalent for all engagements run.

Advantage of First Sighter

In general, air combat engagement outcomes favor the pilot who sights his opponent first. This first sighter advantage is reflected in the frequency of engagement kills shown in Figure 4. Note that these kills occur in the secondary phase of the engagements, i.e., after the aircraft have passed each other. The high kill frequency in the secondary phase is due to the low proportion of early shot opportunities in the initial phase of combat.

Poorer target resolution had the effect of increasing the advantage to the first sighter in the Head-On engagements. For the low target contrast condition, the proportion of kills by the first sighter increases from 64% for 2 arc min. of resolution to 79% for 4 arc min. of resolution. In the high contrast condition, the effect of poorer resolution is even greater. The proportion of kills increases from 54% for 2 arc min. to 100% for 4 arc min. Target contrast effects had generally little effect on first sighter advantage for 2 arc min. case but substantially increased the advantage for 4 arc min. of resolution.

The differential effects of target resolution and contrast for the two types of engagement scenarios on the relative advantage to the first sighter are due to several factors. The nature of a Head-On intercept is such that, at the longer detection ranges occurring with 2 arc min. the difference in detection time for both combatants is sufficiently small to permit defensive maneuvering by the second aircraft, thus lowering the advantage to the first sighter. With the decreased detection range at the lower resolution (4 arc min.), a higher proportion of engagements occur in which only one aircraft sights the other. The higher contrast increases the frequency of this occurrence. In the Right-Angle scenario overall detection range is much less with an increased frequency of cases in which only one aircraft sights the other. This is due to the tail-chase maneuver that is typically executed by the first sighter in these engagements. Higher resolution in the type of engagement had the effect of increasing the time that the first sighter has to achieve a positional advantage (tail-chase) over his opponent. This resulted in a higher proportion of cases in which the first sighter was never detected in the engagements run with 2 arc min. of target resolution. Improved target contrast offset the advantage to the first sighter by permitting a higher probability that the first sighter would be detected by the second aircraft. The improved detection by the second aircraft resulted in defensive maneuvering and a lower lethality of early shots fired by the first sighter.

Weapons Selection

These differential effects of target resolution and contrast for the two scenarios are also found in the selection of weapons during the engagements. In Figure 5, the proportion of missile kills for target contrast and resolution values are shown for the two scenarios. In the Head-On engagements the proportion of kills due to missiles increases substantially as target resolution is reduced from 2 arc min. to 4 arc min. The difficulties in achieving positional advantage with reduced target resolution results in a higher frequency of selecting a missile over a gun solution in these engagements. In general, the shorter detection associated with the Right-Angle scenario eliminated any influence of target resolution on weapons selection. That is to say, the vast majority of engagements were missiles. Increased target contrast has the same effect on weapons selection for both types of engage- ments. An increased frequency of missile selection occurred consistently with increased target contrast. Engagements run with high target contrast resulted in much shorter differences in time required for the two aircraft to detect one another. This reduced time differential generally favors a missile shot.

DISCUSSION

The purpose of this study was to investigate variations in target resolution and contrast in simulated air combat engagements with the intent of deriving information which would assist in the design of visual displays for manned flight simulators in air combat training programs. The results of the study indicate that increased target resolution had only a small effect on initial target detection. Despite the fact that these resolution values are representative of design goals in simulators, the differences in the critical early phase of an air combat engagement that result from improved target resolution are small. The training value for display configurations with a resolution beyond 4 arc min. is doubtful but increased resolution to 2 arc min. does not result in substantial gains in the early phase of engagements when measured by average detection range or early shot opportunities. A substantially greater benefit results from improved target contrast in the initial phase of air combat. This is largely due to the fact that initial detection of an opponent aircraft will more likely occur in the pilot's visual periphery where acuity is poorer but responsiveness to contrast is much greater.

In subsequent phases of air combat engagements, resolution plays a more important role. Poorer resolution clearly results in some scenarios in which the first sighter will have an overwhelming advantage. The advantage is so large as to allow little opportunity for defensive maneuvering. Poorer resolution also resulted in an unreasonably high frequency of missile engagements, in some cases eliminating the gun as a viable option. In training for positional advantage and weapons selection, a lower resolution display would seem to be a poor choice. However, in some engagements such as the Right-Angle intercept resolution, differences have little impact.

Target contrast enhancement can be a useful device to improve initial detection and thereby permit some training with poorer resolution displays. Despite the substantially different contrast values used in this study, the effects of enhanced target contrast on the qualitative nature of the engagements after initial detection is not great. In general, the contribution of target contrast in air combat training will depend upon the extent to which location of targets in visual periphery (as in initial detection) is deemed critical.

This study has demonstrated the advantage of examining the potential impact of simulator display characteristics on air combat training by using computer modeling techniques. The changes in the nature of air combat engagements with variations on target resolution and context is useful in determining the type of skills that can be trained in simulators having these display features. The use of computer modeling techniques in studying simulation fidelity requirements has the potential to provide procurement agencies with objective data on the benefits of training device as a part of cost-benefit analysis prior to purchase.

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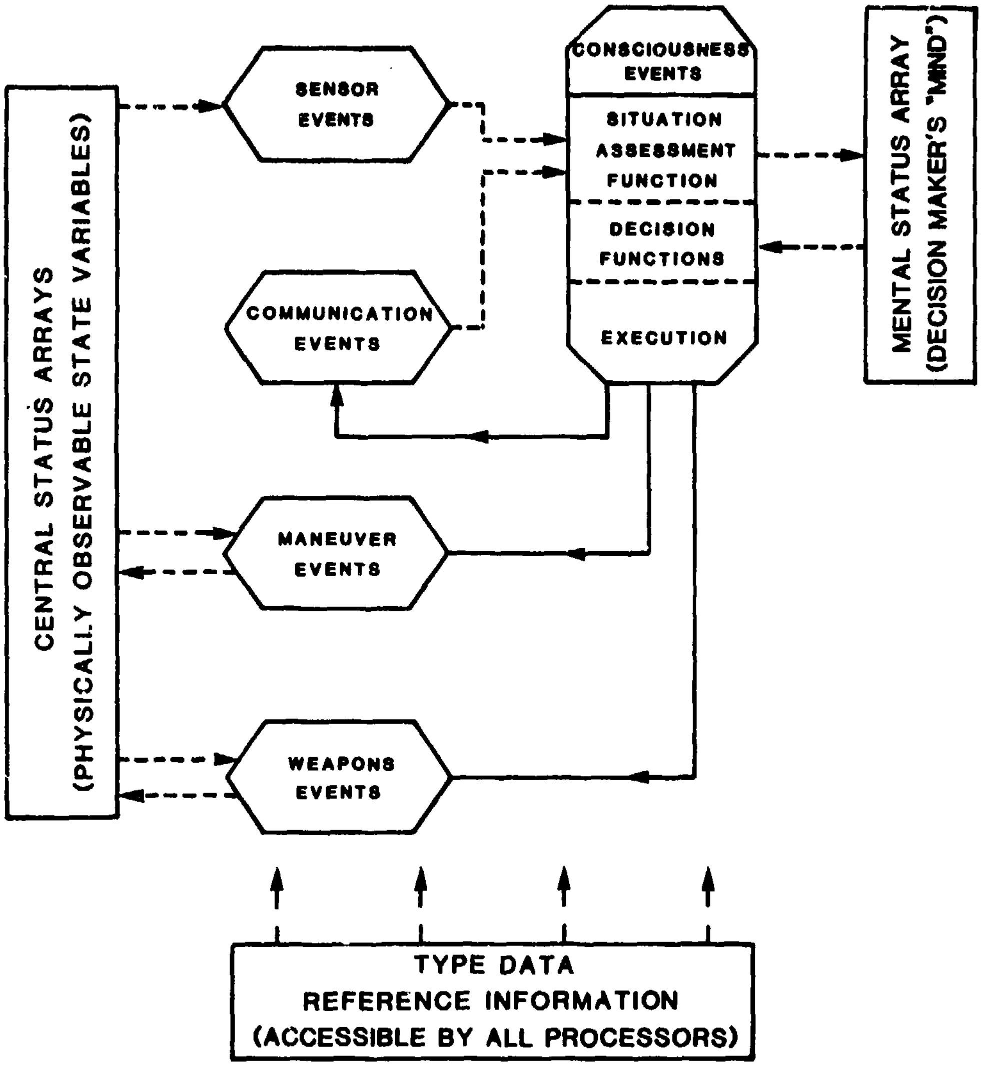


Figure 1. Conceptual Representation of Information Flow

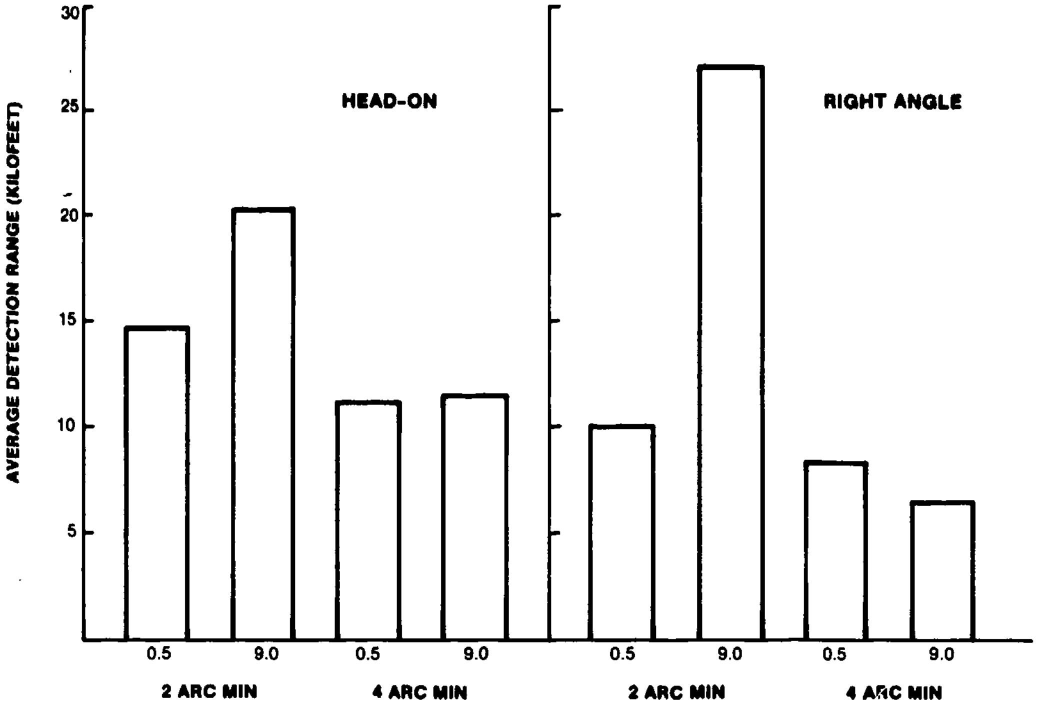


Figure 2. Average detection range for Head-on and Right Angle engagement scenarios as a function of pilot acuity and target inherent contrast.

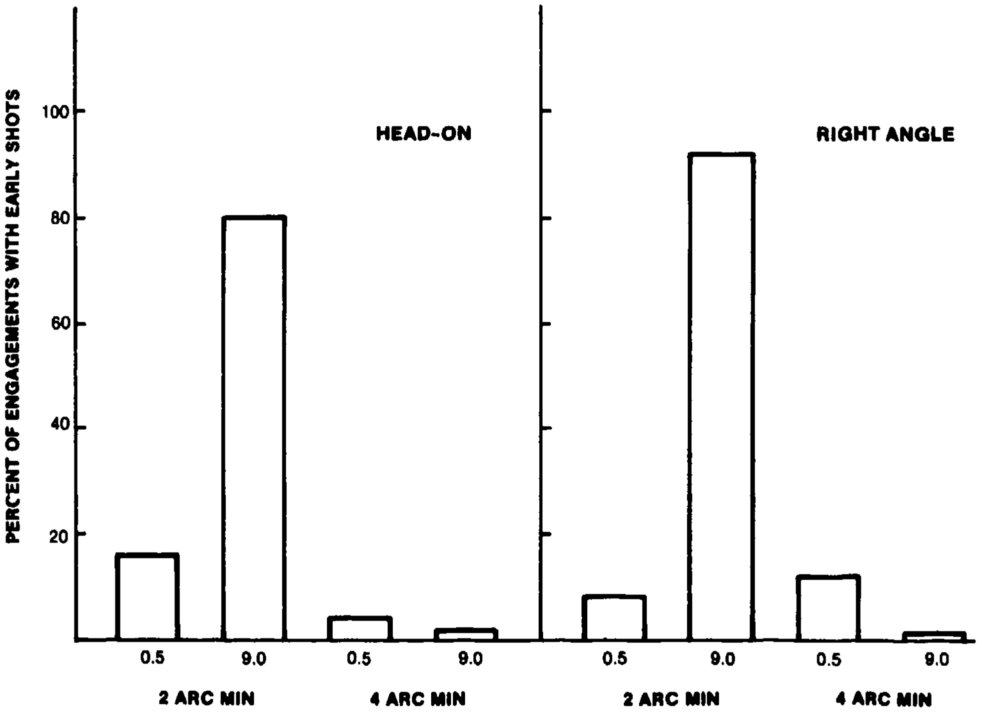


Figure 3. Percent ongagements with weapons fired during first phase (early shots) as a function of pilot acuity and target inherent contrast.

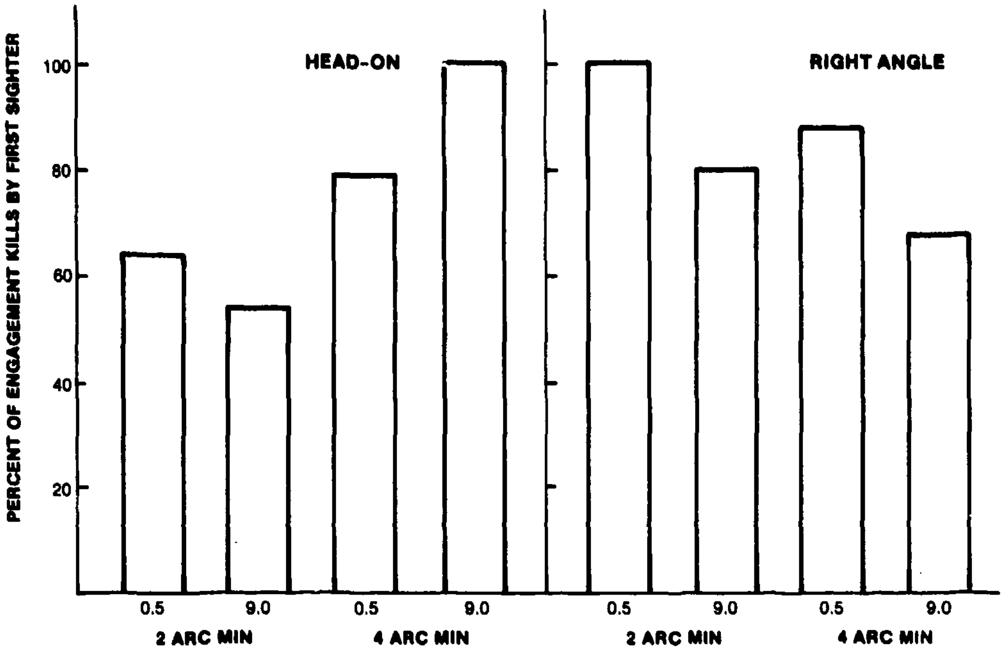
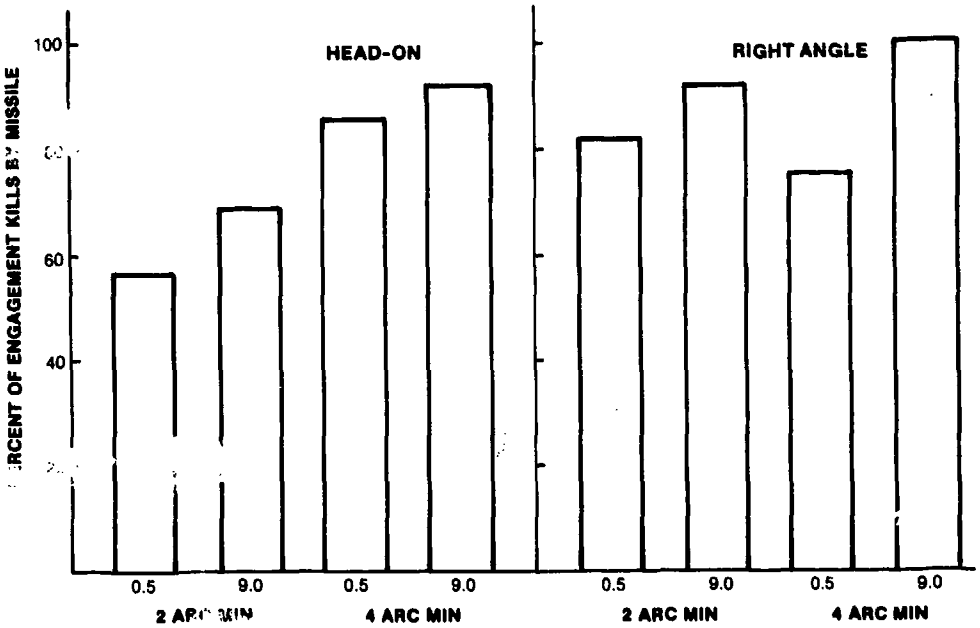


Figure 4. Percent of engagement kills by first sighter as a function of pilot acuity and target inherent contrast.



Figu[illegible]ercent of kills in engagements due to missiles as a function of pilot acuity and target inherent contrast.

AN AUTOMATED GUNNER PERFORMANCE EVALUATOR

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ABSTRACT

The training of gunners for man-portable tactical missile systems (such as Dragon) currently requires the gunner to track a vehicle-mounted target and field IR source beacon. This means that large areas are required, approximating tactical target ranges. These space/facility requirements limit training opportunities. To increase opportunities while eliminating (or reducing) space requirements, a simulation device is required that displays battlefield scenario images in the gunner's sight. Currently, simulator technology can optically generate simulated battlefield scenes via a computer controlled display screen. However, the high cost and complexity of such a system is prohibitive when used in a tactical training scenario. This paper describes a low-cost, microprocessor-based training device to overcome these drawbacks. The major component of the system is a high resolution graphic display sub-system that generates images via multiple gray-level video signals displayed on a Cathode Ray Tube (CRT). The image data is stored in memory and accessed via software. Gunner tracking movements are measured and used to modify the position of the displayed image, thus realistically simulating tactical scenes. The gunner's performance is evaluated by determining tracking errors relative to target line-of-sight (LOS) and comparing these errors to established error limits. Since the system will be small and relatively inexpensive, it will readily lend itself to classroom or field training.

INTRODUCTION

The U.S. Army's Dragon missile system is a man-portable anti-tank weapon that gives the infantryman the capability to destroy armored vehicles. The air vehicle is launched from a recoilless launch tube supported by a bipod and the gunners right shoulder. The gunner observes and tracks the target through either visible optics or a thermal imaging device coupled with the missile tracking system. Target tracking is maintained from just prior to launch until the air vehicle impacts the target. Target ranges extend to 1000 meters. Figure 1 illustrates typical Dragon usage.

Presently, training for Dragon gunners is accomplished using either a day or night tracker along with a Launch Effects Trainer (LET) and a performance measuring device, the Monitoring Set. This training requires the use of a physical range out to 1000m and a vehicle mounted infrared beacon so that the gunner's tracking errors can be measured. These errors are compared against error limit curves which are a function of time. An error that exceeds the limits for a predetermined length of time is scored as a target miss. A major drawback of this training is the requirement for target ranges to 1000m and the associated costs of range operation and maintenance. Thus, training is limited to Army bases where this type range facility exists.

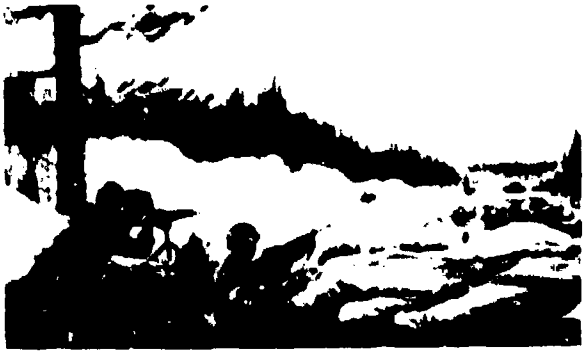

FIGURE 1: TYPICAL DRAGON USAGE

Effective initial training and periodic requalification require realistic scenarios in the gunner sight. This scenario requirement is especially critical in night tracker training because of the widely variable target appearance. Targets vary in size, shape, density and contrast in the thermal night-sight display. When used in the daytime, the thermal images take on yet another set of variables. Therefore, the full spectrum of target recognition, range estimation, and target tracking exercises are very difficult to implement repeatedly in a training program and become a second major drawback to present training methods.

These drawbacks indicate the need for a simulator to generate sight scenarios in a controlled, repeatable and realistic fashion. Realism dictates an interactive display that senses gunner movements and modifies scene positions accordingly. The scene simulations must be easily interchangeable, thus allowing varied scenarios including both stationary and moving targets. The system must evaluate gunner aiming errors and score the gunners tracking performance. The score must be displayed and/or printed. The system should also be self contained and portable for field use.

Future man-portable tactical missile systems will utilize day-night imagers as the gunner's sighting device because of their inherent performance advantage under adverse conditions. These systems will need effective training devices, such as the one described here, which can easily be updated to meet their requirements.

DESIGN CONCEPT

System Overview

The Automated Gunner Performance Evaluator system block diagram is shown in Figure 2. The system is based on off-the-shelf microprocessor hardware. The 8-Bit Central Processing Unit (CPU), operating system Read Only Memory (ROM) and scratch pad Random Access Memory (RAM) form the nucleus of the hardware. The operating system ROM stores the firmware to control system functions, such as image display control and gunner position updates during a simulated flight, and gunner evaluation and scoring after the fight. The image data ROM contains the scene data for a particular simulation and is interchangeable. The display subsystem stores and decodes the currently displayed image. The gunner interface inputs tracking position data to the system. The scoring display and/or printer inform the gunner and instructor of the gunner's performance.

Scene Simulation

The simulation of tactical scenarios in the gunner sight is implemented using digital data that is compacted and stored in ROM. A portion of this data is transferred to the display subsystem where it is decoded into multiple gray levels per picture element (pixel) and displayed on a CRT using rasterscan graphics techniques. The CRT replaces the normal thermal imager electronics/display and is directly viewed by the gunner. The stored image graphics (SIG) technique was choosen over a calculated computer generated image (CGI) for several reasons. First, the fact that the gunner operates from a fixed position for any one flight allows stored image usage. The gunner's range to the target and relative roll position are fixed and the LOS only changes in vertical and horizontal angle. Thus, a stored image that is larger in horizontal and vertical dimensions than the displayed image results in a realistic scene scan when the gunner's LOS is sensed and used to position the displayed image within the stored image. The stored image dimensions were chosen to be four times the displayed image in width and two times the displayed image height for a scene area eight times the displayed image. These dimensions were chosen because the primary target movements are in the horizontal plane and vertical LOS movements are only necessary during target acquisition.

The second reason for choosing the SIG technique is reduced software overhead. The software task reduces to memory data transfers using horizontal and vertical offset pointers. Calculated CGI techniques use complex mathematical operations and require very high processing speeds to operate in real time. The SIG technique allows system implementation using standard microprocessor hardware that is inexpensive and easy to develop.

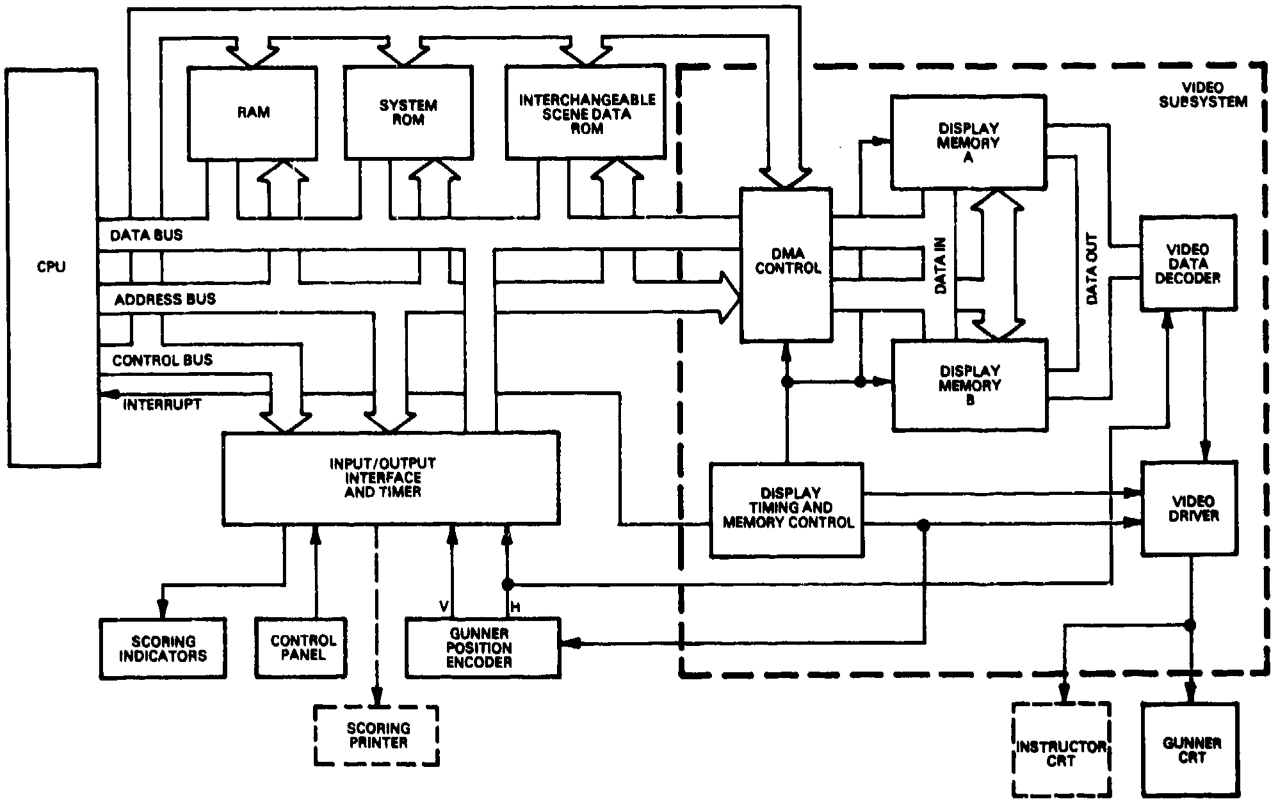

FIGURE 2: AUTOMATED GUNNER PERFORMANCE EVALUATOR BLOCK DIAGRAM

The displayed image is a raster scan CRT image consisting of 128 lines and 128 pixels per scan line. The displayed image requires only 4096 bytes of memory due to the data compaction used. Thus, the overall scene is stored in 32768 bytes of memory (8X image size). The portion of the scene displayed depends on the value of two memory pointers, horizontal and vertical offset, as shown in Figure 3. The pointer values are controlled by the horizontal and vertical gunner position sensors described below. A typical simulation run starts with these pointers set to nominal values and gunner position nulled to zero. Thus, the displayed image is centered in the overall scene. When the gunner has assumed his firing position, the instructor starts the simulation. The memory pointers are now modified by the gunner position data as he moves around to acquire and track a target. Realistic image movement is then simulated within the limits of the overall scene.

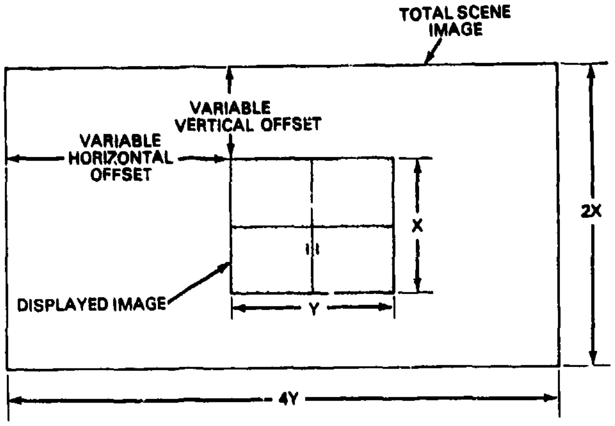

FIGURE 3: SCENE DATA MAP SHOWING DISPLAYED IMAGE DATA OVERLAY

Each pixel is represented by two bits of an 8-bit byte of memory data. These two bits are decoded to produce four CRT intensity levels. These levels are black, white and two intermediate gray levels. Intensity approximation to four levels was chosen as adequate because of the limited intensity ranges actually displayed in thermal night sights. The gray level decoding is hardware implemented in the display system video data decoder (see Figure 2).

Two bit intensity data per pixel results in compacting four pixels of data per byte of memory data. There are two advantages to this data formatting. First, only 32 bytes of memory are accessed per raster scan line, resulting in a time of 2 microseconds between display memory read cycles. Thus, slower memory can be utilized. Secondly, the software for transferring data to the display memory generates only 4096 memory address (128^2 pixels/4 = 4096) bytes which reduces software overhead.

The only disadvantage of this pixel data format is that the displayed image moves in byte or four pixel steps when horizontal image movement is required if the software uses byte addressing only to access the data. This limitation is overcome using hardware so that bit manipulation is not required in software. The method used converts the data format from parallel to serial and selects the required pixel offset for the data to be displayed. The selection is controlled by the gunner position error data. Thus, image movement can be resolved in one pixel increments in the horizontal direction by special hardware and byte increments by changes in data addressing.

The scenes simulated must be interchangeable to allow maximum flexibility of the simulator. Various mass storage mediums were considered. The need for a portable system that could be used in the field under diverse environmental conditions indicated the best storage medium to be ROM devices. ROM's are readily available in an 8192 X 8 bit word size and only four memory devices are necessary per scene. These devices were also choosen because equivalent erasable, programmable ROM's (EPROM's) are available for use during development work. The final scene modules will be packaged in an easily replaceable plug-in cartridge for ease of use.

Gunner Interface

The Dragon missile system uses a bipod to support the front of the launch tube (see Figure 1). This bipod allows movement in the vertical and horizontal directions. Gunner movements can be sensed by attaching sensors to measure the relative movements at the swivel joint of the bipod for the horizontal axis and the changes in launch tube inclination for the vertical axis. The sensor resolution required is approximately 0.5 milliradian (mr). This resolution is most easily obtained using an incremental optical shaft encoder in the horizontal axis and a pendulum type inclinometer in the vertical axis. The shaft encoder is used with a preset up-down counter to derive position data. The counter preset is the nominal value for the horizontal offset pointer and is initialized to this value prior to a simulation run. The inclinometer is interfaced to the microprocessor via an A/D converter and the initial value at the start of a simulation is substracted from all subsequent data. This configuration allows easy initial setup and does not require absolute bipod positioning.

The microprocessor CPU accesses the gunner position through two 8-bit input ports fed from the up-down counter output and the A/D output. The two least significant data bits in the horizontal axis are fed to the video decoder hardware directly to select the pixel offset in the data word, thus implementing individual pixel resolution of display movement. The position data is read at 1/30 sec. intervals, synchronized with the vertical sync pulse of the video generator. The data acquired is used to set the vertical and horizontal offset software pointers and update the displayed image position within the overall scene.

Gunner Performance Evaluation

The value of the vertical and horizontal offset pointers versus time during a run are a direct indication of the gunners aim point since they have a fixed relation to the center of the display area. Therefore, a data table of these pointer values can be used to evaluate gunner performance.

Man-portable tactical missile systems such as Dragon that require target tracking until impact have aiming error limits that vary with time after launch. The general shape of these curves is illustrated in Figure 4. The initially wide limits allow for launch transients. If, prior to the target impact, the gunner's error exceeds these limits longer than a predetermined amount of time, the gunner will miss the target. Also, the error must not exceed target dimensions at impact.

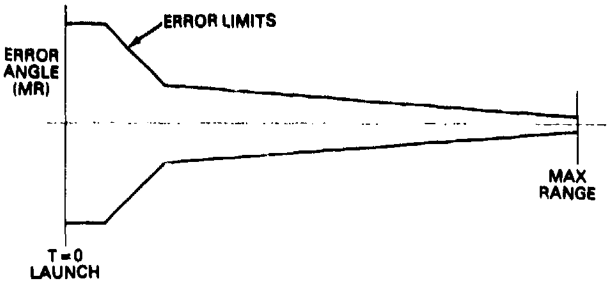

FIGURE 4: TYPICAL GUNNER AIMING ERROR LIMIT CURVES

At the end of a run, the gunner aiming error is computed by subtracting the target position from the gunner aim point data. The aiming error is then compared against the limit curve data to score the gunner.

The gunner's score will be displayed on the front panel of the evaluation set as a HIT or MISS. If a MISS is scored, the time that the error exceeded the limits is also displayed. If a HIT is scored, the aim point data is displayed to indicate actual impact point.

Provisions are made for an optional scoring printer. In addition to printing the scoring data noted above, the printer will provide a graph of the vertical and horizontal aiming error versus time for further gunner evaluation. Corrective action mesages will also be printed in response to various types of errors.

DEVELOPMENT SYSTEM HARDWARE

Microcomputer System

The microcomputer used is an Ohio Scientific (OSI) model C3-OEM. This system utilizes OSI's triple processor board that allows easy program development on 6502, Z80 and 6800 type processors. The RAM is configured as 48K of static user memory. Program entry and display is through a serial terminal. Two 8" floppy disk drives are connected to give about 500K bytes of program and data storage. A printer is connected to the system for hard copy printouts when necessary.

The video subsystem is a custom designed circuit that incorporates the pixel intensity decoding and pixel selection hardware referred to above. The display memory, memory multiplexer, display memory address scanner and special video driver are also on this board. Figure 5 illustrates this hardware setup.

Video Scene Data Acquisition

The initial scene data being used in developmental work is acquired via a television camera. This data is suitable for simulation of day tracker scenes and hardware checkout. Data is acquired using a Biomation model 1010 data digitizer and a custom sysnchronizing circuit to digitize the video on a line-by-line basis of the frame scan.

Simulations of thermal nightsight scenes require gathering data using a thermal tracker video source. Data is gathered in a similar fashion using the Biomation 1010 and a second custom synchronizing circuit.

The raw digital video data is stored in memory of the Biomation 1010. An input/output (I/O) port of the development system microcomputer is used as an interface to obtain the data from the Biomation 1010 memory. The digital data is processed by a software routine that senses and ignores sync pulses. The threshold levels for the four gray levels are controlled in the same routine. Each pixel is compared to the thresholds and assigned a gray level. The software also accumulates four pixels into one data byte and then stores the data in a file on disk memory for usage later.

PROGRESS TO DATE

Video Subsystem

The video subsystem described above has been implemented and is totally functional. A standard television monitor is used to display the video. Figure 6 shows a test pattern generated to verify all gray levels are present, and generated in the proper sequence.

Scene Acquisition and Data Reduction

The television camera and the Biomation 1010 have been successfully used to digitize stationary target test scenes. The threshold and compacting software routines properly reduce the data, generating data files for these scenes. The picture resolution and intensity approximations are compatible with the performance of the existing Dragon thermal night sight (AN/TAS-5).

Gunner Interfacing

The gunner position sensors are in the final design phase. The up-down counter and I/O port have been functionally verified using an oscillator, proper gating and "joy-stick" to simulate the incremental shaft encoder. The only remaining tasks are physical integration of the shaft encoder to the bipod/ launch tube and the electrical connections. This effort should be completed by the fourth quarter 1981.

AREAS OF FURTHER INVESTIGATION

Both moving and stationary targets are needed if the full spectrum of tactical targets are to be simulated. Investigations to implement moving targets will consider scene data

FIGURE 5: DEVELOPMENT SYSTEM HARDWARE SETUP

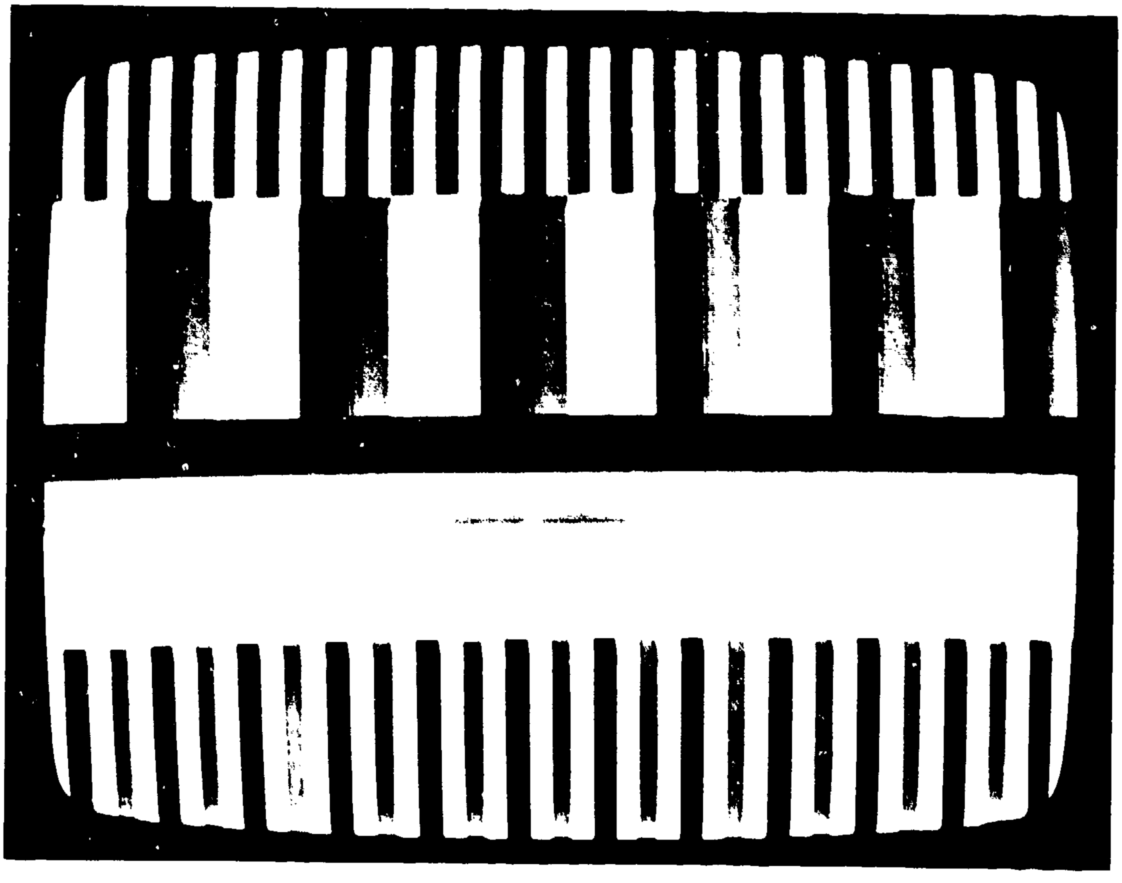

FIGURE 6: FOUR GRAY LEVEL GRAPHICS TEST PATTERN

substitution techniques utilizing a separate target memory and appropriate software pointers to position the target.

Simulation of battlefield obscurants such as smoke and explosive round impacts would enhance the realism of the simulation. Another enhancement would be simulation of an explosion at the target if the gunner gets a target hit. Investigations to implement these enhancements will also consider scene data substitution techniques. The additional software overhead necessary to implement moving targets and the additional enhancements may degrade real-time performance of the main scene simulation. If so, a second microprocessor will be considered that would handle all dynamic images. Tradeoff studies will balance additional hardware complexity against desirability of the enhancements.

Four gray level intensity approximations can result in less than optimum images under some conditions. Therefore, pixel averaging will be investigated to determine if image improvement results. The techniques investigated will most probably use hardware in the video decoder-driver so that software overhead is not effected.

McDonnell Douglas training studies have shown that the gunner/instructor communication and training effectiveness is greatly enhanced if the instructor can actually see the same sight picture as the gunner. Therefore, a CRT display for the instructor will be added. The software for using this display to replay the simulation run will be developed, thus allowing the gunner to see any tracking mistakes he has made. The possibility of displaying scoring information and aiming error plots on the instructor CRT also will be investigated.

CONCLUSIONS

Training equipment to simulate thermal night sight images, such as the Dragon AN/TAS-5, does not presently exist in the Army inventory. The Automated Gunner Performance Evaluator described in this paper fills a need for a cost effective, small, portable night sight training device that can be deployed for field usage in initial and skill maintenance training. The system is implemented using standard, off-the-shelf microprocessor hardware, thus keeping potential production costs low. The stored image techniques used to generate images minimize the software overhead, allowing standard microprocessors to accomplish the simulation. The interchangeable scene memory feature allows generation of a wide spectrum of images using hardware that is reliable in all potential field environments.

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DIGITAL PROCESSING OF COLOR PHOTOGRAPHY FOR VISUAL SIMULATION

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ABSTRACT

This paper describes the full color out-the-window visual system simualtor for the Navy's A7E Weapons System Trainer (WST), based on the Vought - developed Computer Animated Photographic Terrain View (CAPTV) concept. The system has excellent scene realism due to its real-world photographic data base. Any geographic area can be 'flown over' in the simulator with virtually no restrictions on aircraft attitude, position, altitude,heading or velocity. The flyspace can be increased indefinitely by additions to the terrain library. The display field of view is modularly expandable up to nearly the full encircling sphere while maintaining resolution of all parts of the scene.

I. INTRODUCTION

The need to provide scene realism in Visual Systems for flight simulators is well recognized. To this end, real world imagery is used in Vought developed Computer Animated Photographic Terrain View (CAPTV) Concept. The first successful CAPTV system (1) employed monochrome aerial photographs in a large random access video data base, which, through computer processing, provided smooth high detail simulated visual motion cues to the pilot trainee. This paper describes the follow-on effort at Vought to provide a full color out-the-window visual system for the Navy's A-7E Weapon System Trainer.

II. CAPTV CONCEPT

The basic CAPTV concept assumes an array of still photographs taken from an airplane that covers the gaming area defined by pilot training requirements. Photographs are taken at regular intervals along straight and/or cross tracks. These photos are scanned, formatted, and stored in a bulk storage device. As the pilot 'flies' through these photos using controls similar to the ones on the cockpit panels, they are retrieved from the storage medium for display. At any given instant, knowing the pilot's eyepoint in space, the photo in the database nearest his location is stretched, skewed, rotated and translated in a piece-wise continuous mathematical transformation such that the transformed photo would overlay a different photo taken from the pilot's eyepoint (Fig. 1). This process is a continuous one each frame time under computer control and allows the introduction of smooth translation into a basically still picture set for any direction of travel through that set. During the period in which motion is taking place using a given fixed scene, the computer is fetching a new appropriate view to be used as an overlay substitute. The new view is selected by a sophisticated prediction scheme that determines when the present photo must be discarded in favor of a new photo. It is important to understand that the transformation process does not cause unrealistic distortions of the viewed scene. The key to CAPTV lies in its unique capability to make one fixed photo serve in a dynamic translation situation long enough to fetch another view and incidentally perform many other functions as well.

III. OFF-LINE IMAGE GENERATION

The off-line image generation of the color Visual System is used to develop the data for the playback system. The image generation consists of the following subsystems.

(a) Aerial Camera

To provide for the 360° of azimuth coverage and 100° of elevation (with high resolution throughout), a special camera (Fig. 2) incorporating seven lenses with associated mirrors has been fabricated. A typical exposure on a 9" color film is shown in Fig. 3 (actual photographs used in the simulation are in color). Six lenses capture the oblique views and the central lens covers the straight down vertical view. The gaming area is partitioned to contain a large number of 'eyepoints' distributed in several altitudes in several straight and cross tracks. The photography density varies inversely with altitude to provide the required coverage for smooth transition from scene to scene. Objects

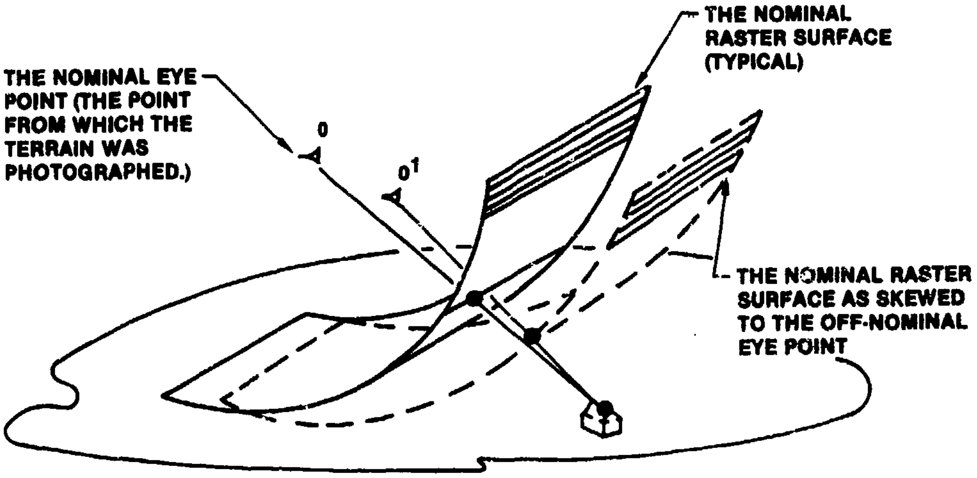

Figure 1 Production of Moving Scene from Still Scene

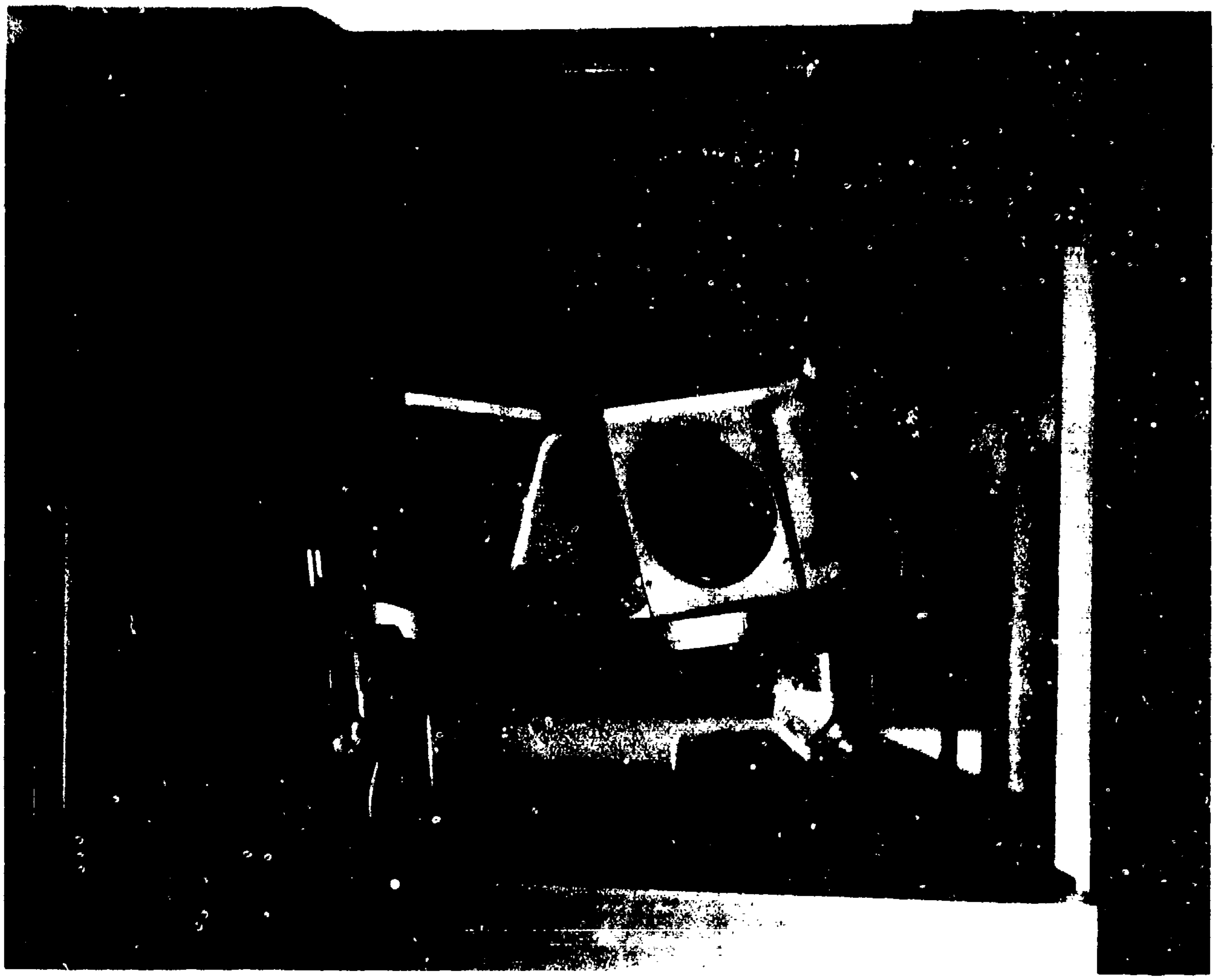

FIGURE 2 THE SEVEN-LENS AERIAL CAMERA

FIGURE 3 A TYPICAL TERRAIN EXPOSURE

which move as the terrain is photographed are treated as stationary anomalies or are removed during the record process.

(b) Record Processor System

The record processor system (Fig. 4) converts the photographic image into video signals for recording on Video Tape Recorders (VTR). A flying spot scanner is used to scan the 9" film roll to provide a pixel resolution of approximately 4000 pixels in both horizontal and vertical directions. Because of the size of the film and separation of the seven views, scanning is done in steps. All of the seven views are assembled in a pseudo-film plane using a resolution-preserving mathematical transformation. The video in the primary colors of red (R), green (G) and blue are digitized, and formatted such that each terrain scene is made up of several NTSC frames (typically 72). Appropriate sync signals are inserted to make the signals suitable for recording on standard 1 inch video tape recorders and laser disks. To obtain faster access during playback, pieces of a complete scene are stored in three different videotapes. During the record process, opportunity is afforded to manipulate the luminance gain and color balance of each view in every scene so that a) the edges of the view exposed by all the seven lenses match up b) successive scenes have their color and brightness matched. The key to this processing is a luminance and color corrector block together with the large, fast semiconductor memory called the scene storage system (SSS) which can store upto 256 National Television System Commission (NTSC) frames.

(c) Photographic Film Edit System

Using highly accurate photogammetric techniques (2), the eyepoint of every scene is determined. This information aids in the proper sequencing of the scanned scenes on the tape recorders. The knowledge of accurate eyepoints also allows matching one distorted scene to another when both scenes are viewed from the same intermediate pilot position.

(d) Video Disk

The data base recorded on the video tape recorders is transferred to video disks suitable for playing on the Disco Vision 720 industrial optical disk player. Each of the video disks can store up to 54,000 standard NTSC frames or approximately 700 color visual scenes. Both frame identification numbers and Society of Motion Picture and Television Engineers (SMPTE) Codes are used for the proper sequencing of the frames.

New data bases can be created simply by going through the above steps of aerial photography, scanning, recording, disc mastering and photogammetry in the proper sequence. Therefore, there is virtually no limit to the expandability of the gaming area.

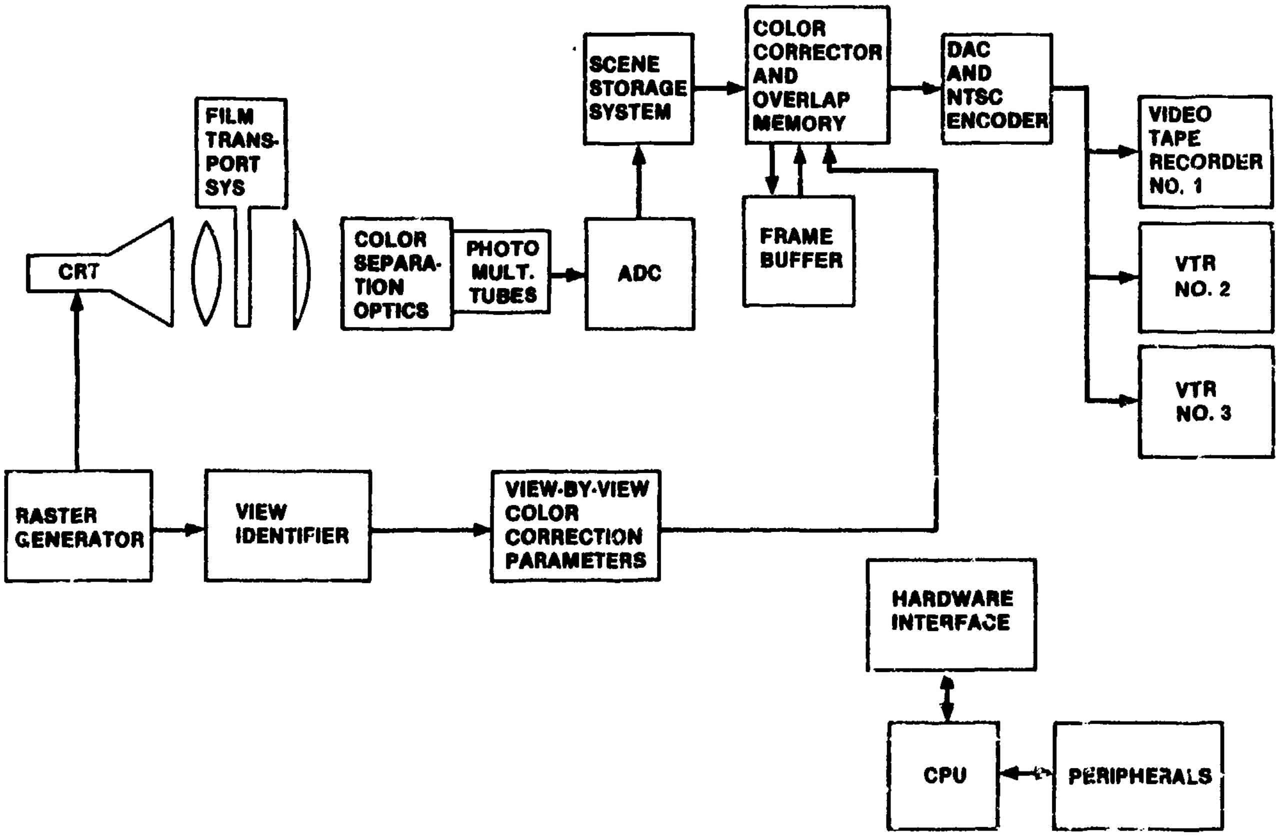

Figure 4. Record Processor System

IV. ON-LINE PLAYBACK SYSTEM

The real-time on-line playback system (Fig. 5) consists of the following subsystems.

(a) Video Storage System

Analog storage using television techniques is a practical and economical alternative to digital storage and is especially suited to pictorial data. The purpose of the storage system consisting of the sixteen video disks is to provide large segments of the desired data under control of the host computer in anticipation of the real time needs of the simulation. The bulk data is distributed over the sixteen disks to optimize the retrieval of the desired data. Any randomly accessed TV frame on a single play-back unit can be located and made available in 2 to 8 secs. Adjacent or sequential frames require much less time than this, however. The players operate essentially independently and are rotationally synchronized to the system timing references for color subcarrier and horizontal/vertical raster scans. In operation, all these units do not supply data at the same time. Data is transferred from only three players at a time while the others are searched for the anticipated subsequent scenes.

(b) Video Digitizer System

The Video Digitizer System (VDS) (Fig. 6) is the functional unit which processes analog composite video from the Video Storage System (VSS) and sends digitized video to the scene storage system (SSS). The VDS has three identical channels since at any given time three video disc players can be simultaneously accessed. The quasi-NTSC video from the VSS is read, time base corrected, clamped and digitized in the VDS. Composite video to component video conversion and spatial compression of the digitized video are carried out by the luminance and chrominance processors in an

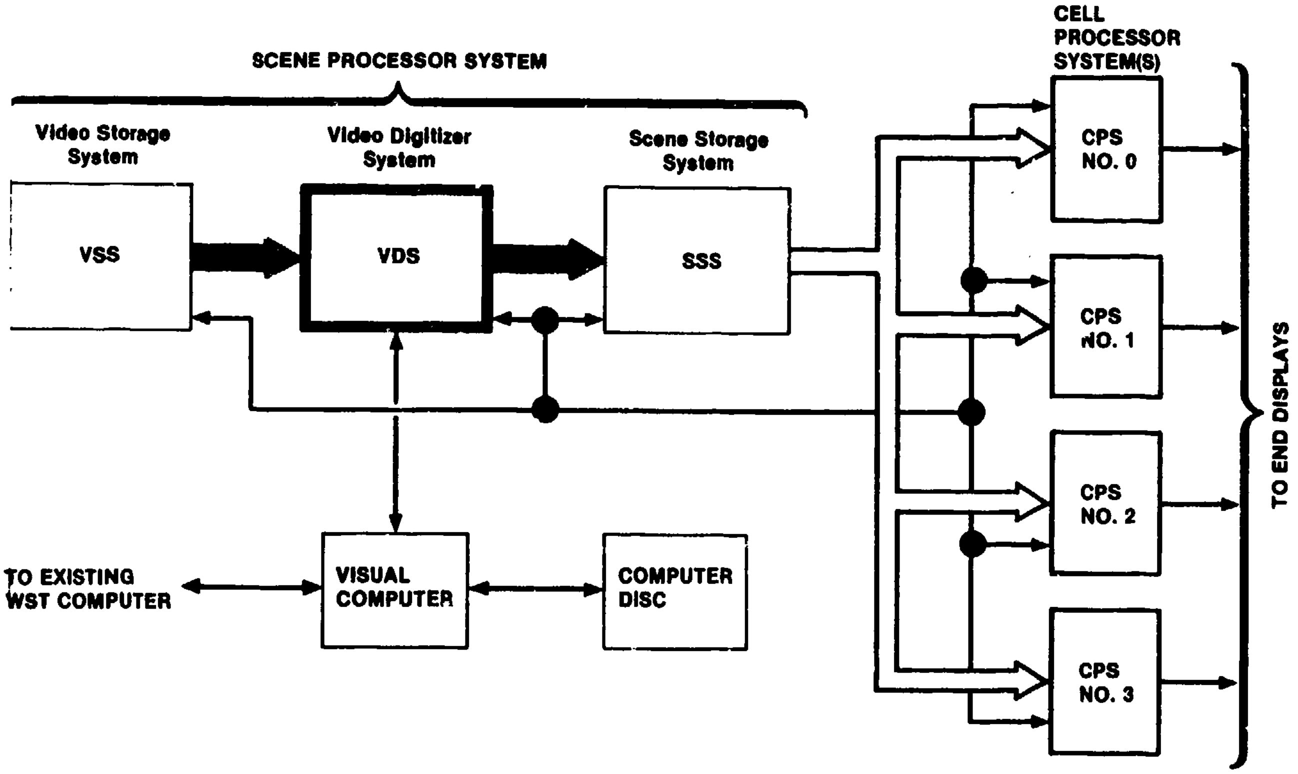

Figure 5. Visual On-Line Playback System

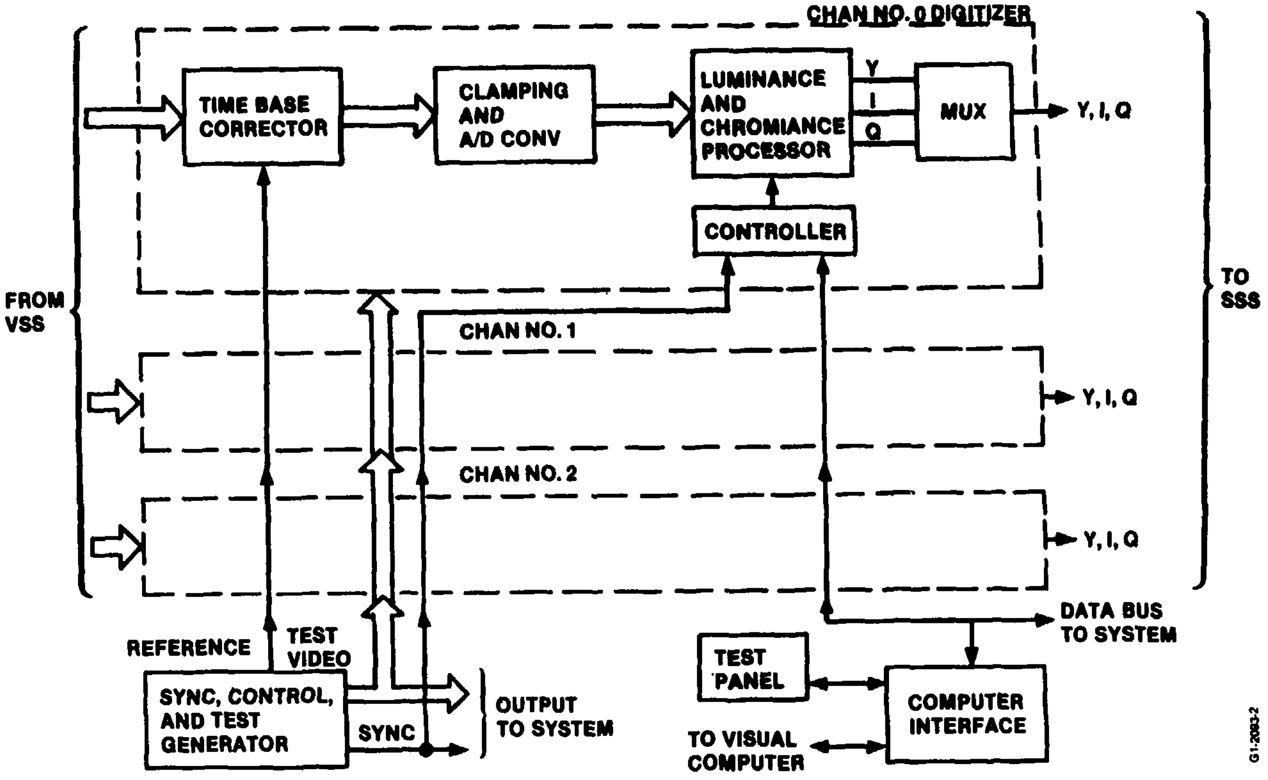

Figure 6 Video Digitizer System

effort to take advantage of the redundancy present in the I and Q components of the color signal and to save memory storage space in the SSS. The VDS also provides the interface between the visual system computer and the rest of the visual system hardware.

(c) Scene Storage System

The SSS comprises of two identical sections-upto 128 tracks each. Each track has the capacity to store digital video information including color, present in one NTSC TV frame (1/30 sec.). Video information can be written to one section while it is read from the second section. When fresh data is required, the input side becomes the output side and vice versa. Three channels of data can be input to the SSS and the SSS in turn can provide multiplexed Y, I & Q digital data to the 4 cell processor systems simultaneously.

(d) Cell Processor System (CPS)

The cell processor system receives the digital luminance and chrominance data corresponding to a scene photograph from the SSS. Under software control it selects the portion which is visible to the pilot through one window, performs the geometric transformation on this data as required by motion of the pilot's eyepoint, and generates analog red, green and blue video signals for display. Data is received from the SSS by four input interpolators which operate independently and simultaneously (Fig. 7). Each of the interpolators channels the Y, I & Q into separate data streams, performs low-pass-filtering, and interpolates or decimates as required to provide data at the proper rate to be loaded into the cell memory. Filtering and interpolation are done in both longitudinal and transverse directions, and the parameter controlling these operations is supplied by the visual computer.

The cell memory consists of two sections. One section may be read for display while the other is being loaded by the interpolators. An output multiplexer selects the data from the appropriate section and provides it to the output processor.

The addresses for the Cell Memory are provided by the Address Generator. The read addresses are obtained from the display-raster pixel coordinates by a transformation corresponding to a piecewise continuous rotation, skew, and magnification in order to create a display of the scene data as seen from the pilot's eyepoint.

The output processor receives data through the memory multiplexer, performs the conversion from Y, I, Q format to Red, Green, Blue format, performs low pass filtering, simulates haze, and inserts a blue sky above the horizon. It also provides for replacement of a number of pixels in

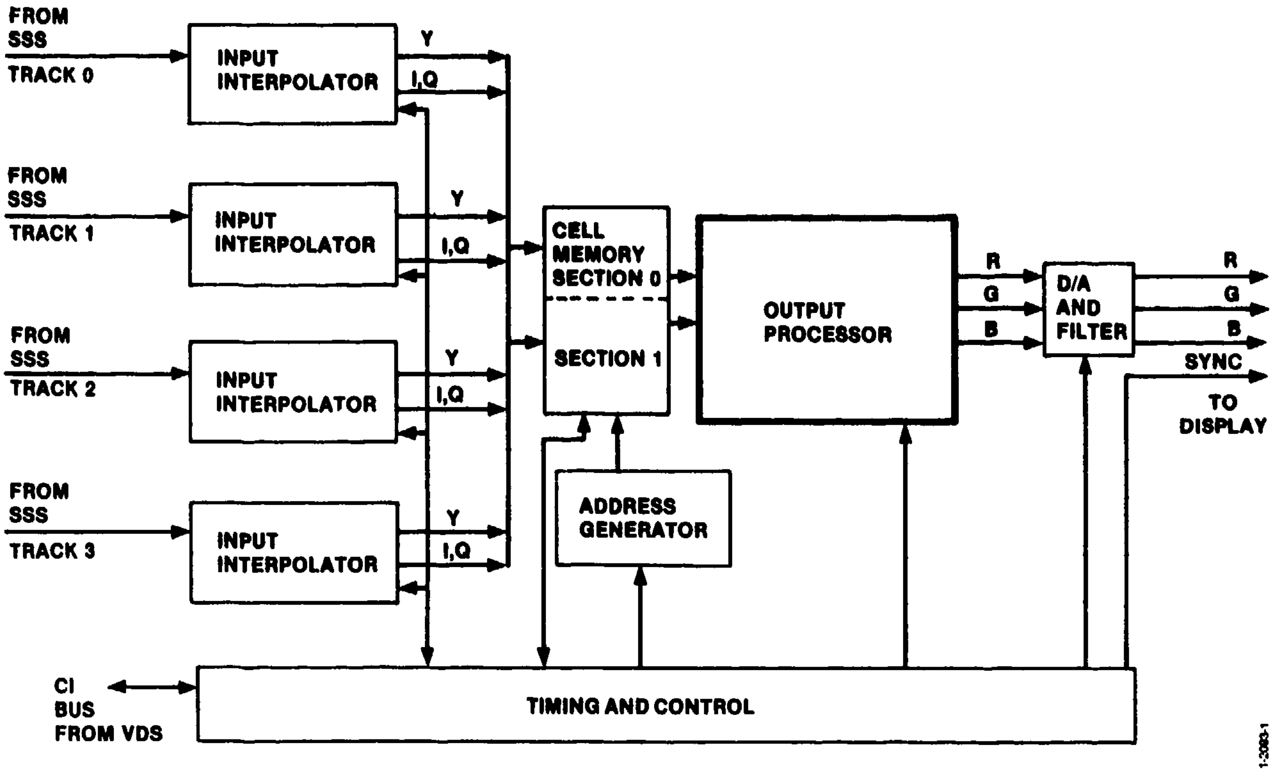

Figure 7 Cell Processor System

the output scene with pixels supplied by the Visual Computer and for insertion of a light point surrounded by a black square for the automatic position error sensing system. Finally the R, G, B digital data streams are converted to analog signals, filtered and provided to the display along with a composite sync signal.

V. IMAGE DISPLAY SYSTEM

The image display system consists of a multiple rear screen television projection system providing essentially the total forward hemisphere field of view (FOV) available from the A7-E cockpit. This is obtained by joining together six flat projection screens into a single mosaic. The total FOV and the FOV of each channel is depicted in Figure 8. Each separate rear pro-

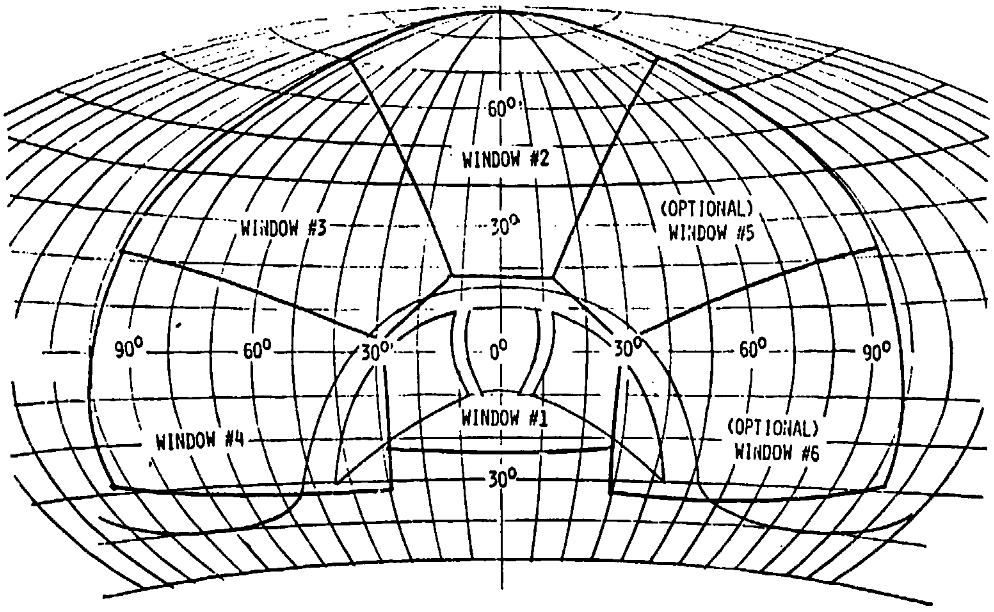

FIGURE 8 DISPLAY SYSTEM FIELD OF VIEW

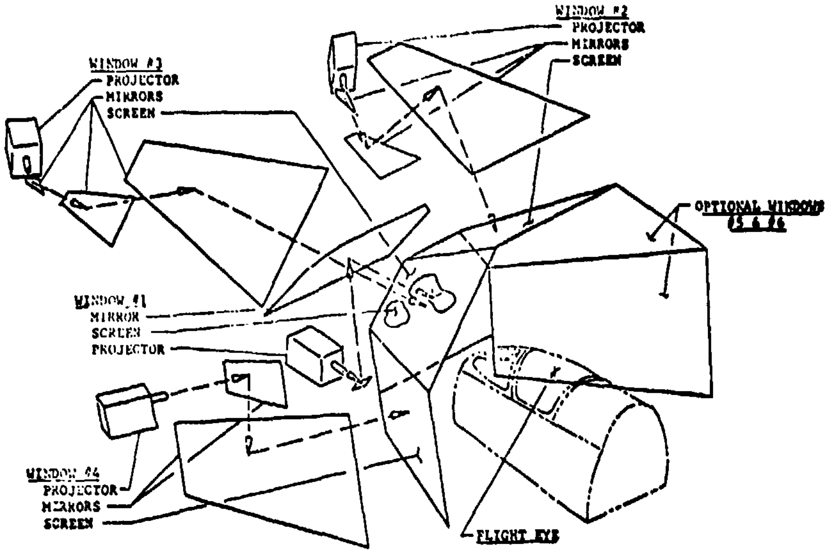

FIGURE 9 A7E WST VISUAL SYSTEM

EXPLODED VIEW

jection channel consists of an 875 line General Electric Light Valve TV projector, two or more folding mirrors and a lenticular rear projection screen. The overall system design is depicted in Figure 9.

VI. CONCLUSION

CAPTV offers some major advantages over the CGI visual system. Some of these advantages are its ability to provide scene-realism, detail, 3-dimensionality, and texture that is limited only by photography and virtually unlimited for expandability of data base. The real-time play back system, when added to the existing WST equipment, will provide the pilot with a continuous display of the gaming area as presented on a hemispherical rear screen projection system. The scope of the gaming area is large enough and flexible enough for a simulator pilot to fly a mission with total maneuvering freedom. Registration with the radar, FLIR, and projected map display in the WST will be maintained regardless of the simulated aircraft maneuvers throughout the flight.

VII. REFERENCES

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TRAINING LOW LEVEL TERRRAIN FLIGHT IN A SIMULATOR

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Operations Training Division
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ABSTRACT

In this study the use of augmented feedback was investigated as a means of training low altitude perceptual motor flying skills in a flight simulator. Sixteen T-38 students pilots enrolled in Air Force undergraduate pilot training participated as subjects. Eight subjects in an experimental group were trained to fly low level in a simulated A-10 aircraft using special altitude prompts (lights on the glareshield and auditory tones in the headset) to assist them in discriminating altitude cues provided in the simulated visual environment. Eight subjects in a control group received training identical to that of the experimental group, less prompting. A computerized data record system captured a continuous record of altitude, vertical velocity, number of crashes, and other performance parameters on each of eight training trials and two test runs in which prompts were omitted. All subjects flew a total of ten runs. The prompted group achieved significantly lower altitude performance on two of four critical task segments compared to the control group during the training trials. However, subjects in the prompted group crashed significantly more times per trial than did subjects in the control group during the training. During the test runs performance of the two groups for altitude, vertical velocity, and frequency of crashes was not significantly different. The results of the study do not appear to warrant continued investigation of this technique for low level training.

PROBLEM: TERRAIN FLIGHT SIMULATOR TRAINING

Lack of adequate visual scene detail limits the usefulness of currently available computer generated imagery (CGI) for training low level flight. Present levels of detail and picture resolution are inadequate to produce desirable representation of ground patterns and features. Both ground textural patterns and vertical objects appear to be used as primary visual cues by pilots in judging aircraft height above the ground. Since present CGI limitations preclude adequate terrain detail, questions remain as to how to manipulate scene content and training techniques in order to optimize existing CGI capabilities. It is to be hoped that such developments can compensate to some extent for the current lack of scene fidelity.

LOW LEVEL ENVIRONMENT DEVELOPMENT: RELATED RESEARCH

Touchdown Study

Studies at AFHRL/OT have focused upon the manipulation of visual content as media for training landing and terrain flight. In the first of these researchers investigated T-37 pilot landing performance in response to variations of checkerboard-like textural detail level superimposed upon the simulated runway touchdown area. The check sizes used were 4, 8, 15, and 25 feet for four experimental runways. Two other runways also were used; one a simulated Air Force runway with standard markings, and one completely bare except for a dashed centerline. A night runway scene was also added bringing the total number of runways to seven. Vertical velocity at touchdown was used as the performance indicator. Although the simulated aircraft vertical velocities at touchdown were much higher than those averaged in actual T-37 landings (32 feet per minute), the CGI texturing did significantly reduce vertical velocities at touchdown in the simulator ranging from 195 feet/minute for the night scene to 147 feet/minute for the four-foot texture pattern. In this study vertical velocity at touchdown was shown to decrease as a function of the amount of textural detail available to the pilot.

FOUR FOOT TEXTURE PATTERN RUNWAY

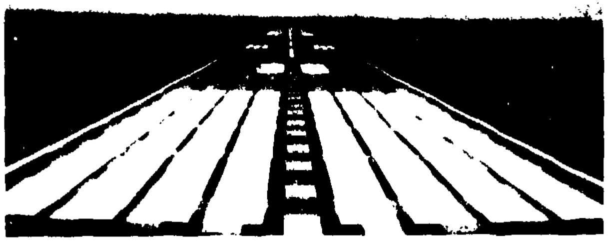

Figure 1

"Checkerboard Study"

In a subsequent study AFHRL/OT investigated the effects of three types of visual cues: texture patterns (checkerboards, 220, 440, or 880 feet on a side), vertical objects (present or absent), and aircraft shadow (present or absent), upon pilot performance during low level flight in a simulated A-10 aircraft. In this study pilots were instructed to fly 50 feet above the ground on an eleven-nautical mile course which consisted of eight flat valleys separated by low rolling hills. Hills were either 100 or 300 feet high. The pilots were scored on their ability to maintain aircraft altitude at 50 feet plus or minus 30 feet in the valley. Average altitude values were also collected at the crest of each hill. The pilots flew the course at 300 knots indicated airspeed plus or minus fifteen knots.

In general the pilots reported that all three types of visual cues were useful, however, the vertical object cues and texture patterns were of greater help than the aircraft shadow. Some pilots reported that the aircraft shadow was particularly useful in signalling impending contact with the ground. The vertical object cues, especially, the tree shaped cones of known height were subjectively very useful in gauging height above ground. The texture patterns were also reported as desirable, but to a lesser extent than the vertical object cues. Pilots reported a definite preference for the smallest texture pattern (220 feet square) over the two larger size patterns. They especially disliked flying over the largest texture pattern without vertical object cues. Pilots would have also preferred more irregular "natural" patterns rather than the highly regular checkerboard features.

440 FEET TEXTURING WITH VERTICAL OBJECTS

Figure 2

Both the texture patterns and the vertical object cues produced statistically significant differences in pilot performance. However, only the texture pattern cues produced a significant effect on the time within tolerance scoring for altitude in the valleys, and the average minimum altitude values in the valleys. The vertical object cues did have a significant effect on the average aircraft altitude at the top of the hills. Both the vertical object cues and the texture patterns significantly influenced the average minimum altitude values that occurred over each hill. The presence or absence of the aircraft shadow did not produce any significant effects. The amount of time (cumulative total) in the "crashed" condition (in contact with the ground) was low, with some pilots crashing into the simulated terrain more frequently than others. No significant differences were found for this performance parameter due to visual cue variables. Overall in this study, the terrain textural cues appeared to have a stronger effect on pilot performance than did the vertical object cues.

Terrain Cues

Data from the runway touchdown and checkerboard terrain studies provided some useful insights into the problems of modeling low level environments. For one, pilots found the checkerboard pattern effect visually monotonous, even distracting. Previous research (4) and (7) has suggested regular pattern texturing is important in conveying cues to the observer for surface slant orientation and that irregular textures are less effective in conveying surface slant cues. However, these findings were relevant to static rather than dynamic display content. Low level training would seem to involve a relationship between surface texture plus the motion cues conveyed in simulated flight. Research with random texture designs in a dynamic display context suggests motion cues can provide for reasonably accurate judgment of surface orientations (5). This effect appears to be based on velocity gradient information carried by texture rather than the texture gradient per se (2). In short, the motion component seems essential as a cueing element and there appears to be enough evidence from the literature and from current in-house studies to warrant testing the utility of the random pattern modeling for low level terrain flight training.

Vertical Objects Modeling

Another aspect of the problem of low altitude visual cueing is the modeling of vertical objects. A continuing problem is getting the maximum number of cues using the least number of computer graphic edges. The most edge-efficient object, it turns out, is a three-dimensional triangle, technically a tetrahedron. It uses six edges. In the checkerboard study, we used these shapes (sometimes referred to a "cones") for trees, with the point up. In working with an experimental CGI combat environment, researchers have found the "cones" to be more effective as cues when turned upside down so the broader base is more visible to the pilot. "Cones" have been used very effectively by pilots to evade simulated ground fire. Having the object point down seems to give a particularly accurate ground level cue. We also found that planning the use of cueing edges along a more or less defined flight path is more edge efficient since cues visibly usable by the pilot can be concentrated near his flight path rather than spread over a large area.

DEVELOPING A CGI LOW LEVEL ENVIRONMENT

The present low level flight CGI was developed applying experience, research findings, and inferences from previous CGI developments at AFHRL/OT. Random ground patterns, vertical object development, concentration of edges along the flight path, and the use of turns in the course were all derived from previous work. Other aspects of modeling were included with a view toward making the environment somewhat realistic. The environment was modeled to approach as nearly as a 2000-edge capacity permits, the irregular features likely to be seen in actual terrain flight. The 22-nautical mile flight path is bordered by hills which slope away from it at realistic rise angles. The width of the corridor ranges from 500 to 2000 feet and the elevation is 0 feet throughout. Heading change turns through the course increase from 23 to 45 to 60 to 90 degrees in order of increasing difficulty for low level flight. Inverted "cones" of several heights (25, 40, and 55 feet) are represented with the shape proportioned as a height cue following recommendations of Stenger et al (9).

LOW LEVEL TERRAIN CGI ENVIRONMENT

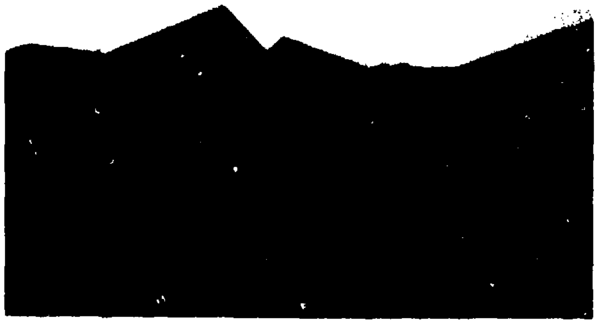

Figure 3

Environment Tryout

In subjective test flight evaluations ten instructor pilots reported the random ground pattern provided a useful altitude cueing. They confirmed that the inverted "cones" or trees were effective as altitude cues and that the peripheral cues provided by the hills along the flight path were also effective. Data from these tryout runs was recorded and analysed for use in developing parameters for an experimental training study. The concensus among pilots was that this imagery is the most effective produced to date for low level training in the Advanced Simulator for Pilot Training.

SKILL TRAINING STUDY

The basic visual perceptual skills for low level flight appear to be the hand-eye coordination behaviors involved in maintaining extremely low altitudes over a given terrain area. Many other aircrew skills are involved including navigation, systems monitoring, and communication. But the basic aircraft handling skills are critical. The thrust of the present research was to investigate training techniques for this task component.

Various methods have been considered for training low level flight. For present purposes in the simulator, the objective was to train the pilot to use available terrain cues as effectively as possible, under conditions of very limited terrain fidelity. Long-established methods of training visual discrimination have been reported by a number of researchers (10, 11, 6, 1, and 3). Relevant visual discriminations are established by providing some form of obviously distinguishable auxilliary stimuli in the presence of the more subtle discriminations to be learned. A two-step flow is implied: first, effective prompts must be developed and applied, then they must be removed as the relevant discriminations are transferred to the primary stimuli. To be effective prompts must indeed facilitate relevant discriminations, but there is the possibility that they may compete with, rather than compliment the primary cues. Since prompts may be initially useful but terminally detrimental, they must be removed as correct responses are transferred to discriminative stimuli. Prompt removal has been called fading or vanishing (8) and is to be accomplished in a gradual, systematic manner.

This technique has been used successfully in a number of educational and pschological contexts, but its usefulness for the present simulator task has not been investigated. In the present study the objective was to determine if prompting would facilitate development of visual judgment and concomitant aircraft control skills to a greater degree than equivalent training without prompting.

METHOD

Subjects

Sixteen T-38 student pilots enrolled in undergraduate pilot training at Williams Air Force Base participated as subjects. They were all undergoing the initial phases of the T-38 syllabus and none had received any form of low altitude training in the aircraft.

Procedure

Assignment of Subjects to Groups. The subjects were randomly assigned to one of two treatment groups as follows: The experimental group (N=8) received low level training as prompted by lights and audible tones in the cockpit. The prompts were computer actuated in response to specific altitude limits. The control group (N=8) received training identical to the experimental group, less prompting.

Experimental Training. Each subject was given a standardized five-minute in-briefing describing the training task. The briefing consisted of a video introduction, explanation of the flight route, primary visual references, and relevant flight procedures.

Subjects assigned to the experimental group received the altitude prompting from two small lights mounted in vertical array on the cockpit glareshield and from audible tones through the headset. During the briefing, they were told to use these altitude references as a means of attaining consistent low altitude during the training. When the subject exceeded 150 feet above ground level (AGL), the top light illuminated until descent below that altitude. When he descended below 35 feet AGL, the bottom light illuminated until ascent above that altitude. The audible prompts were presented simultaneously with the lights; a 1000 Hz tone for the 150-level, and a 600 Hz tone for the 35-foot level. Subjects in the experimental group were told to use the 35 foot prompt particularly as a low level performance guide and to try to associate the occurence of the prompt with the appearance of terrain features for this altitude, trying to maintain this altitude as much as possible.

Following this orientation, each subject was introduced to the A-10 cockpit of the ASPT by an instructor pilot who gave him a standardized, ten-minute familiarization and warmup exercise. This included a takeoff, several turns and a landing. He was also allowed to "crash" into the ground and "fly through" several simulated ground objects in order to establish these simulation effects before beginning the training exercise.

The subject was then initialized at the starting point of the low altitude training environment at 200 feet AGL. The subject was instructed to fly through the environment maintaining as low an altitude as possible without crashing into the ground or trees. He was instructed that consistency and smoothness of flight were important and that he should maintain an indicated airspeed of 280 to 300 knots. He was given an approximate throttle setting as an assist. He was further advised that turn points in the flight path would be the most difficult segments in which to maintain low altitude, and that he should make a special effort to stay low in the turns by using rudder. Finally, he was instructed that he could use any flying technique or ground track he preferred through the course so long as he maintained the minimal altitude possible without crashing. If the subject crashed, he heard a computer-actuated voice say "zero altitude" but he was able to continue to "fly out" of the crash condition and complete the training trial.

Each subject flew eight trails over the course, with each trial taking about 4.5 minutes at the required airspeed. At the end of each trial the subject was re-initialized at the same starting point and altitude. During the trials, no further verbal instruction or performance feedback was provided to the subject. Time elapsed for the entire exercise including the briefing was about one hour and ten minutes.

On the last three training trials of subjects assigned to the experimental group, the intensity of the light and tone prompts was faded as follows: trial six, 75 percent intensity; trial seven, 50 percent; and trial eight, 25 percent. Thus, by trial nine (the first test run), the prompts had been completely faded for the experimental group.

Following completion of eight consecutive training trials, all subjects were given two additional trials as a test of training effectiveness. During the two test runs the number of vertical objects (trees) in the CGI scene was reduced by 50 percent. Subjects were also instructed to maintain a more critical airspeed tolerance (300 KIAS, plus or minus 5 knots).

Performance Measures

Dependent measures for the simulated low level task were: mean altitude, mean vertical velocity, and frequency of crashes during training trials and test runs. The altitude measure and crash frequency were taken as indicators of the subject's ability to use available visual cues to maintain minimally low level safe flight. Vertical velocity measures were intended as an indicator of aircraft control and overall smoothness of flight. Measurements of these parameters were taken during the three most difficult turns (45, 60, and 90-degree heading changes). The start and stop of turn maneuvers for each subject on each trial were determined at the point where bank angle exceeded (start) and dropped below (stop) 15 degrees nearest the geographical x-y coordinates of turns. The measurement of a mean altitude during wings level flight was also taken as a general indicator of the altitude attained over the route for each trial. This was the residual of altitude sampling by the system across the entire flight course, less the turns and hills (150 and 200 feet high) placed at two points across the flight path. Performance measures were sampled at a rate of 30 Hz during all training and testing for each subject via a computerized data record system. Following data collection these data were re-sampled at a one Hz rate for reduction and analysis.

Experimental Design

A Lindquist type 1 experimental design was used. One-way analysis of variance was performed for altitude, vertical velocity, and crash frequency data to test treatment by subject by trials effects for each of these performance parameters.

RESULTS

Figures 4-7 show the mean altitude for each of the eight training trials for the experimental and control groups. Between group differences were found statistically significant across mean altitudes on both the 90-degree turn (F= 5.82, $p < .03$) and the 45-degree turn (F=13.25, $p < .005$) trials as illustrated in Figures 7 and 5 with the experimental group achieving the lower altitudes across trials. Although the experimental group's achieved trial means during wings level flight and the 60-degree turn were also numerically lower than the control group (Figures 4 and 6), these differences are not statistically significant.

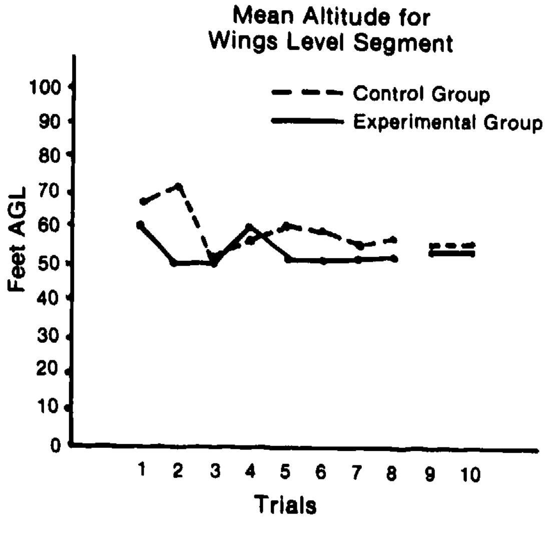

Figure 4

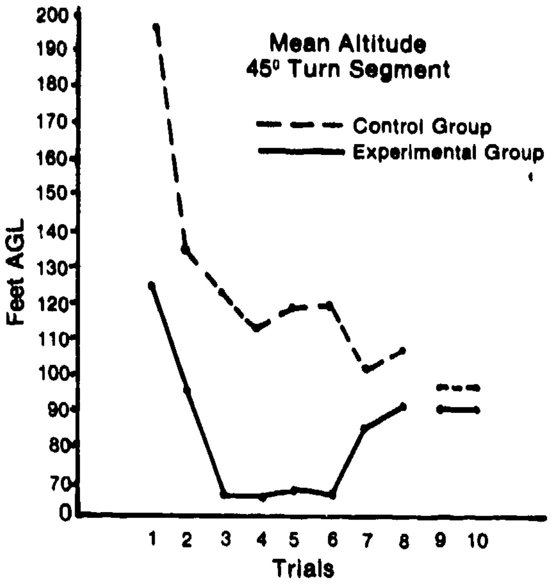

Figure 5

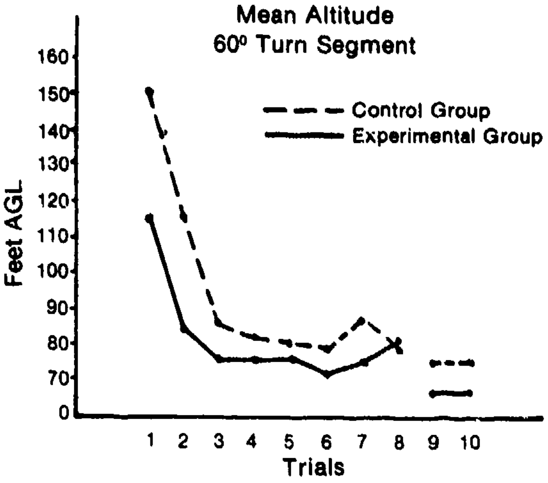

Figure 6

Achieved altitude performance during the testing condition is also shown in each of the figures as a two-trial mean plotted for trials nine and ten. None of these between group comparisons was statistically significant.

ANOVA comparisons of vertical velocity performance on all task segments for all trials revealed no significant findings. Frequency of crashes during the training trials did show a group effect. The control group subjects crashed significantly ($F=5.43$ $p<.03$) fewer times (.94 crashes per trial) than did the experimental group (1.86 crashes per trial). However, no reliable difference between the groups' crash performance was found during the test runs.

Aside from the treatment effects, the trials effects revealed by the ANOVAs for altitude during the training show consistent and highly significant practice effects for both groups as a result of the low level training. Learning curves for mean altitude across the eight training trials (combined group trial effects) were significant on all turns (45-degree - $F=9.65$, $p<.0001$; 60-degree - $F=10.93$, $p<.0001$; 90-degree - $F=8.21$, $p<.0001$).

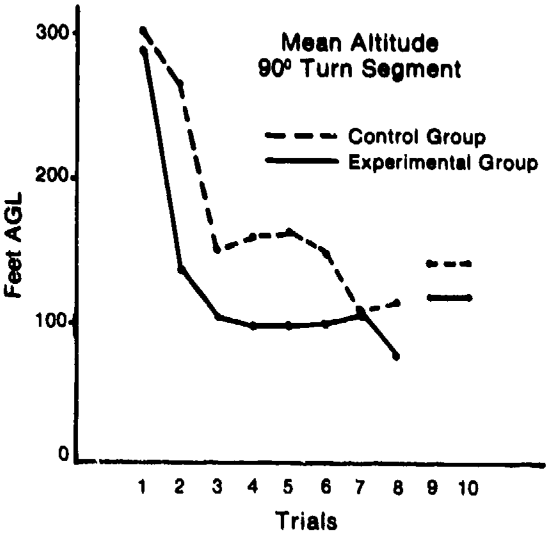

Figure 7

DISCUSSION

The purpose of this study was to assess the utility of a specific type of augmented feedback (audiovisual prompting) for training low altitude perceptual motor skills. The use of the prompts did enable subjects in the experimental group to achieve significantly lower altitude perfomance on two of the four critical task segments during the training trials. While in evidence, this effect was insufficiently powerful to produce reliable performance improvements over the control group during the test runs. This inadequacy appears to be a problem specific to the prompting technique and not the discriminative stimuli available to the subject via the computer imagery.

The CGI environment was effective. The highly reliable trials effect indicates that the visual imagery was indeed powerful in conveying altitude-relevant discrimination cues to the pilot and is also consistent with the plaudits this visual environment has received from a considerable number of pilots experienced in terrain flight.

While vertical velocity data provided no additional clues to performance differences between the groups, the crash frequency data present something of a puzzle. While it would seem that the 35-feet prompts could serve as a reasonably effective warning away from the ground during the training trials, the data indicate otherwise. Prompts seem to have interferred in some way with the subjects aircraft control, perhaps distracting them below 35 feet. If this is the case, this type of prompting is obviously inappropriate and dangerous for the task.

However, the specific process operable within the prompting, for the present, can only be speculated upon.

Returning to theory momentarily, the use of effective prompting presupposes a two-step flow: (1) the arrangement of suitable ancillary information by which transfer of desired behavior to relevant stimuli can be facilitated, and (2) an effective means for removing the prompts once the desired responses are established so that the learner no longer relies upon the ancillary information. The technique can be problematic. Prompts are actually additional information to an array of existing complex stimuli. As a mediational device, prompts must be sufficiently powerful to justify the additional information load. However, if prompts become too obtrusive, primary task-relevant stimuli may be over-shadowed precluding desired associational transfer, and defeating the objective of prompting.

It is not clear from the results or the above theory why the present prompting application produced less than a useful level of training. On the one hand they seemed too weak during trials to produce strongly differential training effects, at least for the altitude performance dimension. Conversely, as terrain avoidance cues (crash data), it seems the prompts were too obtrusive or in some other way inappropriate, to the point of possible performance interference at extremely low altitude. Aside from the training trial effects, training transfer to the test runs shows no differences in group performance for either altitude or crash frequency, the test runs being the crucial factor in the present effectiveness comparisons.

Perhaps variation of the prompting would significantly improve effectiveness. It is possible that the altitude limits set for the present study were not appropriate for the subject population, although the limits were arrived at systematically as a result of repeated trials by T-38 and research instructor pilots. Perhaps too, a more flexible or adaptive system of prompting in which the altitude limits of prompts vary as a function of student performance across trials would be effective. This is very speculative, and on the basis of present evidence, it would seem hard to justify the time and costs of developing such a prompting system. Results of the present study do not appear to warrant continued investigation of this technique for training low level flying skills.

Other substantive questions remain relative to training terrain flight in simulators which deserve investigation as research issues. Visual environment issues include influence of field of view upon low level training and techniques for improved modeling of object and texturing features. Training variables include investigation of task difficulty and task sequencing variables, and alternative performance feedback techniques for terrain flight training.

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EFFECT OF FIELD OF VIEW ON PERFORMING A LOW ALTITUDE MANEUVERING TASK

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ABSTRACT

Visual systems with a single window display are often utilized in ground based simulators used to study helicopter flying qualities during visual low altitude maneuvering tasks. The effects of this limited field of view (FOV) on pilot assessments of flying qualities are uncertain. A study was conducted using a variable stability UH-1H helicopter to compare restricted and unrestricted FOV for a range of flying qualities. With the restricted FOV, the pilots reported reduced ground track precision owing to loss of visual contact with the course markers. However, the predictable ground track of the repeated S-turn task with no obstacles made it easy for them to anticipate their maneuvers, and resulted in only a slight degradation of pilot ratings. This degradation was not sensitive to large changes in helicopter flying qualities.

INTRODUCTION

Factors that can affect the fidelity of ground based simulation include the mathematical model, visual system, motion system, aural cueing, cockpit layout, and environmental conditions. Visual systems with a single window display are often utilized in the ground based simulators used to study helicopter flying qualities. The purpose of this experiment was to evaluate the effects of FOV restrictions on the pilot's perception of flying qualities for a low altitude maneuvering task. The study was conducted using a variable stability helicopter, with the evaluation pilot's FOV restricted to that of a single window simulator display. The procedures described in (1) and (2) were used to restrict the field of view. To determine the sensitivity of FOV effects to large changes in handling qualities, modified helicopter flying qualities configurations were selected from those used in the experiment reported in (3); they are summarized in Table 1. The four FOV configurations used in this experiment are defined in Table 2.

EXPERIMENTAL APPROACH

FOV Setup Procedures

The simulator FOV with respect to pilot design eyepoint was measured using the specially adapted transit shown in Figure 1. This FOV was then mapped onto the test helicopter windscreen, as shown in Figure 2. Orange masking film was installed on the inside of the aircraft windscreen, except for the mapped area. When viewed through the blue visor (Fig. 3) all sections of the aircraft windscreen covered by the orange masking film become opaque. Objects viewed through the mapped window appeared to the pilot as different shades of gray. The light transmission characteristics of the orange masking film and blue visor are presented in Figure 4. In the right seat, the safety pilot had only a small loss of visual acuity looking through the orange masking film. On bright, sunny days, the safety pilot used the sun visor on his helmet to reduce the glare from the orange masking film. No flying was conducted under IMC or at night because of safety considerations.

Evaluation Task

The FOV flight experiment was conducted at Ames Research Center's flight research facility at Crow's Landing in conjunction with the flying qualities experiment described in (3). The task consisted of low altitude maneuvering around a series of markers, set up along an 8,000 ft runway (Fig. 5). The pilots were instructed to traverse the course while using the 1,000 ft runway markers as points around which to turn the helicopter fuselage without considering rotor blade clearance. The pilots were also instructed to maintain an airspeed of 60 knots and, for safety, an altitude of 100 ft.

Data Acquisition

Quantitative flight data were recorded by an on board analog magnetic tape recorder and were also telemetered to a ground station for real time monitoring and postflight analysis. Variables recorded included control positions, attitudes, rates, accelerations, airspeed, and altitude. A tracking radar produced ground track data for real time x-y plots. For each FOV configuration, the pilots provided an overall Cooper-Harper handling qualities rating and specific commentary on the precision of control through the course. A Cooper-Harper rating scale is shown in Figure 6.

RESULTS AND DISCUSSION

The results of this experiment are presented in the form of qualitative pilot opinion ratings and comments (Table 3) and quantitative flight data (Table 4 and Figures 8 and 9).

Pilot Ratings and Commentary

For the task used in this experiment, the pilot ratings were not, in general, sensitive to restrictions in FOV. This was true for large changes in aircraft flying qualities. The best flying qualities configuration, UH-1H manual mode (MAN), with no FOV restrictions was given a handling qualities rating (HQR) of 3, and the worst flying qualities configuration (R8.5, defined as sluggish and highly coupled) was rated about 7.5. With these same flying qualities configurations, the restricted FOV did not produce degradations greater than 1 HQR for pilots familiar with the task. Only pilot R, who initially was not familiar with the task, rated the good (MAN) configuration at 5 on his initial run with a restricted FOV. The rating was lowered to 4.5 and 4 for the second and third runs, respectively. However, these ratings, which reflect pilot learning, did not converge to the 3 rating that the pilot gave the nonrestricted FOV case. Pilot D reported a maximum degradation of 1 HQR with the restricted FOV on the initial qualitative checkout flight. Subsequent flights by pilots D, G, M, and T failed to produce greater than a one-half HQR degradation, as shown in Figure 7. On his first flight, pilot M actually rated the restricted FOV case better than the unrestricted case for the highly damped, highly coupled R8.5 configuration, as shown in Figure 7 and Table 3. However, on his second flight, he rated both restricted and unrestricted FOV the same for configuration R8.5. The fact that all pilots except pilot R were familiar with the task from the experiment reported in reference 3, and that the flight course was predictable, may have influenced these evaluations. Pilot T noted that it required only one pass through the course to be able to guess where the next marker was located, and that a more difficult course, tighter turns, or a less predictable flightpath might have shown a greater effect due to limiting the field of view.

Control Activity Statistics

A statistical summary of lateral and longitudinal control positions, series-servo positions, aircraft rates, and attitudes for selected data runs is presented in Table 4. For the good handling qualities configuration (SBO*) the data show very little difference between the restricted and unrestricted FOV cases. For the poor handling qualities configuration (R8.5), the restricted FOV resulted in a small reduction in standard deviations, especially for the longitudinal parameters.

Aircraft Flightpath Control

The moderately high altitude (100 ft) at which the task was flown meant that precise aircraft flightpath cues were not available. In addition, the pilots reported losing ground track precision because of loss of visual contact with the course markers during runs with the restricted FOV. However, most portions of the radar derived ground track plots shown in Figures 8 and 9 indicate a relatively close correlation in ground track between restricted and unrestricted FOV runs. This may imply that the predictable course layout of repeated S-turns with no obstacles made it easy for the pilots to anticipate their maneuvers.

The pilots also experienced difficulty in judging aircraft height above the ground with the restricted FOV without referring to the radar altimeter. This was attributed to the lack of peripheral cues with the restricted FOV and the high reference altitude above ground level.

Related Flight Program

Previous unpublished restricted FOV flight tests performed at Ames Research Center in December 1973 using a UH-1B helicopter produced similar qualitative results for low level day flying. Those tests consisted of performing a number of basic low level helicopter maneuvers, including takeoff, landing, precision hover, pedal turns, and air taxi tasks; the maneuvers were performed over a runway with no obstacles or traffic to monitor. Maneuvers were performed with no FOV restrictions, with a helmet fitted with a visor that restricted the pilot's FOV to 48° × 34°, and also with opaque material used to mask off the windscreen to produce a 48° × 34° FOV. A slight degradation in performance was reported for the case with the visor. This was attributed to the fact that inadvertent head movement could be interpreted as an attitude change of the aircraft causing the pilot to make undesirable control inputs. With the masked windscreen, the pilot was able to maintain a performance level comparable with the unrestricted FOV case.

FOV Requirements for Nap-of-the-Earth Flight

The FOV effects on flying qualities ratings for the task used in this experiment may not apply to a course requiring the pilot to fly around real obstacles or to actual Nap-of-the-Earth (NOE) flight. With the restricted FOV, the pilot would be unable to monitor rotor blade clearance in confined areas or monitor flightpath during sideward or rearward flight. Reference 4 reported the operational suitability evaluation of the UH-60A helicopter in an advanced attack helicopter role which involved low level, contour flight and NOE flight. The most critical reduction in visibility in the utility helicopter compared with that in the attack helicopter was the pilots' inability to see the main rotor at the 90° point. During the evaluation, this accounted for six blade strikes by the utility helicopter crew; there were no blade strikes by the attack helicopter crew. Other limitations of the utility helicopter that were noted included limitations in overhead visibility and downward visibility both to the left and right.

Attempts to establish a realistic NOE task for the experiment reported in (3) and the experiment reported herein were not successful. Safety precautions required that a minimum altitude of 100 ft be used. The necessity to monitor both the aircraft and real time telemetered data required that the experiment be conducted in the immediate vicinity of the Crow's Landing data station. Installation of high obstacles to fly around was precluded because they would have interfered with other air traffic at Crow's landing.

CONCLUSIONS

The flight experiment described in this paper was conducted to determine the effects of field of view (FOV) on helicopter flying qualities when a low altitude maneuvering task was performed. The task consisted of flying "S-turns" over a series of runway markers, separated 1,000 ft longitudinally and 250 ft laterally, at an airspeed of 60 knots and at an altitude of 100 ft. Qualitative and quantitative results were obtained for the nominal FOV of a UH-1H helicopter and with the FOV restricted to that of a simulator with a single window visual system. FOV effects were evaluated on the basic test helicopter and on a variety of configurations with degraded flying qualities. From the limited data obtained during this experiment and from related data discussed in this paper, the following trends and conclusions are noted:

1. The results showed only a minimal variation in pilot flying qualities ratings and statistical data while performing this task with restricted and unrestricted FOV. Restricting the FOV resulted in a maximum degradation of one pilot rating even for configurations with widely differing flying qualities.

2. The predictable ground track of the repeated S-turn course, the relatively high altitude, and lack of obstacles, made it easy for the pilots to anticipate their maneuvers and did not

demand high precision. These factors appeared to lessen the effect of reduced field of view.

3. The restricted FOV made height control difficult and required a frequent scan of the radar altimeter to maintain the reference altitude.

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TABLE 1. EXPERIMENT FLYING QUALITIES CONFIGURATIONS

Configuration	Description
MAN	Manual mode or basic UH-1H helicopter
SBO*	Manual mode using the series servos in the automatic flight control system. Approximately same characteristics as basic helicopter with increased yaw damping, $N_r = -3.5 \text{ sec}^{-1}$
R4	Roll damping $(L_p) = -4 \text{ sec}^{-1}$ Cross coupling (L_q/L_p), $(M_p/M_q) = 0$
R4.5	Roll damping $(L_p) = -4 \text{ sec}^{-1}$ Cross coupling (L_q/L_p), $(M_p/M_q) = 0.5$
R8	Roll damping $(L_p) = -8 \text{ sec}^{-1}$ Cross coupling (L_q/L_p), $(M_p/M_q) = 0$
R8.5	Roll damping $(L_p) = -8 \text{ sec}^{-1}$ Cross coupling (L_q/L_p), $(M_p/M_q) = 0.5$

Note: During the experiment, the lateral control sensitivity (L_δ) was held at 0.55 rad/sec^2/in., and the longitudinal control sensitivity (M_δ) was held at 0.14 rad/sec^2/in.

TABLE 2. EXPERIMENT FIELD OF VIEW CONFIGURATIONS

Configuration	Description
1	No FOV restrictions
2	Pilot wearing blue visor, no orange masking film on windscreen
3	Helicopter windscreen covered by orange masking film except for a clear 48° × 36° area in front of the evaluation pilot; no blue visor
4	Pilot wearing blue visor, orange masking film on windscreen

TABLE 3. SUMMARY OF PILOT HANDLING QUALITIES RATINGS

Configurations		Pilot	Pilot rating	Pilot Comments
Helicopter	Visual			
MAN	1	D	3	
	2	D	3	Acuity reduced, but workload still the same
	3	D	3	Orange glare in bright sunlight
	4	D	4	Like simulator with restricted FOV; height perception poor; turns no problems, but cannot see what you are turning towards
MAN	1	G	3[†]	
	4	G	3-3.5	Feels slow; cannot see pylon as you go by it; would be a problem in real NOE flight; gray appearance from blue visor no problem
	4	G	3-3.5	
MAN	1	R	3	
	4	R	5	Pilot not familiar with task; excursions in yaw exaggerated (especially turbulence); airspeed seems slower; difficult to judge height with limited FOV, tended to get low; more comfortable after learning period
	4	R	4.5	
	4	R	4	
MAN	1	G	3[†]	
	3	G	3.5	Helicopter handles well
	3	G	3.5	
	4	G	4	
R8	1	G	5.5[†]	
	4	G	5	
R8.5	1	G	6.5[†]	
	4	G	6	Poor altitude control, poor airspeed control because of helicopter configuration
SBO*	1	M	3.5[†]	
	3	M	3	Used sun visor to reduce annoyance from orange masking film glare (sun visor not lifted until R8.5 configuration; made seeing airspeed indicator difficult for pilot for runs with blue visor)
	4	M	3.5	Difficult to see airspeed indicator for instrument cross-check; would use next marker as guide on when to turn after losing sight of marker being passed over
R4	1	M	4[†]	
	3	M	3.5	A little more control activity required
	4	M	4	
R4.5	1	M	5[†]	
	3	M	4.5	Significant increase in control activity; no real problem with FOV, but think lack of peripheral cues makes difference on accuracy in flying course
	4	M	5	
R8	1	M	5[†]	
	3	M	4.5	Sluggish, large inputs required; lack of peripheral vision caused pilot to let deviations build up larger than with full FOV
	4	M	5	
R8.5	1	M	7[†]	
	3	M	6	Configuration very uncomfortable, jerky; required almost full lateral control coming out of the turns
	4	M	4.5	Felt more comfortable with restrictive FOV, seemed more accurate with task and in better control

[†] Averaged data from (3).

TABLE 3. CONCLUDED

Configurations		Pilot	Pilot rating	Pilot Comments
Helicopter	Visual			
SBO*	3	T	3	
	4	T	3.5	Visual acuity good, everything clear; only takes one pass through course even when you cannot see markers to guess where next one will be; a more difficult course or tighter turns or a less predictable flightpath might show up in worst ratings
R4	3	T	3.5	
	4	T	3.5	Very little difference in running course with restricted FOV
R4.5	3	T	4.5	
	4	T	4.5	Airspeed control more difficult; cannot tell airspeed by looking outside
R8	3	T	4	
	4	T	4	
R8.5	3	T	7	
	4	T	6	
SBO*	1	D	3†	
	3	D	3.5	
	4	D	3.5	Can see enough going out of a turn or into a turn to complete course
R8	1	D	5†	
	3	D	5	Definite degradation in flying qualities
	4	D	5	
R8.5	1	D	7†	
	3	D	7	
	4	D	7	Do not think FOV degrades this configuration much; biggest problem is the almost sustained oscillation of airframe
SBO*	1	M	3.5†	
	1	M	4	Roll sensitivity felt high; gained 40 ft but was able to correct; airspeed control was good
SBO*	3	M	4	Used the clear area of windscreen mostly; problem with airspeed not FOV
SBO*	4	M	4	Had to use airspeed indicator due to lack of peripheral cues
R8.5	1	M	7†	
	1	M	7.5-8	Configuration has loping motion; cannot establish precise bank angle, altitude or airspeed
R8.5	1	M	7.5	Large control inputs required; problems with airspeed, altitude, roll sensitivity, and damping
R8.5	3	M	7.5	
R8.5	4	M	7.5-8	Very uncomfortable

†Averaged data from (3).

TABLE 4. STANDARD DEVIATION SUMMARY FOR SELECTED LATERAL AND LONGITUDINAL PARAMETERS

Pilot Pilot rating Helicopter configuration Visual configuration	M† 3.5 SBO* 1	M 3 SBO* 3	M 3 SBO* 4	D† 3 SBO* 1	D 3.5 SBO* 3	D 3.5 SBO* 4	M 6 R8.5 3	M 4.5 R8.5 4	D 7 R8.5 3	D 7 R8.5 4
Standard deviations										
Lateral cyclic, in.	0.61	0.60	0.60	0.86	0.75	0.74	0.81	0.73	1.41	1.15
Lateral series servo, deg swashplate	0.99	0.77	0.76	1.36	0.96	0.94	0.83	0.80	1.07	1.00
Roll rate, deg/sec	5.66	5.38	5.15	8.70	7.16	6.78	5.08	4.78	7.99	6.90
Roll attitude, deg	16.62	16.47	14.60	21.38	19.51	19.70	14.88	14.37	21.24	18.39
Longitudinal cyclic, in.	0.23	0.28	0.22	0.42	0.32	0.32	1.17	0.54	1.12	0.82
Longitudinal series servo, deg swashplate	0.43	0.44	0.34	0.76	0.50	0.45	0.54	0.46	0.71	0.71
Pitch rate, deg/sec	1.73	1.92	1.54	3.60	2.34	1.95	2.07	1.49	3.57	2.77
Pitch attitude, deg	1.41	1.72	1.41	2.35	1.83	1.56	3.15	1.54	2.41	1.59

†Data from (3).

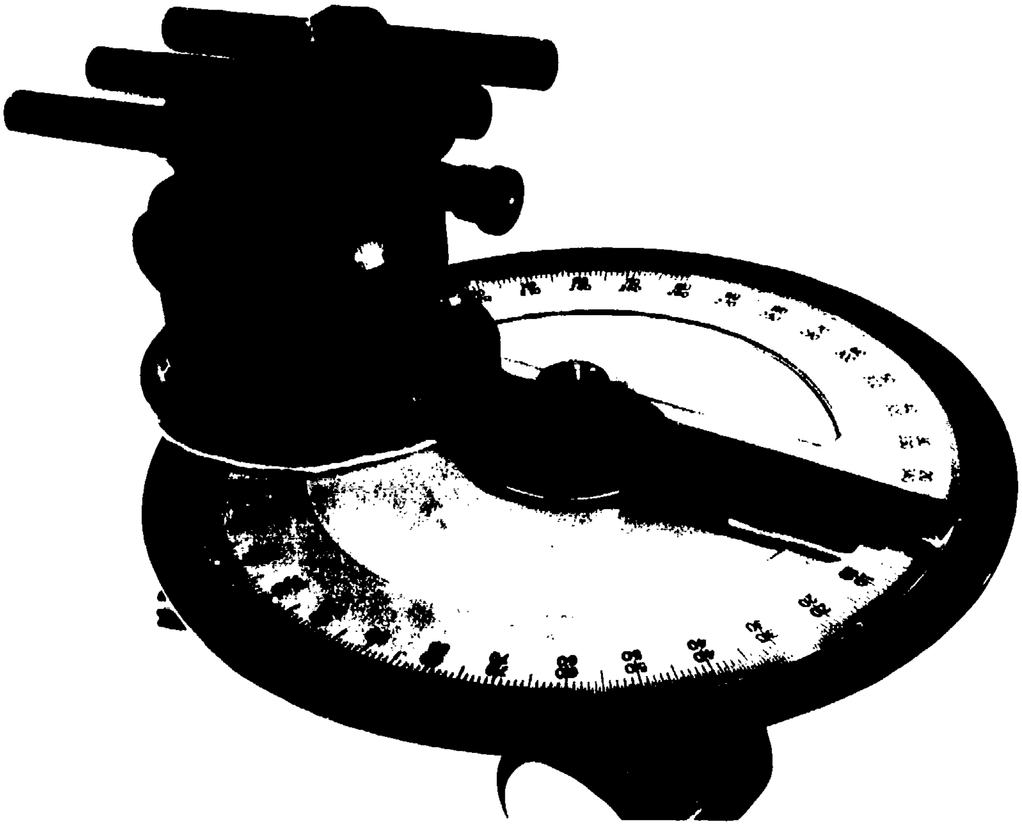


Figure 1. Field of View Transit

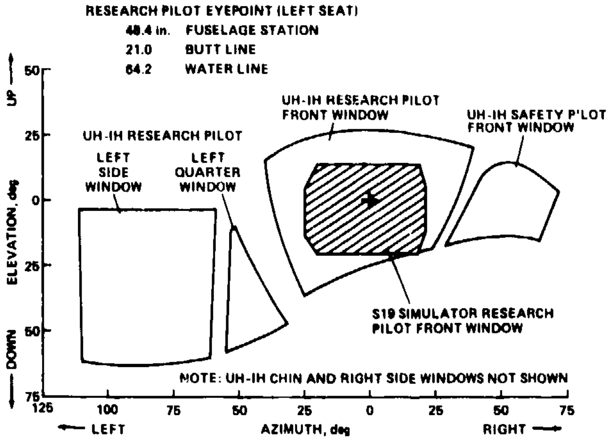


Figure 2. UH-1H Helicopter and S19 Simulator Vision Plot

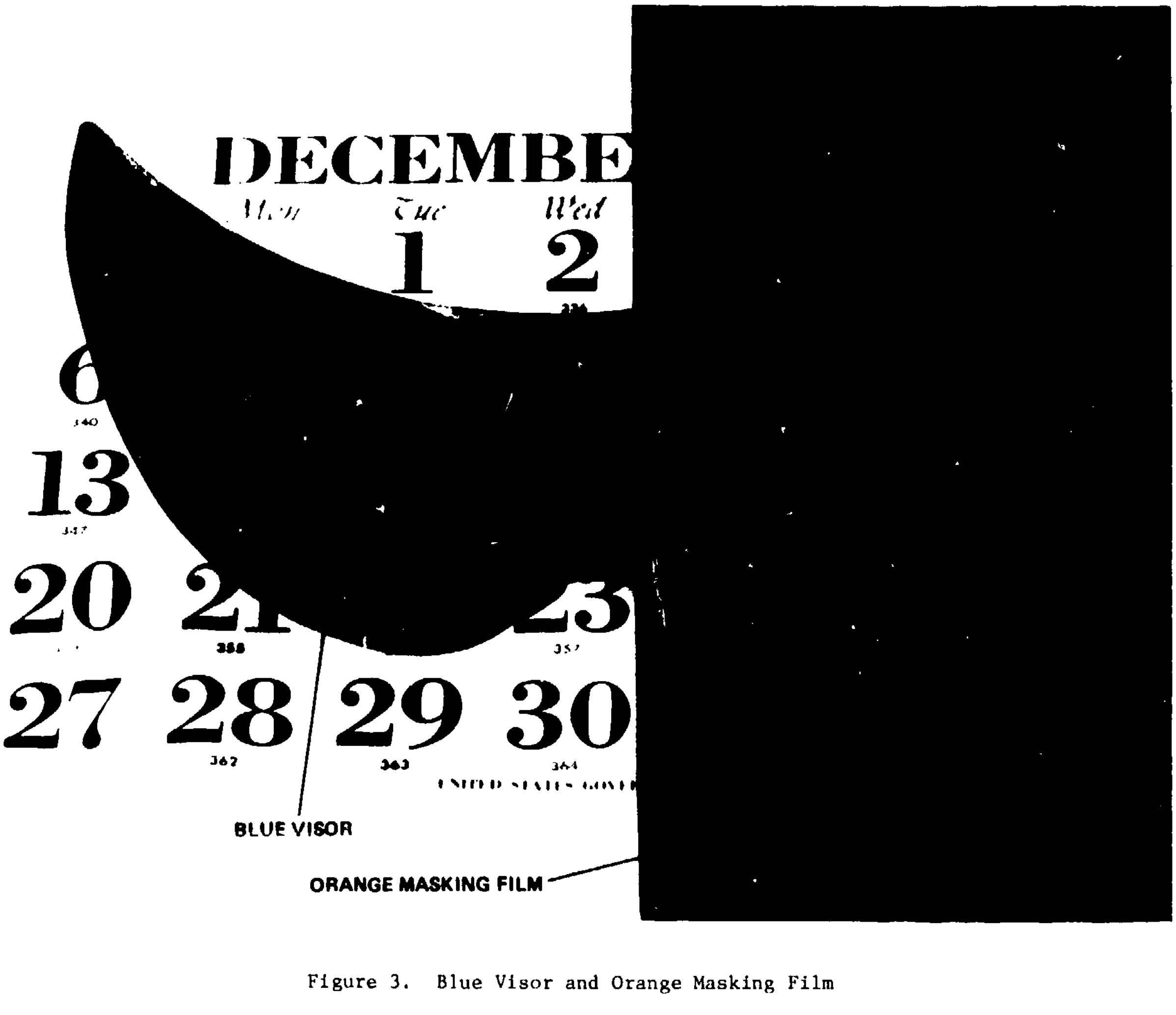


Figure 3. Blue Visor and Orange Masking Film

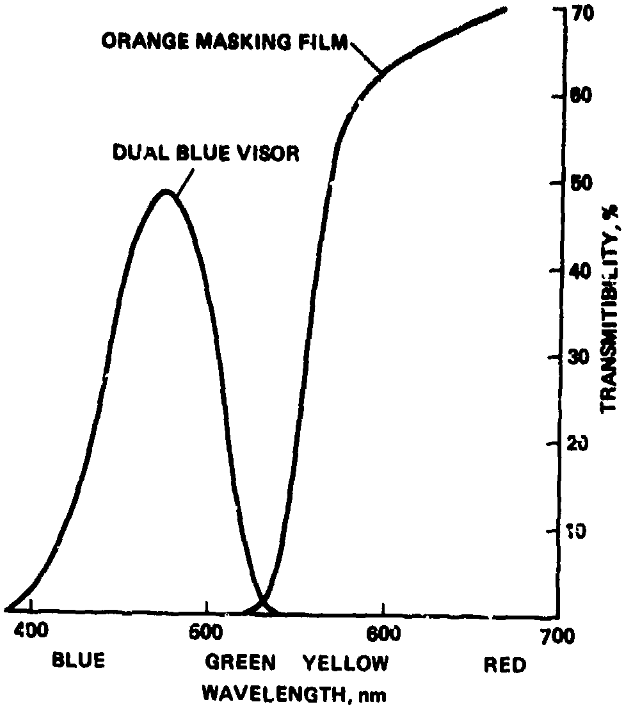


Figure 4. Light Transmission Characteristics

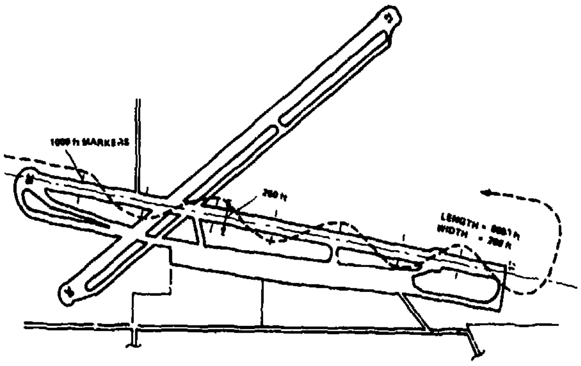
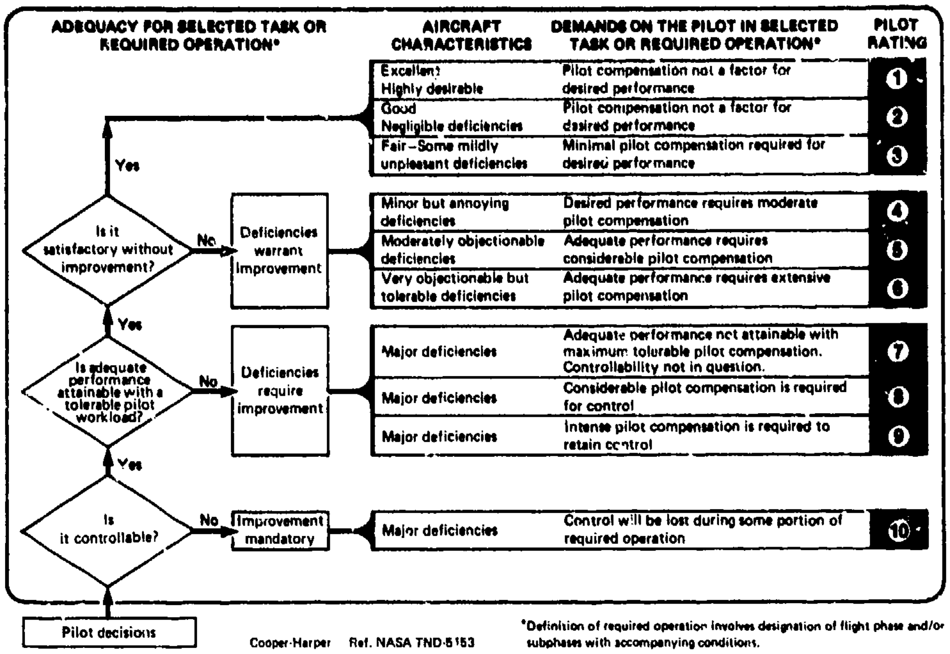


Figure 5. Low Altitude Maneuvering Course Task



Cooper-Harper Ref. NASA TND-5153

*Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

DEFINITIONS FROM TN-D-5153

COMPENSATION

The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics.

HANDLING QUALITIES

Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role.

MISSION

The composite of pilot-vehicle functions that must be performed to fulfill operational requirements. May be specified for a role, complete flight, flight phase, or flight subphase.

PERFORMANCE

The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task. (Pilot-vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner or efficiency with which a pilot moves the principal controls in performing a task.)

ROLE

The function or purpose that defines the primary use of an aircraft.

TASK

The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment.

WORKLOAD

The integrated physical and mental effort required to perform a specified piloting task.

Figure 6. Handling Qualities Rating Scale

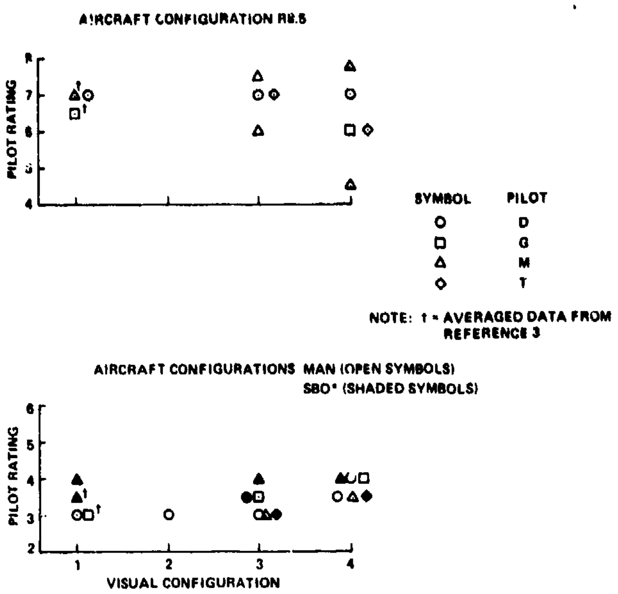


Figure 7. Effect of Visual Configuration on Pilot Ratings for Selected Aircraft Configurations

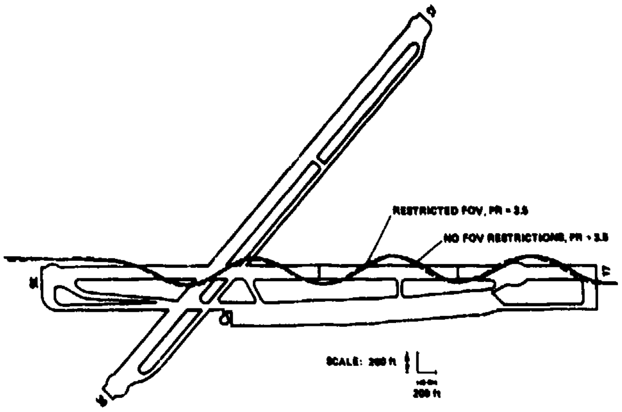


Figure 8. Ground Track Plot Showing Effects of FOV for Configuration SBO*: Pilot D

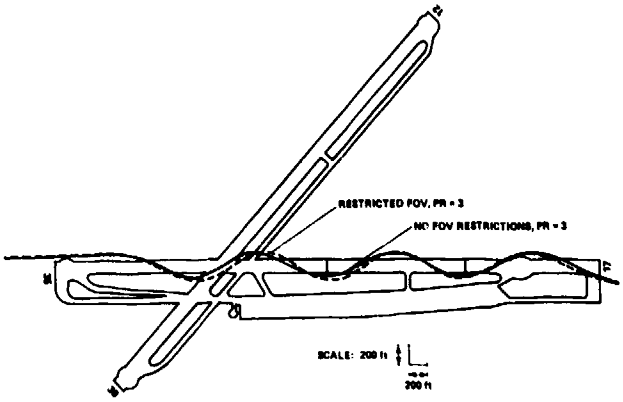


Figure 9. Ground Track Plot Showing Effects of FOV for Configuration SBO*: Pilot M

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TRINOSCOPE COLOR DISPLAYS FOR SIMULATION

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ABSTRACT

The resolution capabilities of computer image generators (CIG) used for simulation and training have advanced to the degree that they exceed the capabilities of existing shadow mask, direct view color TV displays and color TV projectors. One solution to this problem is the modern day implementation of a trinoscope color display that uses the optical merging of three high resolution monochrome cathode ray tubes--red, green, blue color phosphors, respectively--to produce a full color image. Such systems are particularly suitable for telescopes and periscopes needed in tank or submarine simulations where the color-combining optics can be integrated into the simulated sight optics. This paper describes the technical advances required to assure maximum resolution and, more importantly, superior color convergence (i.e., the capability to make the three CRT images fall exactly on top of each other so that the resulting full color image is produced without undesirable color fringing).

INTRODUCTION

There are many training situations where it is desirable to view a color TV image through the eyepiece of a simulated telescope or periscope. Examples would be the gunner's and commander's sights of a modern main battle tank or the periscope of a killer submarine. These situations usually carry with them a fairly stringent constraint on the total volume available for the display and optics. This means that the size of the display as well as the size of its image must be minimized while still meeting the criteria of color, resolution, etc. A minimal image size likewise conserves on optical path length, which further reduces display system size. These constraints produce requirements for an image source which are far beyond those of the conventional shadow mask CRT. The one image source which provides the highest TV resolution can also provide full color in a very small raster format. It is the trinoscope.

The Optical Industry and Systems Encyclopedia and Dictionary defines "trinoscope" as "a color-television viewing system with three kinescopes, three lenses, and three deflection yokes used to form the red, green, and blue images required for a tricolor television projection." Kinescope is another name for a cathode ray tube (CRT). The only disagreements with the above definition are the use of the words, "three lenses" and "projection." Various combinations of lenses, mirrors, and dichroic filters can be used--each with its own sources of problems and each with its advantages. Also, as will be seen in Figures 5 and 6 later, the system can be direct view. Figures 1 through 4 show various configurations that have been used in the past and which are now being revived for home color TV projection systems. Figures 1 and 2 show configurations which meet the original definition. In Figure 1, the images of the viewing plane are tipped and must be held within the system depth of focus to provide acceptable image quality. This problem can be resolved somewhat by applying the Scheimpflug condition, commonly used with view cameras and in photogrammetry.(1) Electronic keystone correction is required. Within the Figure 2 configuration, the lens axes are all parallel and perpendicular to the image plane, but the outer CRTs are displaced laterally outward so that the outer optical axes converge at the screen. This combination reduces the need for keystoning correction and provides better depth of field control but places more constraints on the lens.

Figure 3 illustrates a trinoscope system that uses only two lenses and is used commercially for a home TV projector. Figure 4 uses only one lens and is the basis of ESP's Aquavision projector. Even though this system does have a single exit pupil--a necessary feature for a telescope/periscope trainer application--the crossed dichroics become difficult to implement for higher resolution systems. The discontinuity at the intersection of the four dichroic mirror elements acts as a distributed central obscuration, in optical terms, limiting the spacial frequency optical modulation. It is, however, suitable for home and industrial TV projection applications. It also has the practical problem that each of the three CRTs are affected by the earth's, as well as manmade, magnetic fields in a different manner causing long-term convergence problems--particularly on a nonstationary system such as a moving gun turret.

PRACTICAL SYSTEMS

Figures 5 and 6 illustrate two of several configurations which have proved useful in telescope/periscope simulation. SRL has delivered several of each of these implementations during the latter half of 1980 and first half of 1981 for the gunner's and commander's sights in tank conduct of fire trainers (COFT). Both configurations have proved to be capable of providing the required color resolution.

One version used a 127 mm CRT with a 108 mm useful diagonal. Shown in Figure 7, it demonstrated over 1400 TV lines per picture height and width resolution using an SRL designed and fabricated beam combining optics. The second system, shown in Figure 8, is used in General Electric's successful COFT prototype. It uses a modified color TV camera prism assembly to combine the images of the three CRTs. Even though the CRTs only had a 40 mm useful screen diagonal, it exhibited 1000 TV lines per picture height horizontal resolution. Both of these two systems had a circular format image area where the square CIG raster was overscanned such that the full useful diagonal area of the round CRTs was used as shown in Figure 9. An engineer is shown in Figure 10 aligning the General Electric trinoscope display.

Since the full color image from a trinoscope is derived by optically overlaying three separate images, it becomes obvious that means must be provided to converge the three images so that they appear as one. For lower resolution systems, such as home TV applications, the only corrections needed are individual size and position of each of the three rasters. Keystone (trapezoidal) correction is also needed for multiple exit pupil systems such as shown in Figures 1 and 3. But for high resolution systems, more elaborate matching circuitry is required. Not only must this matching circuitry allow for accurate registration, it must be very stable with both time and environmental changes.

Figure 11 shows a simplified block diagram of one of the COFT trinoscopes. From a block diagram viewpoint, the other COFT trinoscope was the same except that raster rotation was performed in the digital image generation equipment instead of in the trinoscope electronics. To keep relative drift between the three channels to the minimum, much of the circuitry is kept common, thus common mode drift is close to zero. This includes the sweep generation circuits, the main deflection amplifiers, and the high voltage power supply.

The convergence circuitry is included to correct for the differences between the electrical, optical, and mechanical characteristics of the three channels. Therefore, each channel must be independent and, as such, can drift independently of each other. Several factors help, however, to make this drift manageable. Without this correction, the three channels would probably match to within one percent due to the selection of matched magnetic components and CRTs and have no more than 0.25 percent drift with time in normal simulator environments. This basic stability is achieved by use of SRL linear current feedback deflection amplifiers which even correct for change in the deflection yoke resistance with temperature. Due to a patented power-on-demand feature, these amplifiers are significantly more power conserving than conventional linear deflection amplifiers and are particularly suitable for TV raster applications. (2) The convergence circuitry then needs only to correct for the one percent residual error. By using temperature stabilized, linear feedback current amplifiers for the convergence amplifiers, it is safe to assume that the convergence circuits also only drift an amount in the order of 0.25 percent of full output. Drift, then, reflected to the CRT is 0.25 percent times one percent, or 1/40th of a pixel element in a 1000 × 1000 pixel element system. Of course, there will be differential heating and other second order effects in the system that will cause some misconvergence errors, but suffice to say, convergence drift can be made to be insignificant.

It is difficult to measure misconvergence through a telescope/periscope optics system. However, SRL was able to consistently achieve a one pixel element center, 2 or 3 pixel element edge misconvergence on a 1400 × 1400 pixel element system. This amount of misconvergence is barely visible with a dot test pattern but is seldom distracting with real life type CIG scenes such as used in simulation and training.

To illustrate the visual system capability, a series of photos from General Electric's highly successful M1 Conduct of Fire Trainer is presented. Figure 12 illustrates the full CIG scene (taken from a conventional 19-inch monitor), which would be observed through the commander's biocular periscope. Figure 13 shows the 3X scene as it would be seen through the Gunner's Primary Sight as he ranges in on the target, and Figure 14 shows the 10X view for the same sight as a hit is scored. Note the high quality of the red recticle and the green numerics of the laser rangefinder produced by the visual system. Figure 15 depicts a "white-hot" thermal image produced from the same data base which further illustrates the flexibility of a CIG visual system. The basic configuration of this mobile trainer is illustrated in Figure 16, which also highlights the premium placed on minimal optical path length.

GE's M1 COFT system consists of four simulated high power sights driven by two trinoscopes and a two-channel CIG. Beamsplitters divide the images such that the commander's two sights are driven by one trinoscope while the gunner's two sights are driven by the other trinoscope. Clever "in-use" sensors tell the CIG which sight is being used so that it will provide the proper scene.

As mentioned previously, the commander also has a rectangular 1X periscope which is driven by a standard 19-inch monitor and collimating optics. Figure 17 shows the interior of the crew compartment. All five sights are clearly visible.

SUMMARY

The use of trinoscopes in telescope and periscope simulation has proved practical in tank simulators. Trinoscopes would be equally effective for submarine, antiaircraft gun, rocket launcher and any other system which views a target or scene through an optical eyepiece and where optical path length is at a premium.

Since there is nothing in the direct view or projection trinoscope concept that limits it to raster scan, a calligraphic (stroke writing) or a dual calligraphic/raster version could be made using existing circuitry.

Although the trinoscope concept is very old, its uses are as new as the next generation simulator or trainer.

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2. R. E. Holmes and J. A. Mays, United States Patent No. 3,628,083, 1971.

ABOUT THE AUTHORS

Mr. Richard E. Holmes, Chief Scientist, Training Systems Group, Systems Research Laboratories, Inc. is responsible for conceptual development of techniques for visual image pickup, processing and display. A registered Professional Engineer in State of Ohio, Mr. Holmes holds several patents, an EE degree from University of Cincinnati and MSEE from University of Connecticut.

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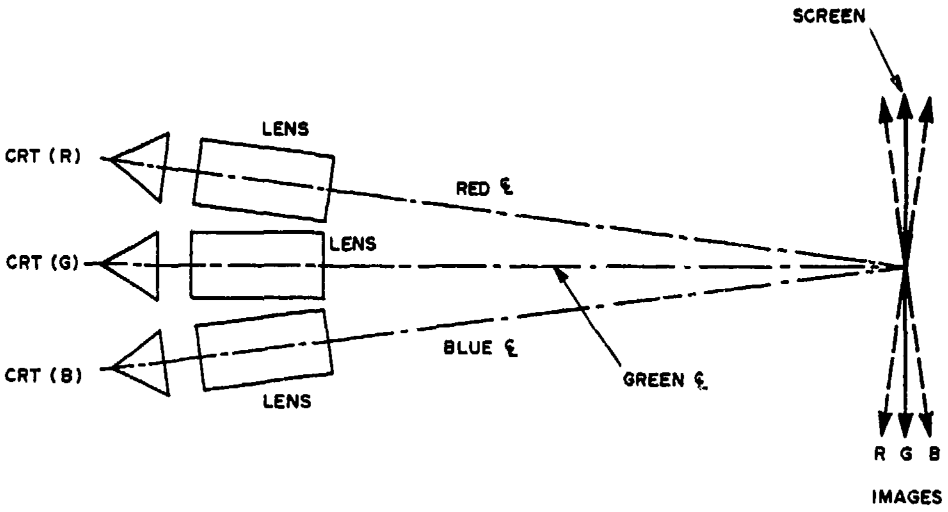

Figure 1. Trinoscope with Three Lenses

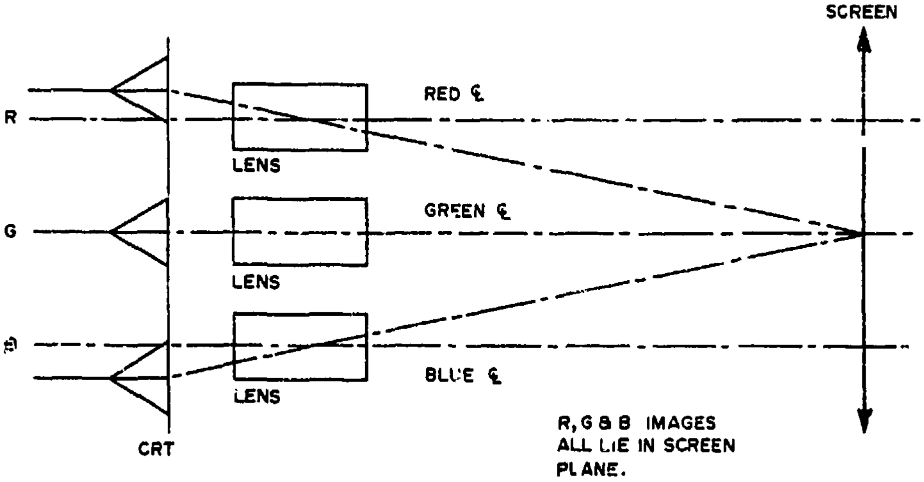

Figure 2. Trinoscope with Three Off-Set Lenses

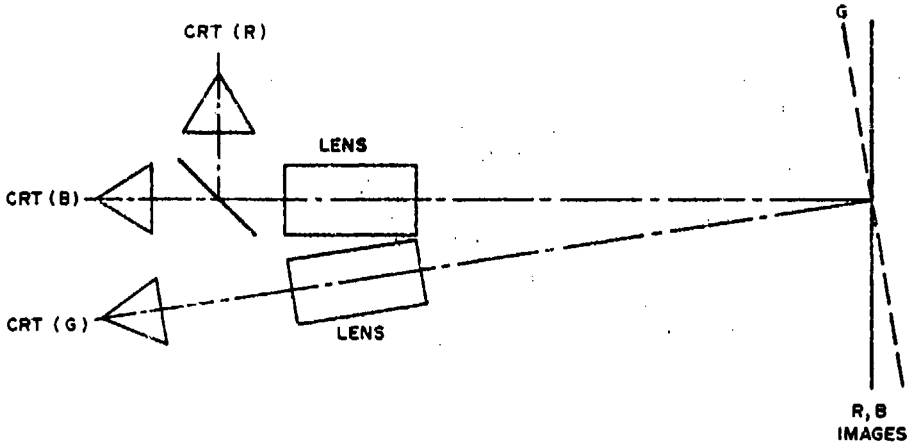

Figure 3. Trinoscope with Two Lenses

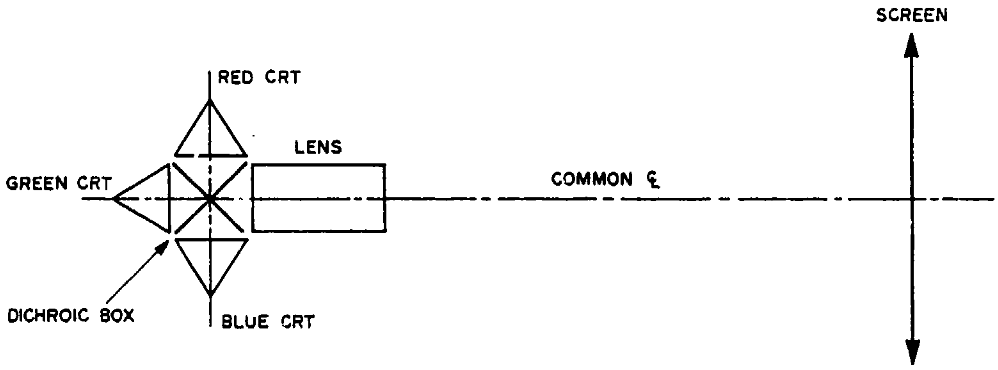

Figure 4. Trinoscope with Crossed Dichroics Image Combiner and Single Lens

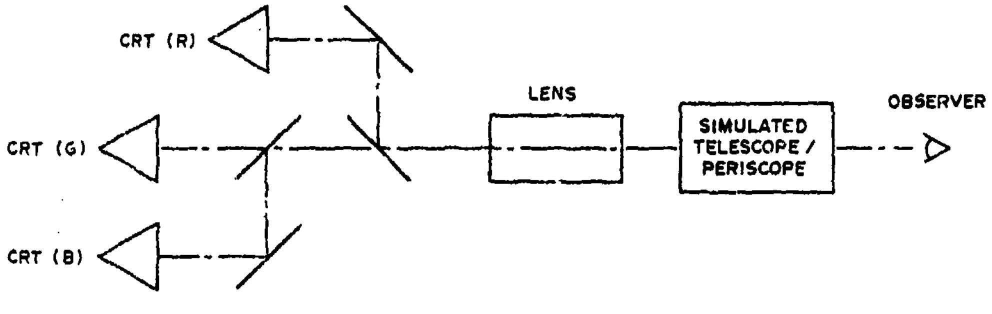

Figure 5. Trinoscope with Mirrors and Dichroic Image Combiners Suitable for Telescope/Periscope Simulation

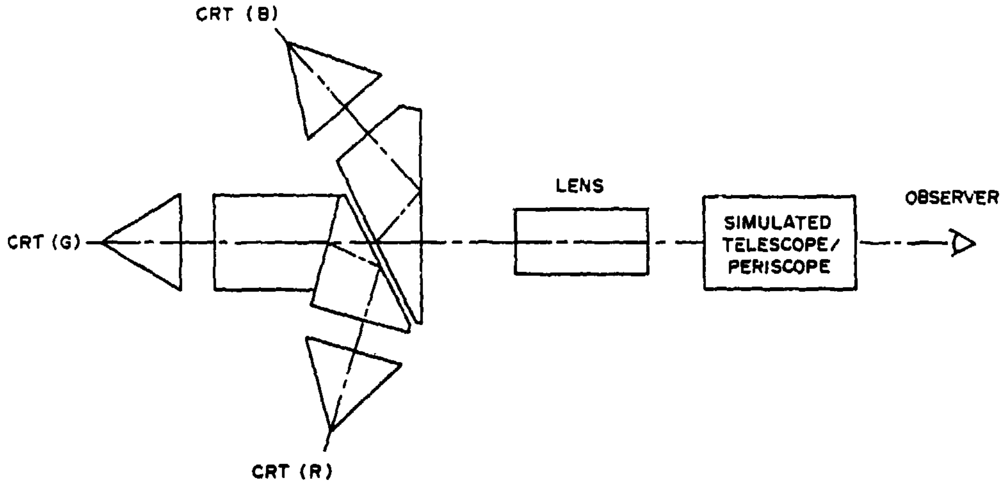

Figure 6. Trinoscope with Dichroic Prism Image Combiner Suitable for Telescope/Periscope Simulation

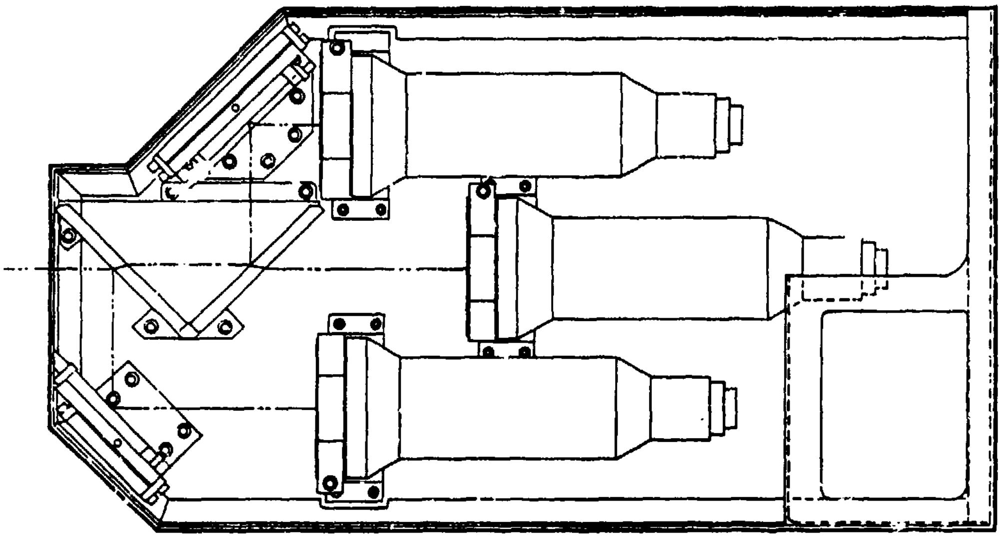

Figure 7. Top View of Beam Combiner Type COFT Electro-Optical Assembly

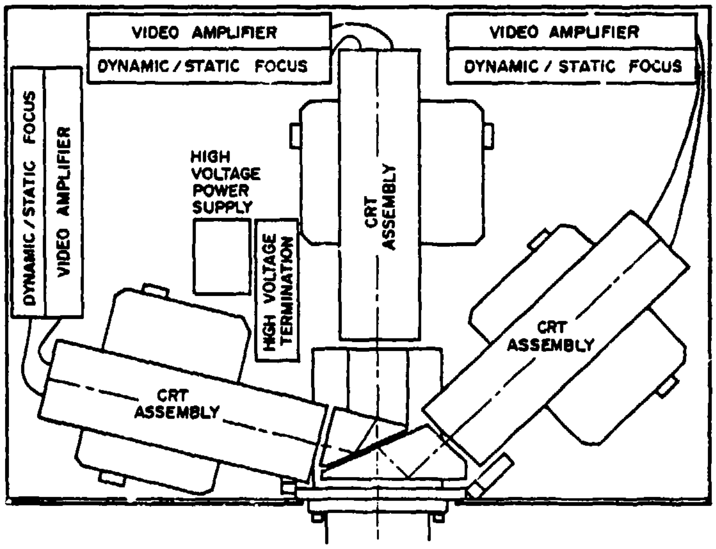

Figure 8. Top View Figure of Prism Type COFT Electro-Optical Assembly

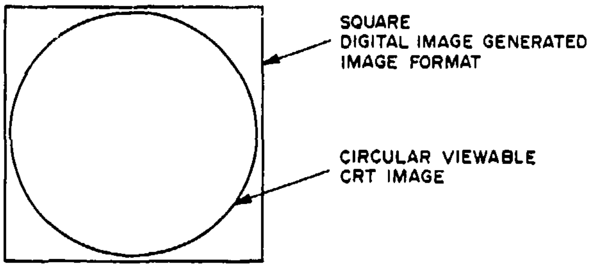

Figure 9. Circular Field-of-View Images of Trinoscope Systems Shown in Figures 7 and 8

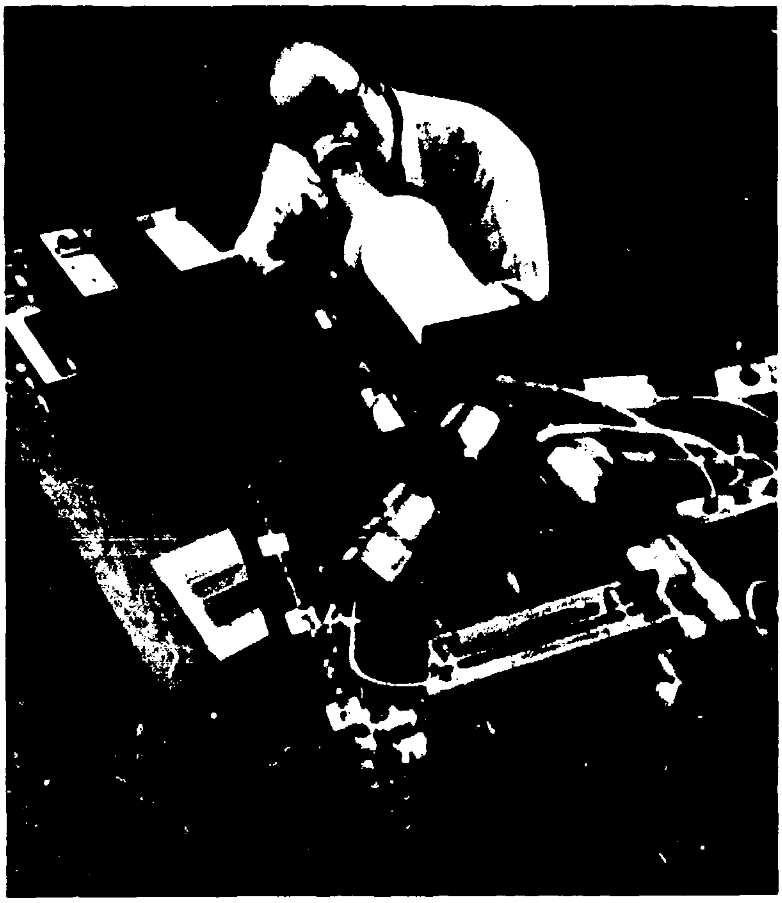

Figure 10. An Engineer Aligns GE's Trinoscope at SRL. The three CRTs are mounted on a base plate assembly along with collimating optics (white tube).

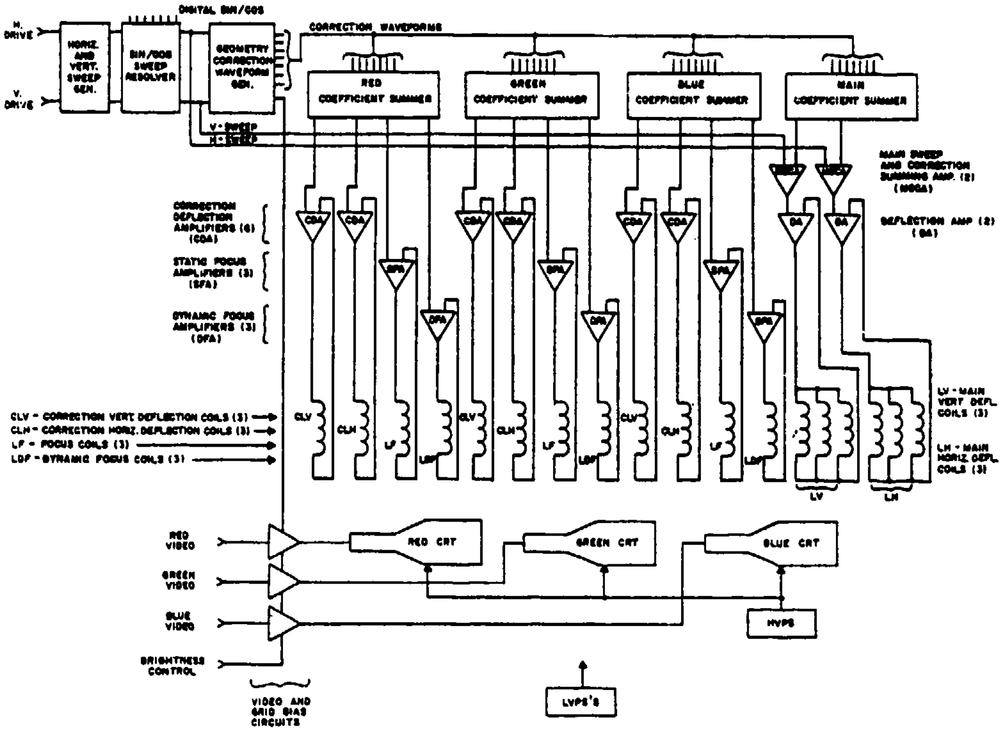

Figure 11. Block Diagram of Typical Trinoscope Electronics Used in Telescope/Periscope Trainers

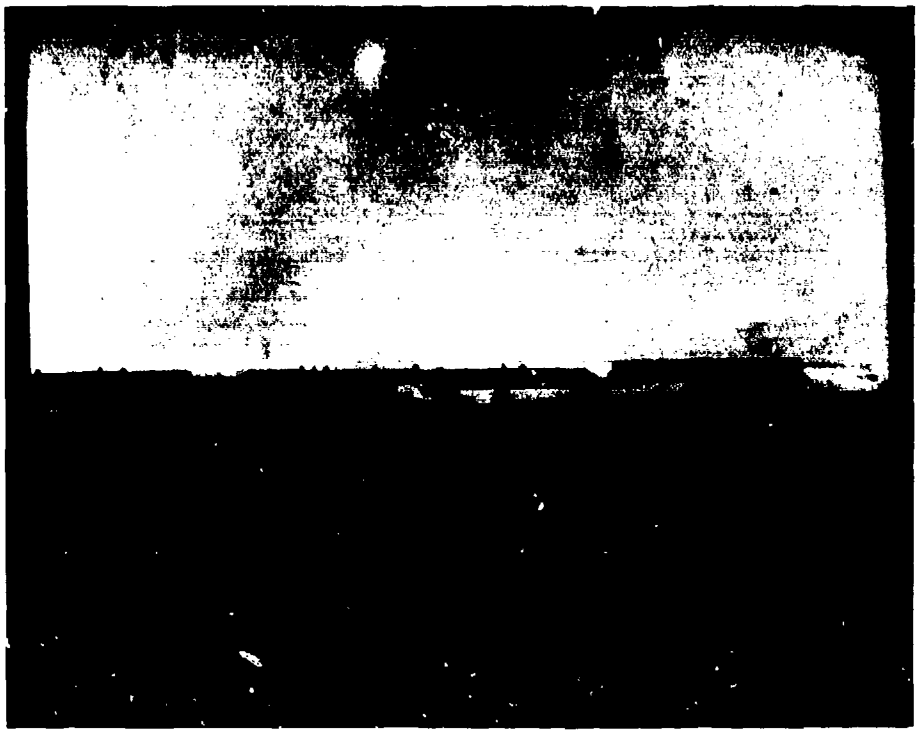

Figure 12. CIG IX Scene Presented to the MI Commander's Periscope Sight. Note middle of scene for subsequent figures.

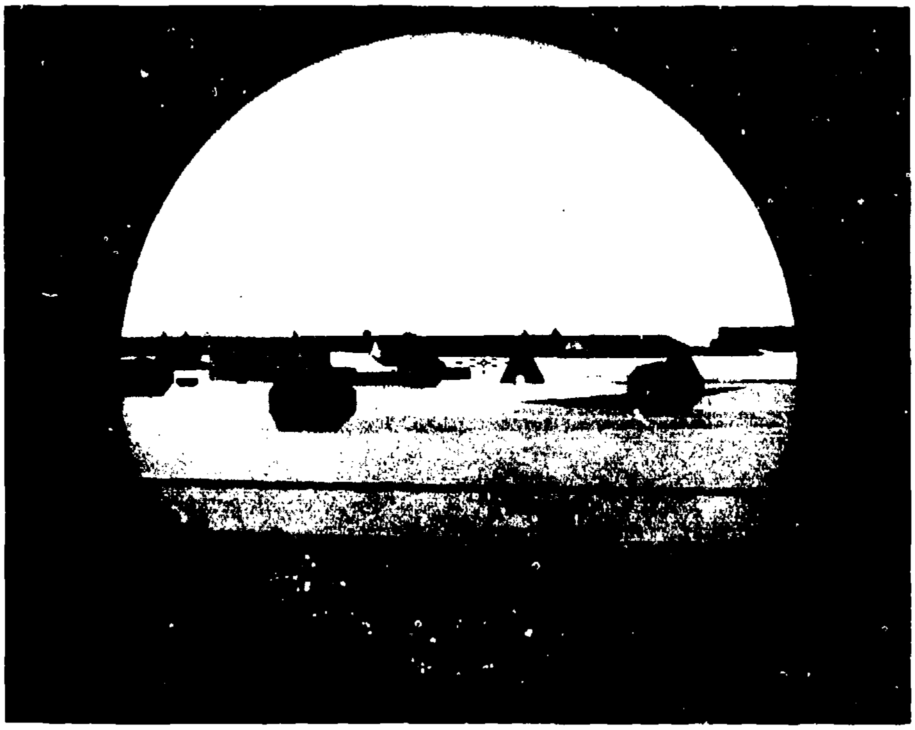

Figure 13. CIG Scene Taken Through the Gunner's Primary Sight (GPS) at 3X. Note excellent registration.

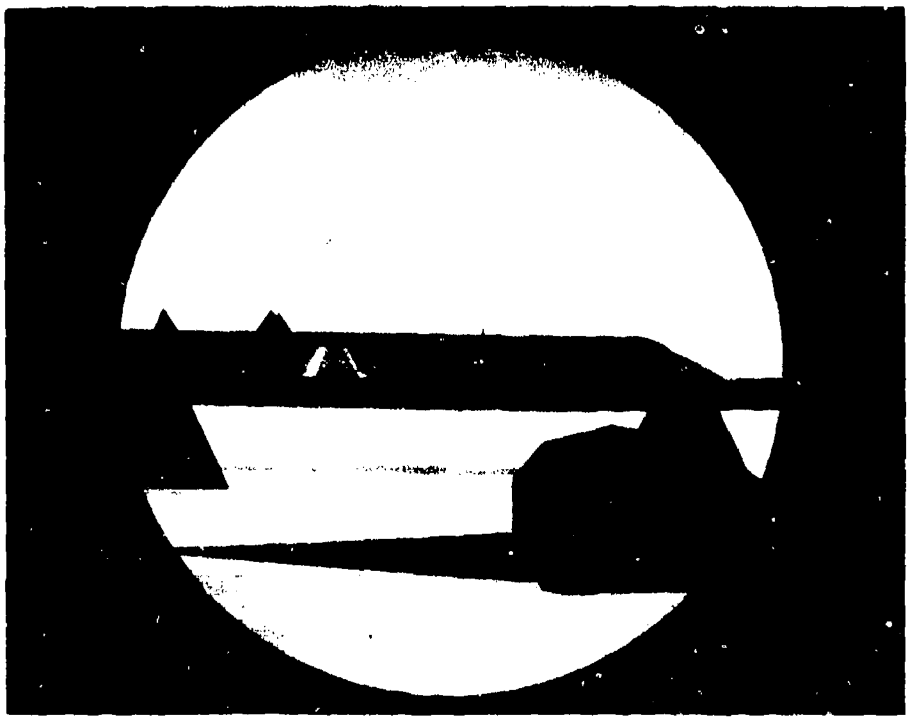

Figure 14. CIG Scene Taken Through the GPS at 10X

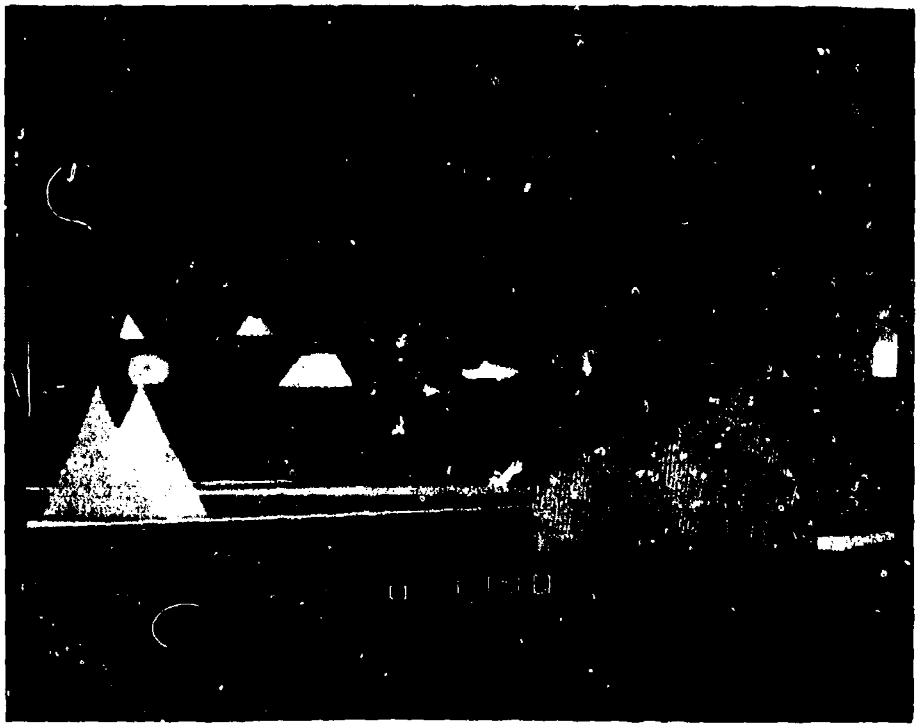

Figure 15. "White-Hot" Scene Taken Through the GPS in the Thermal Imaging Mode

Figure 16. The General Electric Conduct of Fire Trainer (COFT)

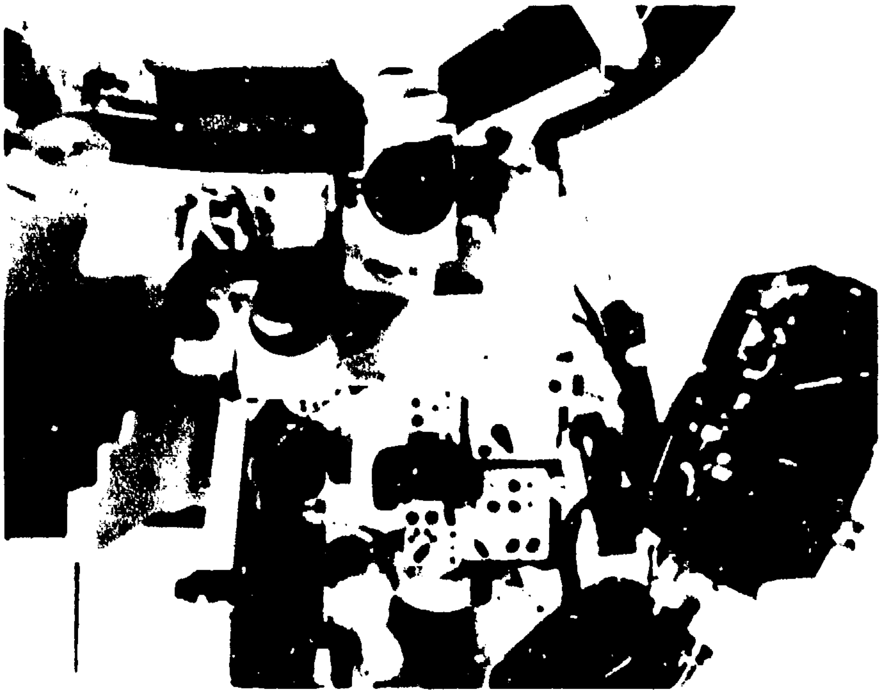

Figure 17. The Interior of GE's COFT Crew Compartment. Note the two gunner's high power sights (lower).

ARMY MAINTENANCE TRAINING AND EVALUATION

SIMULATION SYSTEM

AMTESS

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ABSTRACT

The AMTESS concept is considered to be a forerunner of a new direction in maintenance training. It will have the capability of providing introductory maintenance training at the institutional level, as well as proficiency training in the field environment. The system will be a modular and flexible maintenance concept with broad applicability to perform in various areas. The basic AMTESS requirements were generated as a result of an extensive front end analysis by four highly experienced contractors working independently. The Air Defense and Ordnance Schools were selected for the initial analysis effort. As a result, each contractor provided a basic design of a system which would meet all of the AMTESS requirements. This effort constituted Phase I of the program. The second phase of the program resulted in the delivery of an AMTESS by each of the two most qualified contractors from Phase I. An extensive evaluation period is planned by the Ordnance school, and the Air Defense School to ensure the training effectiveness of AMTESS. The inherent modularity of the AMTESS and the ability of the instructors to modify POI's will provide a device with a wide range of flexibility and adaptability to overall maintenance training.

INTRODUCTION AND BACKGROUND

A typical maintenance training cycle now being conducted at the schools is depicted in Figure 1. Looking at the cycle in reverse order, however, presents a representation of the evoluationary process associated with maintenance training in the Army.

Prior to the introduction of simulators and training aids, the majority of maintenance training was conducted on operational equipment. It became obvious early on that there were several drawbacks to using operational equipment for maintenance training. Granted, it did present the most realistic situation; however, it was difficult to provide efficient and effective training.

In general, operational equipment training required a one-on-one student instructor relationship. Demonstrations could not be conveniently conducted; faults could not be inserted easily, particularly in mechanical equipment; and student assessment was based on a subject evaluation by the instructor.

The use of cut-aways as a training aid was seen as a major breakthrough by many. The housings on engines were cut away to expose the internal components. Tank turrets were even cut open and mounted on stands to allow the interior to be more accessible to the students. These techniques allowed the instructors to demonstrate maintenance procedures to several students simultaneously. However, many of the same problems exist as when standard operational equipment was used for maintenance training. Faults were difficult to simulate; student performance could not be objectively measured; the instructor student ratio was still high.

The introduction of the panelboard trainer was considered to be a quantum jump in the area of maintenance training. The panelboard trainer with its associated computer and visual display system provided an excellent tool for classroom instruction as well as individual, self paced instruction.

At this point, elements of all three stages of evolution of maintenance training were combined to form the present maintenance cycle. The two dimensional panel board allowed the instructor to provide basic instructions, insert malfunctions, and assess student performance. The students were able to learn the techniques associated with initialization procedures, troubleshooting, and fault isolation.

Once the panelboard techniques had been mastered, the student then proceeded to the second portion of the training cycle, the three dimensional mockup. The primary emphasis on the mockup was remove and replace procedures.

The three dimensional mockup is not a necessary ingredient in all training situations. However, it has been found that in complex systems, students have difficulty transitioning from the panel board trainer to the operational equipment. Despite the fact that the student may have mastered the panelboard techniques, some students have considerable difficulty locating specific

MAINTENANCE TRAINING CYCLE

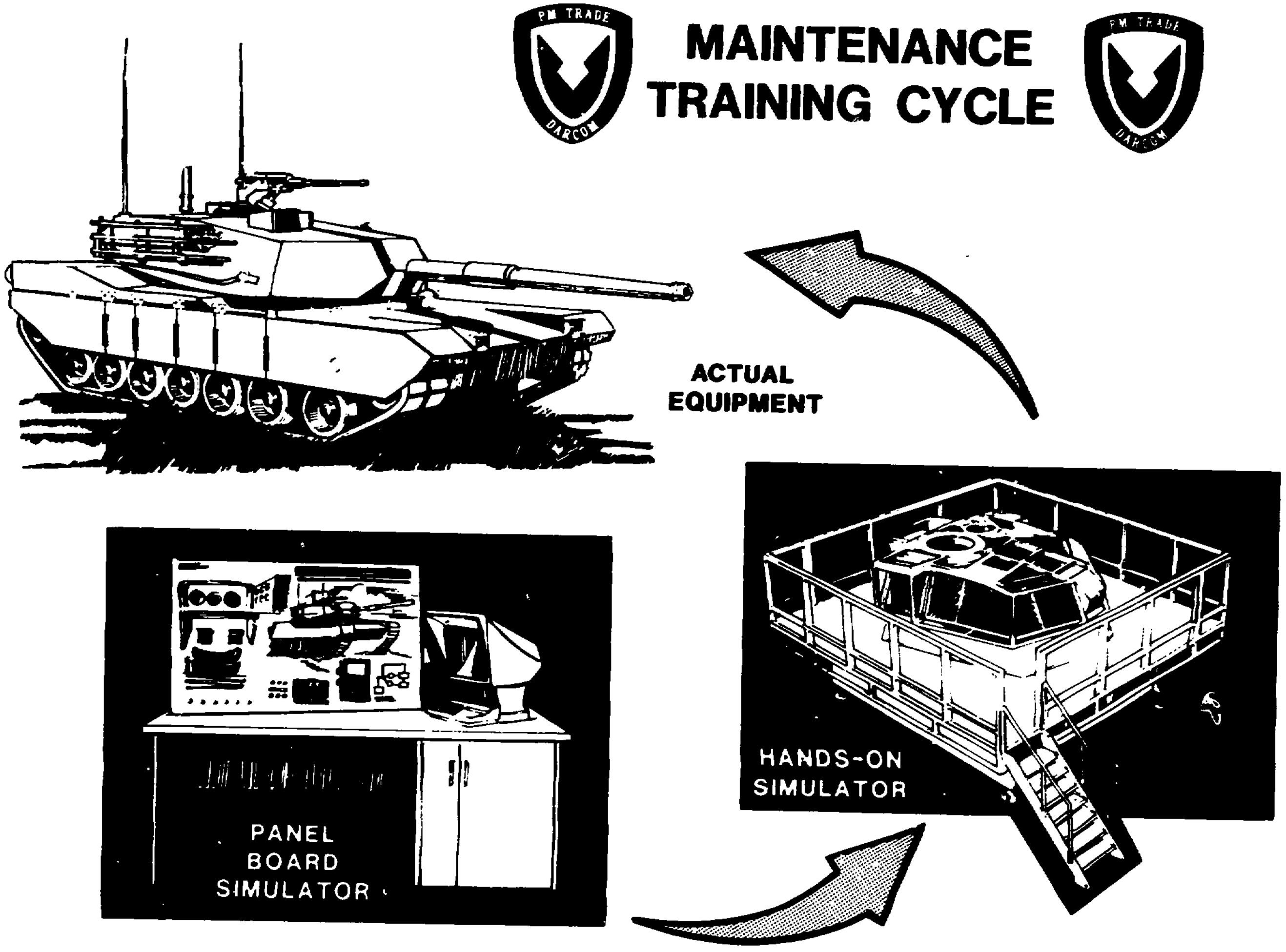


Figure 1

components on the operational equipment. Therefore, the mockup serves as an aid to familiarize the students with the overall system. In addition, the mockup serves to obviate the physical constraints, the degree of difficulty in removing and replacing components, and the particular tools and skills involved.

The final stage of training is on the operational equipment. Eventually the trainee must confront the operational equipment for which he is to be responsible. Generally, the final stage of training is on the job training; however, in many instances, operational equipment is dedicated to maintenance training.

The present maintenance training cycle represents the most effective training available. However, each stage of the cycle contains basic deficiencies. The panelboard type trainers lack flexibility. Any program changes or configuration changes require a fairly major modification to the system. Hardware and software changes must be accomplished by the contractor.

The system mockup has many limitations. It normally provides only a remove/replace capability. There is no interaction with a central processing unit to assess student performance. faults cannot be inserted conveniently into the mockup, and the cost-benefit ratio if not favorable.

The primary drawback with using operational equipment in the final stage of maintenance training is the Army's emphasis on reducing the use of operational equipment for training.

To alleviate the deficiencies associated with the present maintenance training cycle, the AMTESS program was initiated in June 1978. This program was established as a two-phase effort. Phase I consisted of four separate tasks associated with the Air Defense School, Fort Bliss, Texas, and the Ordnance School, Aberdeen, Maryland. Under Task I, all the skills associated with the maintenance of selected automotive and missile components were analyzed for commonality, and representative tasks were selected for use in AMTESS. Task 2 was an analysis of the training requirements for the tasks selected. The object of Task 2 was to determine the types of skills with which the trainees were to emerge. The third task was to analyze the fidelity requirements associated with each phase of training. Task 3 was particularly significant since, in the past, there has been considerable resistance on the part of the instructors to use devices which did not exactly duplicate the operational equipment in question.

Despite the fact that studies have been conducted to validate the theory that exact replication of operational equipment is not always necessary to provide effective training,* instructors remain skeptical.

Task 4 of the program was to be the culmination of the first three tasks. Based on the data relating the tasks associated with particular areas of maintenance training, the training requirements for those tasks, and the level of fidelity required, each contractor was to provide a Preliminary Systems Engineering design of a system incorporating those data.

The primary objective of Phase II of the AMTESS program was to procure an AMTESS in accordance with the Phase I design, and to test the system for training effectiveness. The Army Research Institute (ARI) was tasked with the responsibility of providing a plan for determining the training effectiveness of AMTESS, and to monitor the evaluation process.

In addition to providing hardware, a secondary objective of Phase II was to provide a technique for defining a training system to meet a particular training requirement. The standard technique for establishing training programs has been to start with a training device, and try to fit the training requirements into that device. Little thought was generally given to types of devices needed, or whether a device of sorts was needed at all.

The Phase I portion of AMTESS required that a thorough front end analysis be conducted prior to designing a training device or training system. It is those techniques developed in Phase I for conducting a front analysis that will be preserved, expounded on, and delivered in Phase II as part of the system specification.

In that form, it is anticipated that the specification will serve as a guide for determining training requirements for future maintenance training situations. The outcome which should evolve will be a training program which meets specific training requirements, rather than an attempt to fit training requirements into a particular trainer.

WHAT IS AMTESS AND WHAT IS IT SUPPOSED TO DO?

The requirements for AMTESS are extremely comprehensive. Since the system is envisioned as the forerunner of a new direction in maintenance training, the requirements necessarily include almost every possible maintenance situation. The following are some of the required features:

- o Train analytically derived requirements.
- o Support both institutional and unit training.
- o Combine heads-on and hands-on training.
- o Be self paced and adaptive.
- o provide for automated hands-on administration of Skill Qualification Tests (SQT's).
- o Exhibit lowest cost of ownership for required level of training effectiveness.
- o Apply to a broad range of Army needs.
- o Capitalize on advanced technology developments.

The hardware and software required to accomplish those tasks must be:

- o Modular in configuration to permit ease of component interchange and custom configuration for the particular application.

- o Closed-loop in design to provide appropriate responses to student inputs and

errors, to provide instructional cues, and to record and display student performance.
- o Generic in construction to assure multiple-vendor producibility, low cost, and type classification.
- o Modifiable by Army personnel to allow easy updating to meet changes in the equipment or instruction.
- o Adaptable to a variety of instructional uses and operating environments.

The two companies (Grumman and Sevelle) awarded contracts under Phase II were selected primarily on the basis of their preliminary design from Phase I. Although both contractors were required to meet the requirements specified above, no restriction was placed on the techniques to be used to meet those requirements. In fact, divergency in technology was encouraged.

The primary factor in determining the acceptability of an AMTESS was the ability of the system to provide effective training. In evaluating the training effectiveness, if it was found that both systems were equally training effective, cost would normally then be the determining factor in selecting a system. Obviously, if one system is complex, difficult to maintain, and is costly, and the other system is less complex and lower cost, but has basically the same training effectiveness, it would be difficult to justify procuring the more costly system.

Training effectiveness evaluations will be completed in May 1981. A decision concerning system selection will be made at that time.

AMTESS was originally envisioned as a module modular system with a central core unit as shown in Figure 2. Although some of the earlier techniques, such as panelboard trainers, 3D mockups, etc., could be included in the system as add-on modules, each module would interface with the central core module. The two dimensional modules, 3D modules, and simulated test equipment would all be active elements; i.e., would respond to the trainees inputs, and provide a means of evaluating student performance.

The primary purpose of the modular concept is to allow a high degree of flexibility. With the control unit as the generic portion of the system, AMTESS can be expanded on to meet the training requirements for any system simply by adding the system peculiar modules.

As the system designs evolved from Phase II, it became apparent that three of the four designs for the central core unit were basically the same. The visual display technique was the main difference in the fourth unit. While two units employed video disc, one used video tape, the fourth unit included a random access slide projection system.

Of prime importance in the system design is the capability to modify the programs of instruction by instructor personnel. As was pointed out earlier, a significant deficiency in some of the present systems was needed for the contractor to make revisions to any programs of instruction. Even minor changes generally required that the panel board displays, as well as the software, be modified at the contractor's plant. With the recent requirement that training devices, particularly maintenance training devices, be available at the same time that the operational equipment is fielded, it is imperative that changes to the operational equipment can be incorporated into the training devices as they occur. Major configuration changes, or drastic changes to the program of instruction will require contractor modification. However, the instructors must have a certain degree of authoring capability to accommodate minor configuration and program changes.

The AMTESS which is now evolving is typically shown in Figure 3. The central core unit for this particular configuration consists of a CRT monitor which will display alphanumeric characters, still drawings and photographs, and motion pictures. Visual images are generated from a videodisc system and the computer.

The CRT will also include a touch panel capability. The present design includes a CRT/keyboard arrangement. However, this function may be incorporated into the touch panel with a projected keyboard on the CRT monitor. The touch panel keyboard will actually provide greater flexibility than the separate CRT/keyboard arrangement.

The computer provides the instructional program, interfaces with the three-dimensional module, and evaluates the trainee's performance. Much of the information associated with performance can be printed to provide a hard copy record for each trainee.

Storage will be either on a floppy disc or rigid disc, depending on the required capacity for the particular program and the personal preference of the contractor.

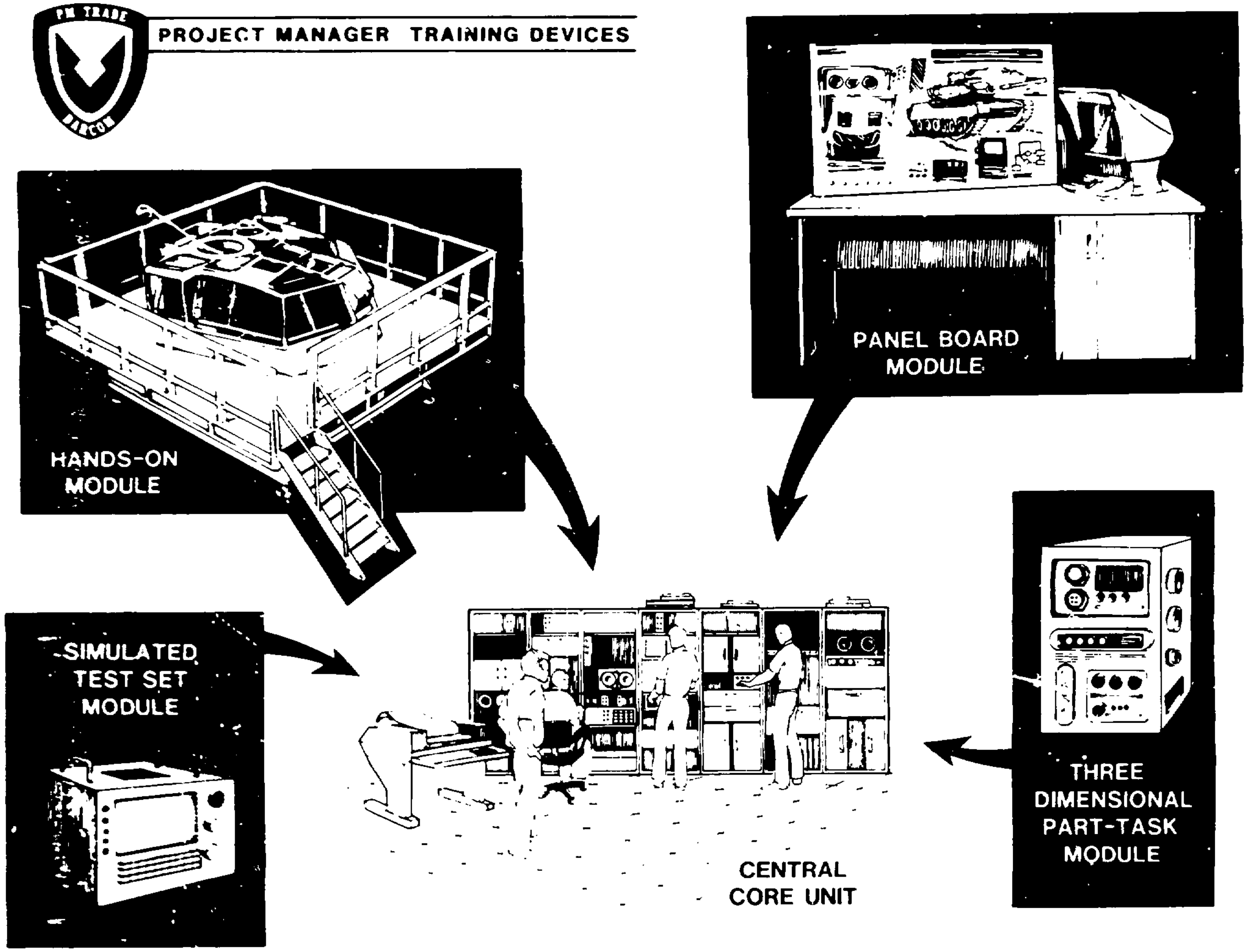
The system depicted in Figure 4 represents the configuration of an automative trainer used in engine maintenance training. The simulated engine, and the components associated with the engine interface with the core unit. In addition to engine components, simulated test equipment such as Simplified Test Equipment, Internal Combustion Engine (STEICE), multimeters, and other types of equipment can be used to produce the same readings as indicated on the operational hardware.

The second area of training which was of concern to this phase of AMTESS was the Air Defense School's radar transmitter. To teach this phase of maintenance requires only that simulated equipment for the radar shown in Figure 5 be substitute for the automotive components. In addition, the video-disc and the computer program must be replaced with the appropriate radar program.

In other less complex training situations, it may be possible to provide adequate training with the core unit through the interactive CRT.

CONCLUSION

AMTESS will not solve all the problems associated with the vast chore of providing maintenance training. However, it is an attempt to present an organized method of determining



ARMY MAINTENANCE TRAINING AND EVALUATION SIMULATION SYSTEMS (AMTESS)

Figure 2

AMTESS
CENTRAL CORE UNIT

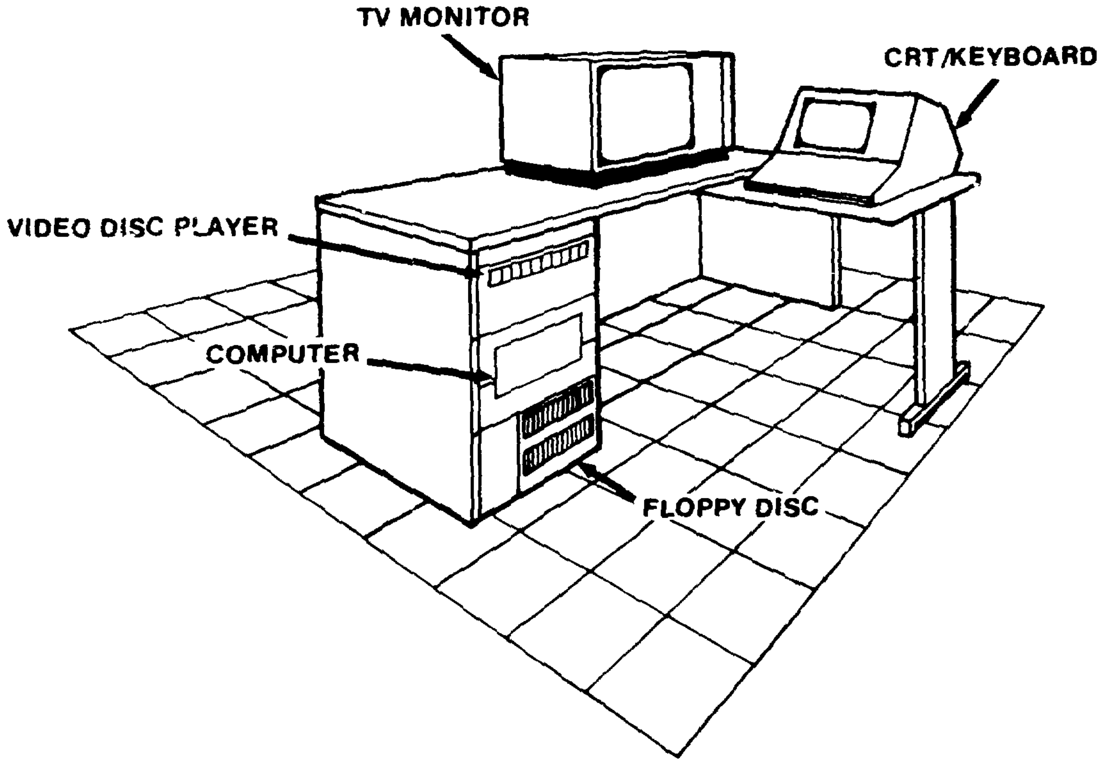


Figure 3

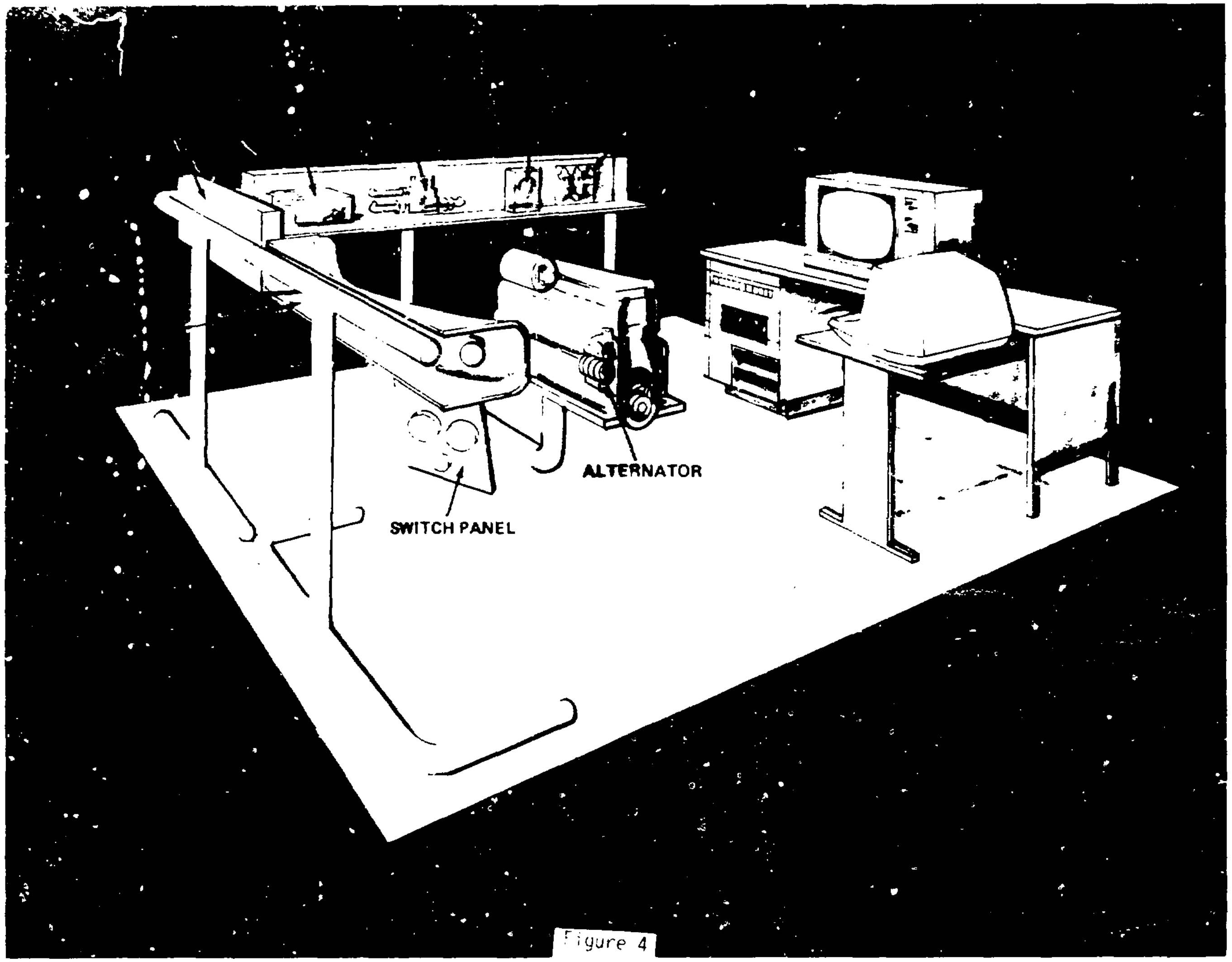


Figure 4

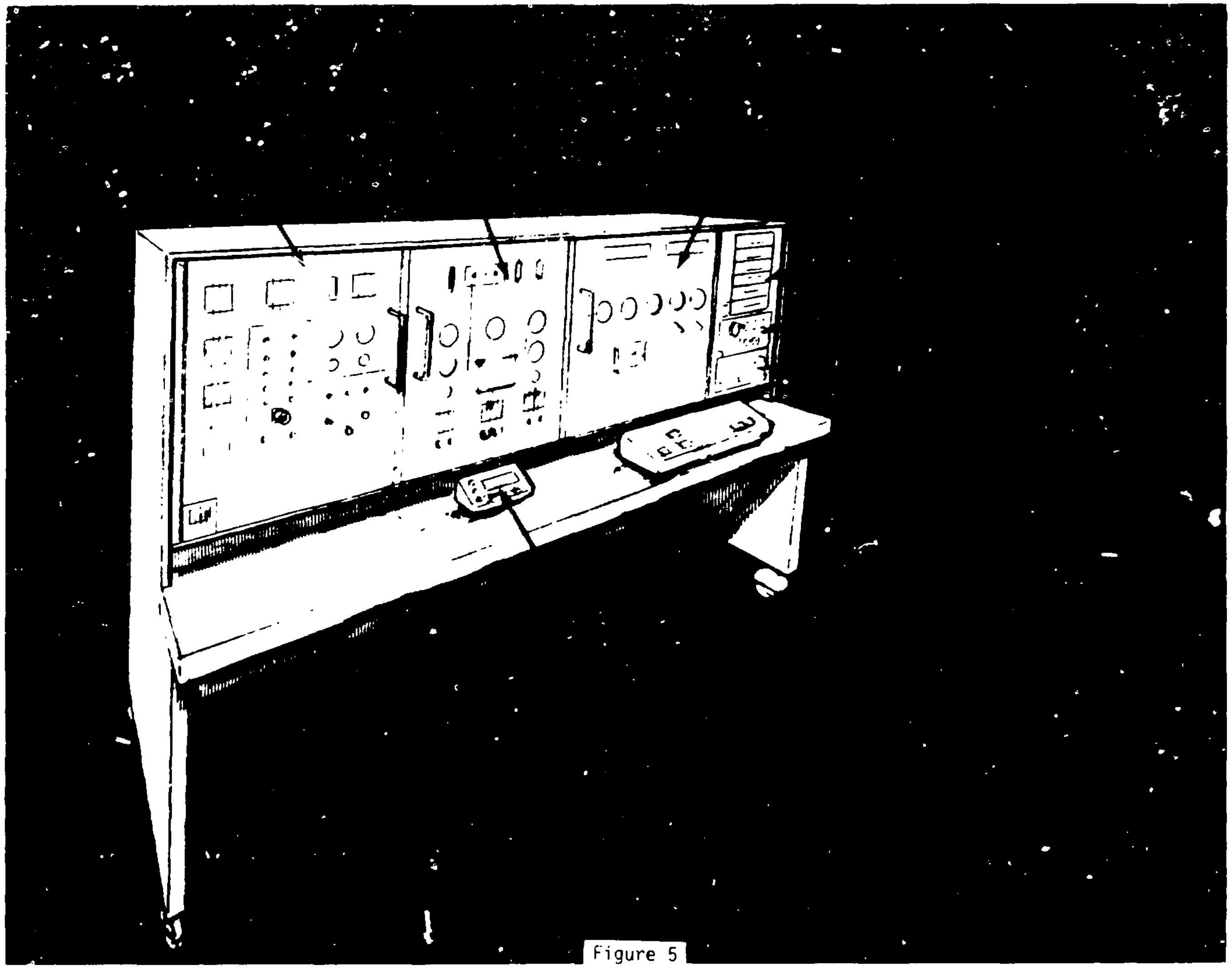


Figure 5

training needs and will provide a method of training a wide variety of maintenance tasks. in a skillful and effective manner. If this system receives universal acceptance within the Army, and eventually in the other branches of the military, two things will be accomplished. First, a means of providing efficient and effective training to maintenance personnel will be possible. Second, it will make it possible to have a base from which to build, thereby precluding the need to essentially start from scratch each time there is a requirement for a maintenance trainer. If AMTESS is successful in accomplishing these two ends, the program will be considered a success.

(*) Reduced Physical Fidelity Training Device Concepts for Army Maintenance Training, Sept. 1978.

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A PLAN FOR THE EVALUATION OF THE F-16 SIMULATED AIRCRAFT MAINTENANCE TRAINERS (SAMTs)

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ABSTRACT

A research plan was developed to evaluate the cost and training effectiveness of the F-16 SAMTs. Historically, such evaluations have been conducted by comparing the effectiveness of the simulator against that of an actual equipment trainer (AET). However, readily comparative training devices and approaches do not exist in the case of the F-16. To evaluate the training effectiveness of the SAMTs, a criterion referenced approach was selected. Students will be assessed on their ability to perform maintenance tasks, taught using the SAMTs, on actual F-16 aircraft. End-of-course measures and follow-up retention testing will be conducted. Engine, pneudraulic, electrical, and flight control system tasks will be evaluated. Task selection criteria include difficulty, criticality, and frequency of performance. Specific training capabilities of the SAMTs to be assessed include two instructional features: the malfunction insertion capability and automatic student monitoring. A comparison will be made between the performance of students trained with the malfunction insertion feature operational versus without this instructional capability. The use of the student monitoring capability will be assessed through interviews with the course instructors. A comparative approach was adopted for assessing the cost effectiveness of the SAMTs. The cost of the hypothetical AET delivery system with the same set of learning objectives as the courses the SAMTs are utilized in will be computed and compared to the SAMT delivery system. Major categories in the cost model include facilities, instructional equipment, instructional materials, personnel, and supplies.

A PLAN FOR THE EVALUATION OF THE F-16 SIMULATED AIRCRAFT MAINTENANCE TRAINERS (SAMTs)

INTRODUCTION

Traditionally, maintenance skills such as calibration, inspection, troubleshooting, and repair have been acquired using Actual Equipment Trainers (AET). However, the use of actual equipment in the training situation has not been without practical problems. These problems are well documented in the literature. Some of the problems include:

- Extremely Low Reliability. Actual equipment is sensitive and delicate and in the training situation the actual equipment can be subjected to student-induced damage. Low reliability results in low availability for training purposes.
- Low Maintainability. Traditionally, spare parts for training has had a low priority. This decreases the availability of the equipment for hands-on practice.
- Limitations. Frequently the components or units to be tested cannot be "failed" in the ways necessary to provide complete and meaningful troubleshooting practice. In addition, emergency conditions often cannot be fully practiced.

These problems, coupled with the generally high initial cost of AET, encouraged the search for a viable alternative.

Growing consideration has been given to the concept of simulation. Maintenance training simulators are expected to:

- Reduce Cost. The initial cost and the operational and maintenance costs of simulators are expected to be lower. Furthermore, a lower downtime rate means increased availability for training.
- Improve Training. Simulators should provide improved training not only through higher availability rates, but through such built-in capabilities as:
  - Automatic student monitoring.
  - Increased availability of more varied student exercises (more malfunction identification and/or correction and emergency situation problems).
  - Immediate feedback to reinforce correct responses.
  - Programmed remedial instruction with in-depth explanation of course content.
  - A trainer with built-in capabilities can function with less instructor dependency; i.e., students can engage in practice without the need for an instructor, thereby decreasing instructor demand.

With these expectations in mind, the USAF acquired a set of F-16 Simulated Aircraft Maintenance Trainers (SAMTs). The SAMTs are the first in an anticipated series of maintenance trainers for major weapons systems. As such, the SAMTs represent an opportunity to determine if the expectations of reduced cost and improved training capability have been realized. Plans for assessing the training and cost effectiveness of these simulators are described in the following sections.

APPROACH

Training effectiveness and cost effectiveness evaluations of simulators are not a new idea. Historically such evaluations are conducted by comparing the cost and training effectiveness of the simulator against the cost and training effectiveness of actual equipment trainers (AETs); i.e., in the past, readily comparative devices and training approaches have existed. This is not the case with the selected F-16 SAMTs; no F-16 AETs exist nor are there any plans to acquire AETs. In addition, because of the newness of the curriculum, there is no baseline data on past student performance and proficiency. Thus, the possibility of comparing the performance of students trained on the selected SAMTs with the performance of students who have been trained using an alternative training program or approach does not exist.

The approach used to evaluate the SAMTs, as well as the results of the evaluation, will influence the acquisition, design, utilization, and evaluation of future maintenance training simulators. The problem is to develop a practical cost and training effectiveness evaluation plan which generates accurate and useful data, given that there is no easily identifiable comparative training approach. Separate plans were devised to evaluate training and cost effectiveness.

Cost Effectiveness

The cost model developed for the current evaluation is based on a review of the most relevant information from Air Force directives and regulations and recent economic analysis publications.

Basically, a comparative approach was adopted for assessing the cost effectiveness of the SAMTs. The cost model will be used to compute simulator costs and to estimate the costs which would have been incurred with the purchase of (hypothetical) actual F-16 hardware equipment trainers. These costs will then be compared. The concern in the cost effectiveness evaluation is with comparing the costs of the two types of instructional delivery systems. The media used in each type of delivery system is only part of the cost of the system. That is, the SAMT devices and hypothetical AETs represent only a portion of the cost required to conduct the courses which use the two types of media. For example, the selection of media may influence personnel costs, facility costs, etc. Thus in conducting the cost effectiveness evaluation, consideration must be given to the total delivery system and not just to the type of instructional equipment used.

Assumptions

There will be a hypothetical AET course for each SAMT delivery system. These corresponding AET delivery systems will be designed to have have the same set of learning objectives as the corresponding SAMT delivery systems. It will be assumed that both types of delivery systems are equally training effective, although it is possible for the courses to be different with respect to the student flow, number of instructors required, facility size, instructional material, and supplies. This approach has several advantages:

- Any other assumptions of AET training effectiveness would have to be based on subjective judgment.
- This approach allows the two competing delivery systems to be compared purely on costs.
- The assumption of equal training effectiveness makes only two results possible:
  - Equal benefits and equal costs.
  - Equal benefits and unequal costs.
- There is some evidence in the literature that support the assumption of equal training effectiveness between the two delivery systems.

Another assumption is that the economic life of the SAMTs is identical to their physical life (15 years). Additionally, the economic life of the AETs will also be assumed to be 15 years.

Finally, it is assumed that the SAMTs and AETs are fixed equipment, and that the variable equipment required by each delivery system are identical.

Cost Categories and Features

The cost model developed for use in the F-16 SAMT evaluation effort has the following major cost categories:

- Facility costs.
- Instructional equipment costs.
- Instructional materials costs.
- Personnel costs (cost of salaries and benefits to instructors and students).
- Supply costs.
- Miscellaneous costs.

Each of the major cost factors or categories is subdivided into associated costs. These subfactors define the costs that compose the major cost factor. Subfactors may reflect cost areas such as acquisition, operation, and maintenance. These subfactors are further divided corresponding to the cost area (for example, equipment acquisition costs can be further separated into procurement, shipping, and installation costs).

Although the cost model was compiled specifically for this project, it is general in nature and can be applied to the costing of other types of delivery systems. The cost model has the following features:

- It considers research and development costs as sunk costs.
- It uses the present value cost concept to account for differential cash flow patterns between the competing delivery system. The present value cost method is used to account for possible differences in cash flow for each year of the comparison period for each delivery system being compared.
- It separates implementation costs from the costs incurred in subsequent years.
- It divides the instructional equipment cost category into types of equipment: Fixed Equipment and Variable Equipment.
- It is comprehensive in its list of subfactor costs; i.e., it includes all relevant cost categories and subcategories for training systems.
- It considers the costs associated with updating:
  - The instructional equipment (SAMTs and AET).
  - The instructional features software/courseware.
  - All types of instructional materials.

- It allows for removing from the present value cost, the remaining value of the following at the end of the comparison period:
  - Facilities.
  - Instructional Materials.
  - Instructional Equipment.
- It separates the utility costs required to operate the facility from the utility costs required to operate the fixed equipment (simulator and AET).

Comparing Costs. The present value cost less the remaining value of instruction materials, equipment and facilities will be compared. In addition to comparing the total costs of each delivery system, the following analyses will be made:

- A comparison of the implementation costs of both types of delivery systems. It is expected that one type of delivery system will require more front-end money than the other.
- The costs of the SAMT delivery systems will be compared. It will be of interest to note which SAMT configurations have the highest and lowest costs.
- The major contributing costs within each delivery system will be examined. Are these major contributing costs the same as those for the SAMT delivery system?
- For each corresponding delivery system, accumulative costs per student will be graphed. If the two types of corresponding delivery systems are different (by 10 percent), then a break-even point in student flow will be calculated. This will allow managers to "see" how many students would be trained by the lower cost delivery system for the same cost as the highest cost delivery system.
- For each corresponding delivery system, accumulative costs per operating hour will be graphed. If the two types of corresponding delivery systems are different (by 10 percent), then a break-even point in operating hours will be calculated.
- Within the SAMT delivery system, the costs of the instructional features will be compared.

It is anticipated that the above comparisons will assist the Air Force in determining the cost/benefit derived from both AET and SAMT type delivery systems. Furthermore, it will provide some insight into the cost of the instructional features under study.

Training Effectiveness

A criterion referenced evaluation will be conducted. Basically, this technique consists of evaluating students on their ability to perform the tasks (objectives) presented in the course, after they have been exposed to the training. If, after training, the trainees can perform what the course was designed to impart, then the training can be judged successful or effective. This training effectiveness study is designed to determine if the graduates of F-16 maintenance training programs (which employ SAMTs) can attain criterion on the learning objectives specified in the course documents.

Rationale for Selection of Approach. There are three strong reasons for selecting a criterion referenced assessment approach. First, the absence of F-16 hardware trainers, with the exception of the F-100 engine AET utilized in F-15 maintenance training (the F-15 and F-16 engines are highly similar), prohibits the adoption of a comparative approach in which the effectivenss of a simulator can be gauged against the effectiveness of an AET.

Although no AET is available, the F-16 maintenance courses were designed to be taught with either the SAMTs or on actual aircraft. This would provide a reasonable basis for a comparative study. The effectiveness of the SAMTs and the effectiveness of the actual aircraft could be assessed and these alternative training approaches compared with a high degree of confidence. In fact, the design of such a comparative study would maximize experimental control (i.e., many of the sources of extraneous variance in the dependent measures could be easily controlled). This degree of control would increase the likelihood that any observed difference in student performance could be attributed solely to the SAMTs, since both courses would be identical except for the use of the aircraft. However, this approach raises the following issues:

- It is, perhaps, unreasonable to expect the Air Force to teach five courses using only the aircraft. The logistics problems (for example, dedicating aircraft purely for training) could be overcome, but the problems of guaranteeing that the same instructor teach both groups, that the courses remain identical to the SAMT courses (except for the use of the aircraft), and other such similar problems may be viewed by the FTD as an unacceptable and costly burden.
- It is highly unlikely that the courses (using just the aircraft) have been taught before. This means that any comparative study would be "loaded" in favor of the SAMTs since part of the variance in the comparative dependent measures would be the "newness" of using the aircraft in the courses (particularly when the instructor would be accustomed to using the SAMTs).

Therefore, a second major reason for selecting a criterion referenced approach is that it requires less manipulation of the existing training environment, as opposed to the demands of conducting a comparative study.

The third reason for selecting the criterion referenud approach is to best meet the project objective for development of a general assessment model. While the Air Force will undoubtedly continue to purchase some AET, it is unlikely that there will be much opportunity for comparative studies in the future.

Because of these reasons, a criterion referenced approach was selected. This is not to imply, however, that a criterion referenced approach is easier to conduct or without research design problems.

Disadvantages of Criterion Referenced Approach. In a criterion referenced approach, isolating the contribution due to the SAMTs is much more difficult than in a comparative approach. The SAMTs are not used in isolation. The training objectives are achieved in a variety of ways, and it is important that the evaluation methodology accurately separate the contribution of the SAMTs in achieving the objectives from the contribution made by the other course media and methods (videotapes, slides, aircraft, and OJT experiences). A comparative study would be much easier to conduct from this perspective than a criterion referenced assessment.

A second difficulty is that the criterion referenced approach requires clearly stated course objectives. The learning objectives appearing in the F-16 course control documents (CCDs) are terminal objectives. For the most part they are skill or performance-oriented; critical enabling objectives (locating or naming parts) are not identified. Also, some of the objectives require amplification or clarification by instructors. Finally, some of the terminal objectives listed in the CCDs may not match what is expected on the job. The evaluation methodology must validate the stated course objectives and proficiency levels, and verify their consistency with actual job requirements and expectations of field supervisors. Validation is needed since it is possible that the tasks are not longer performed in the same manner.

One final drawback of the criterion referenced approach is that it does not result in direct comparative information. That is, it will not be possible to state that the SAMT training program is better or worse than some other training approach, only whether or not the SAMTs adequately train personnel to meet the stated course objectives.

Explanation of Design. In a criterion referenced approach, the main concern is whether or not the students can perform as expected. (Did the students reach the stated course objectives?) In the present case this question is moderated in the following way: Can students perform as expected, and how much of their performance is due to the SAMTS? The answer to this question can be found by using the following basic research design:

$$X \quad [O_{w1}, O_{w2}, \ldots, O_{wn}] \quad O_1$$

where X denotes the course, O_{wi} within-course measures (to isolate the effects of other media), and O_1 denotes the dependent performance measure taken immediately following the course. (Since the use of various media within the course is fairly well blocked--generally only one type of media is used within an instructional segment and the courses typically call for a written within-course exam at the end of each block--it should be possible to segregate the effects of these other media through the use of within-course measures, administered at the end of each instructional block as needed.)

In order to assess how well students retain their training, a follow-up measure is taken several weeks following the end of the course. The design then becomes:

$$X \quad [O_{w1}, O_{w2}, \ldots, O_{wn}] \quad O_1 \quad O_2$$

Some degree of comparison is possible in the research study. The evaluation of the malfunction insertion capability will involve having the instructors teach some classes with the instructional feature operational and other classes with the capability turned off. The performance of these two groups of students will then be compared. The two mode design thereby assesses the malfunction insertion capability by measuring training effectiveness of the SAMT (student performance) with the feature operational, and comparing this data with training effectiveness of the SAMTs when the feature is turned off.

The automatic student monitoring feature will be assessed in a different manner. Instructors will be interviewed and asked to describe how they used the monitoring feature. This information can then be used to structure or recommend more in-depth study.

Sample

SAMTs. Not all of the F-16 SAMTs are targeted for evaluation. Trainers for the pneudraulic, electrical, flight control, and engine systems were selected. These SAMTs were chosen because they represent the range of maintenance task complexity and difficulty. Also, the selected SAMTs vary in configuration.

Each SAMT consists of at least one simulator panel set (SPS) and a master simulator control console (MSCC). The engine operation procedures SAMT is configured as a simulated cockpit.

The other SPSs are vertical flat display panels which pictorially illustrate the location and relationships of the components of each of the major aircraft systems. Both cockpit and vertical flat panel trainers are included in the study.

Also, positioned on each of the panels are simulated test equipment which provide the student with the facilities to troubleshoot simulated malfunctions to a particular location, and to simulate removal and replacement of defective components. Test set connection/disconnection, remove/replace operations and visual inspection steps consist of pushing annotated buttons.

The MSCCs are composed of a Honeywell series 6/36 mini-computer with keyboard/CRT (cathode ray tube) input-output mode, random access 35mm slide projector and hardcopy line printer. The MSCC contains the hardware and software interfaces which operate the SPSs and provides the instructional software.

The simulators are designed to be used by two students at a time. The instructor initializes the system via the MSCC, selects the lesson to be presented, and turns the simulator over to the student. The student then attempts to operate, calibrate, or troubleshoot the system with the aid of the applicable technical orders and job guides. The simulator monitors the progress of the student, administers feedback via CRT or slides, and records time and error as the student works through the problem. For the most part, the simulator responds to the student's inputs as would the actual equipment. Obviously, there are limits to the simulator responses, and these are generally constrained by the SAMT hardware.

Trainees. Maintenance trainees come from a variety of backgrounds. For the purposes of this study, only 3-levels (trainees just coming out of technical school), and 5-levels are being evaluated. Foreign students, civilians, and higher level military personnel (7- and 9-levels) are excluded.

Tasks. Training effectiveness will be evaluated primarily through assessing student performance. Performance testing will consist of observing students during fault isolation procedures, ops checks, and locate/identify drills on the aircraft (in some cases, the tasks have to be performed on the SAMT instead of the aircraft). Task protocols were developed from T.O.s and translated into checklists to be used as a basis for scoring students. These observational checklists detail, in a step-by-step fashion, the actions the trainee should execute.

For each course, a set of tasks were selected to use as a basis for evaluating student performance. Basically, two types of tasks were chosen for each course: operational checkouts (procedural tasks) and fault isolation tasks (problem-solving tasks which involve a knowledge of system logic to find the cause of an aircraft malfunction). Selection criteria included the following:

- Representative of system maintenance skills and knowledge.
- Task difficulty and length.
- Frequency of task performance on flight line.
- Support equipment, materials, and personnel requirements.
- Feasibility of installing nonfunctioning components in the aircraft to present a malfunction situation.
- Potential danger to personnel.
- Potential damage to aircraft.

Data Collection. Other data to be collected include:

- Pretraining information (student record files and profile questionnaire).
- Within-course skill/knowledge tests (currently administered by instructors at the end of instructional blocks).
- Standard end-of-course multiple choice exams.
- Instructor attitudes (questionnaire).*
- OJT log (trainee task experience record).
- OJT supervisor evaluation of student performance (questionnaire).
- Student attitudes (end-of-course and post-training questionnaires).

Method. In order to understand the sequence of data collection and testing, it is necessary to review/describe how maintenance training is conducted. First, students attend training at a technical school. Following this basic systems education, trainees are assigned to an Air Force Base and receive their in-depth aircraft system training. This is the SAMT portion of their education. SAMT course length ranges from 3 to 26 days. After successful completion of the SAMT course, trainees go to on-the-job training (OJT).

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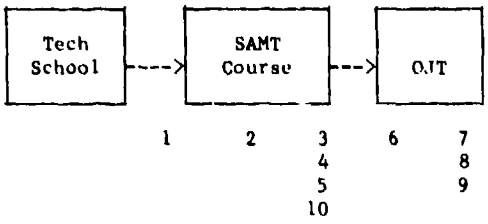
* The Instructor Attitude Questionnaire will be the vehicle for gathering information on the automatic student monitoring feature. Specifically, they will be asked to rate the utility of this feature, list strengths and weaknesses, estimate the amount of use of the feature, describe how and when they used the feature in the classroom.

The study assesses performance (and student attitudes) at the end of the SAMT course, and again approximately six weeks later. In addition to the student performance and attitude data (end-of-course and retention) measures, within-course testing (standard exams) are given. These measures should help in isolating the effects of the SAMTs from other course media. (Indeed, besides slides and overheads, some courses involve hands-on aircraft training along with SAMT exercises.) The data collection timeline is presented in Figure 1.



1. Student File Data/Profile Questionnaire
2. Within-Course Exams (written)
3. End-of-Course Exams (written)
4. Student Attitude Questionnaire (1)
5. End-of-Course Performance Measure
6. OJT Log
7. Student Attitude Questionnaire (2)
8. Retention Performance Measure
9. Supervisor Rating
10. Instructor Attitude Questionnaire

Figure 1
Sequence of Training
and Experimental Measures

Evaluation of Training Effectiveness. Of primary concern in the current study is the proportion of students trained using the SAMT who pass/fail the stated course objectives which are targeted for evaluation or assessment. More specifically, the following research hypotheses will be statistically tested:

- At least 70 percent of the students will reach the stated proficiency level on the objectives targeted for evaluation at the end of SAMT training.

- At least 70 percent of the students will reach the stated proficiency level on the objectives targeted for evaluation at the time of retention testing.

- At the end of the course, it is hypothesized that the proportion of students passing the objectives to the malfunction turned-off mode will be significantly lower than the proportion of students exposed to the malfunction turned-on mode.

- Six weeks after the SAMT training, there will be no significant difference between the proportion of students passing the stated objectives (at the stated proficiency levels) in either of the three experimental modes (malfunction ON and malfunction OFF). This hypothesis contends that any differences between the three modes at the end of training will be "washed out" by the time the retention measure is taken; i.e., the instructional feature effect will disappear.

- The proportion of students passing the stated objectives will be significantly greater after OJT than immediately after the SAMT course, provided that the OJT experience supports the training. The converse is hpothesized for those students who have OJT experience which does not support the training. The OJT log will be used to determine whether or not the OJT experience supports the training. The following rule of thumb will be used. If a student performed the task targeted for evaluation three times or less during the OJT experience, then the OJT experience will be classified as not supporting the training.

- The level of confidence reported on the student attitude questionnaire will increase between the end of training and the time of the retention measure, provided that the OJT experience supports the SAMT training. The converse is hypothesized for those students where the OJT experience does not support the training.

- Positive attitude toward the SAMTs will increase from the end of training to the time of the retention measure, provided that the OJT experience supports the training. The converse is hypothesized in those cases where the OJT does not support the training. Attitudes will be determined from the student attitude questionnaire. Positive attitude will be determined using the following rule of thumb. A perfect positive attitudes score is one in which the student indicated the maximum value for each item on the questionnaire. A perfect negative attitude score is one in which the student indicates the minimum value for each item on the questionnaire.

In addition to the above formal hypotheses, the following descriptive indices will be calculated in order to provide a more meaningful basis for interpreting the data:

- The backgrounds of students not reaching criterion at the end of training will be summarized. This summary might help to determine which type or kind of students benefit least from the SAMT type of training program.

- The average knowledge test score (in-class measure) of those students reaching and not reaching criterion will be calculated. A direct statistical comparison will not be performed, since such information adds little to the problem at hand. However, it should be realized that knowledge measures may help to interpret the performance data.

- The supervisor ratings of those students failing both the end-of-course measure and the retention measure will be calculated. These indices will be reported along with the degree to which the OJT experience supported the training in order to put the supervisory ratings in the proper perspective.

- The correlation between the supervisor ratings and both the end-of-course performance measures and the retention measures will be calculated. These correlations will assist in determining if performance measures can be predicted from supervisory ratings.

- The observational checklist of those students who do not reach criterion at the end of the course and at the time of the retention measure will be examined. The checklists will be screened for the type of errors that are made. A summary of the errors may assist trainer designers in future efforts; i.e., if possible, an attempt will be made to trace the errors to design problems, such as level of fidelity.

The results of this study will be used in a number of ways. Primarily, the results will be used to make recommendations regarding the cost and training effectiveness of simulators and associated instructional features for teaching maintenance tasks.

The Air Force SIMSPO will be in a better position to decide which features to incorporate on future trainers based on the results of this study. The cost and training effectiveness data will provide insights on how to restructure the training development process, as well as the cost/benefit tradeoffs for incrementing the simulator's capabilities in terms of instructional features.

Finally, the study will provide a model for future evaluation efforts. A handbook will be designed for the Air Force to assist individuals in designing and conducting training and/or cost effectiveness analyses of maintenance training simulators.

The approach and results of the F-16 SAMT assessment will influence the acquisition, design, utilization, and evaluation of future maintenance training simulators.

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AN INDIRECT-FIRE TERMINAL EFFECTS SIMULATOR

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ABSTRACT

This paper describes the concept development and feasibility demonstration of a man-safe cueing system for the impact of indirect fire in a simulated battlefield environment. This system provides a safe, cost-effective method for including mortar and artillery into the battlefield training/evaluation scenario for both mounted and dismounted players. This cueing system is based on a lightweight projectile having a very low impact energy and carrying a flash/bang/smoke generator. This projectile is launched from a low pressure pneumatic device that is capable of projecting the cue to ranges of 200 to 300 meters using a simple constant-mass, constant-drag projectile. A manually controlled launcher was constructed to demonstrate the feasibility of the cueing concept. A remote controlled, multiple shot launching device (providing coverage of a one kilometer diameter circle) is well within current technology. The soft-nose projectile is designed to have a terminal energy similar to that experienced during the impact of a served tennis ball. The flash, acoustic and smoke cues are tailored for player safety.

INTRODUCTION

Overview

Increased military awareness of the importance of finding cost effective methods of simulating battlefield conditions for the purpose of testing concepts and training personnel has led the U.S. Army to investigate simulation techniques for indirect fire as well as small arms and direct fire weapons. Examples of the latter are the MILES (Multiple Integrated Laser Engagement System) and the IDFSS (Infantry Direct Fire Simulation System) programs. Current technology for the simulation of indirect fire uses ground-placed flash/bang/smoke (FBS) generators, smoke bombs, referee-designated impact areas, and other techniques which detract from the realism or imperil the participants.

The Engineering Experiment Station (EES) of the Georgia Institute of Technology entered into a one year-three month research program to show the feasibility of an air launched indirect fire cue (1). The overall objective of this research was to perform an exploratory analysis of various methods to accurately and remotely place a cue of an exploding shell in a predetermined area. This cue must automatically and simultaneously deliver a triple-signature display involving a brief but intense flash of light and audible impulse, as well as the deployment of a gaseous or particulate smoke. All facets of the system were investigated with regard to minimizing their potential for causing injury to the operator, players, or observers. Attention was also given to the environmental impact resulting from the presence and use of the system.

Background

The objective evaluation of military tactics and doctrine requires scientifically controlled experiments of free play war game exercises in a simulated battlefield environment. The support for such field experiments requires a sophisticated range instrumentation and data collection system. It also requires a realistic simulation of the weapon systems (in a manner that is player safe) to preserve realism for the player elements. The U.S. Army Combat Development Experimentation Command (USACDEC) at Ft. Hunter-Liggett, California, has established a facility of this type for use with dismounted players, vehicle mounted players, and player and weapon elements that are airborne on helicopters, and combat aircraft.

Direct fire weapons have been effectively simulated at the Ft. Hunter-Liggett test range through the use of co-boresighted laser devices that are attached to the weapon barrels. These laser units trigger electronic casualty assessment devices (photocells) located on other player elements at distances consistent with the effective range of the weapon being simulated. The laser simulation system is triggered for small arms fire by the firing of a blank cartridge in the weapon. With larger weapons such as a TOW launcher or a tank gun, the event of a firing may or may not be accompanied by a simulation of the firing signature (an FBS signature from a weapons effect simulator located at the launch site). These weapon simulation systems have provided many meaningful measurements in predefined tactical situations through the range instrumentation system and data collection facility at Ft. Hunter-Liggett. The simulated battlefield scenario addresses many of the weapon systems encountered in actual battlefield situations, but it does not include a simulation and casualty assessment for indirect fire weapons (howitzers, mortars, etc.). Indirect fire weapons may be used for inflicting casualties on opposing forces or for troop suppression. Inclusion of this important area of weapon technology is highly desirable to develop a realistic and accurate simulation of a battlefield environment. The relatively high trajectory and long firing range of the indirect fire weapon class does not allow the laser illuminator to be used as it is with a direct fire system. The simulation of the indirect fire weapon may be limited to the impact signature without affecting the realism to the players since the gun position would normally be several kilometers away. This impact simulation and casualty assessment is best accompanied by a suitable simulation of a FBS cue.

The impact simulation of indirect fire weapons is an extremely difficult problem to solve in a manner that is cost effective and relatively safe to the player elements in the field. As a result, the term "simulation" is not an accurate description due to the requirements for man safety. A true simulation (normally implying a reproduction or copy of the original) is not desired due to the possibility of human injury resulting from this level of explosion. In the simulated battlefield, a more appropriate term for creating the impact signature from an indirect fire weapon is a "cue" containing the three basic FBS characteristics. Each of these cues must be tailored to provide the required player safety for the battlefield scenario employed.

Evaluation Criteria

Evaluation criteria were applied to each feasibility model design task to optimize the final recommended cueing system. The evaluation criteria were (not necessarily in order of importance):

1. Performance
2. Cost
3. Reliability
4. Safety
5. Operational Life
6. Environmental Impact
7. Ease of Manufacture.

The performance of the deliverable system is of course a function of each integral component, however, the ultimate test of performance was judged on the basis of how accurately an FBS projectile could be projected to a desired location and to what degree the FBS projectile acted as an artillery or rocket fire cue to players engaged in a simulated battlefield situation. Accuracy was determined by a circular error probable (CEP) analysis of the projectile impact locations at the maximum contract-specified range (150 meters). The definition of CEP used in conducting this analysis is taken from (2). The effectiveness of the cue was based on the ability of the FBS unit to generate an attention-gaining audio/visual event. The performance of the deliverable system and that performance which is technically possible differ due to the constraints placed upon the system by the Surgeon General's safety standards as well as cost limitations. Compliance with established safety and health regulations placed ceilings on various parameters (e.g., sound level). Other items were economically regulated. For example, the projectile could employ sophisticated microelectronic circuitry to regulate flight characteristics, timing of FBS deployment, etc., however, the transferral of as much technology as possible from the projectile to the launching device is important because the launcher is a one-time fixed cost while expendable projectiles are a recurring cost and therefore should be as economical as possible. As is usually the case, economy implies simplicity, so constraints were placed on the projectile design complexity.

Operational life and reliability are related factors which also directed the course of the design. For example, the decision to have an expendable projectile (long shelf life but short operational life) was a step toward increased reliability. Reliability was also considered in terms of launcher design since future Army goals require the launcher to operate unassisted.

The predominant risks to environmental safety as a result of using this system stem from fire hazard and toxic materials pollution. The launcher design is completely free of these risks, however, the projectile design necessitates the use of nonbiodegradable materials and minute quantities of volitile substances. Care was taken to avoid toxic materials in the construction of the projectile. Ingestion by man or animal of any part of the projectile, though unsuitable for consumption because of the physical shapes involved, would not result in poisoning (especially in the quantities present). The chance of starting a fire is remote through careful gas containment design and is further diminished by the use of nonflammable and self extinguishing materials (e.g., polycarbonate sheet (Lexan), polystyrene (Styrofoam), teflon, etc.).

Ease of manufacture was essential to provide an affordable and usable cueing system. Economy, reliability, and serviceability all stem from uncomplicated design. Not only the composition and shape of each system component, but the underlying design philosophy had to be considered before recommending a design for mass production.

FLASH/BANG/SMOKE UNIT

The flash/bang/smoke (FBS) unit contained within the projectile has been engineered to deliver a triple-signature display consisting of an intense flash of light, an acoustic impulse, and a cold particulate smoke. The respective signatures have been limited to bounds established by the Surgeon General where applicable, and where no guidelines are available, safety limits have been justified and established through experimentation and consultation with medical specialists. Fire safety has been enhanced through the use of cold ejected particulate smoke, high efficiency light generation with triple light-transmitting/heat-blocking barriers to minimize heat leakage to the environment, and encapsulated, self-extinguishing, or fire-proof projectile and FBS unit components.

The purpose of the FBS unit is to deliver a detectable cue during war games so individual players will realize that they are under indirect fire. A secondary purpose for the FBS unit is that it will in a limited sense simulate the explosion of artillery round upon inpact. The most desirable situation from a cue standpoint and a simulation standpoint would be to have the FBS unit identically simulate an actual artillery impact and yet be man safe. This is a contradiction, however, and in a war game scenario, man-safety has priority over simulated realism.

Numerous restrictions have been placed on the FBS unit in an effort to assure man safety. First, the flash should not exceed that experienced during a normal photographic flash. The exposure to acoustic impulse noise is designated by the Surgeon General of the U.S. Army (TB MED 251) not to exceed 140 dB peak impulse at the ear without the use of ear protection to be earsafe. A distance of six inches from the ear has been interpreted to specify the sound level "at the ear." This interpretation is justified (in the absence of any other guidelines) as being a reasonable estimation of what might be experienced by a player in the prone position having a cue impact on the ground beside his head. Thus, a peak level of 109 dB at 18 feet, for instance, would be nominally 140 dB at six inches. The consultants issuing TB MED 251 have designated the 140 dB peak value as being unlikely to provide hearing problems on successive applications.

The smoke associated with the FBS unit, particularly when used to cue a forward observer, must be visible at a range of one or two kilometers. A relatively dense cloud approximately two feet in diameter by four foot in height has been shown to be a minimum for two kilometer visibility (3). This nominal cloud size was the goal for this development program.

Basic Configurations

Combinations of flash, bang and smoke considered for the FBS unit included an integral flash, bang and smoke; separate flash from bang and smoke; as well as various means for producing each (e.g., electrical flash, pyrotechnic bang and chemical smoke). The success of any given technique as it relates to an FBS cue is somewhat subjective.

A commercially available Magicube camera flashbulb was adopted as an igniter and flash generator. It can be actuated by a slight impact of a small wire on the stem of the flashbulb and eliminates the need for an electrical ignition system or an impact primer system. The Magicube bulb puts out significant light with a 5500° Kelvin color temperature. The heat associated with the flash is such that it can be used to ignite pyrotechnics, thereby acting as a primer for the bang and smoke charges of the FBS unit.

The bang of the FBS indirect fire cue must be sharp enough to be heard, but not exceed on an impulse basis 140 dB peak at the ear of the player. The magnitude of this sound impulse is directly related to the rate of release of the pyrotechnic gases as well as the quantity of the gases. The release rate is a function, therefore, of the rate of escape of a sabot or the rate of rupture of a container.

Smoke is defined as a cloud of particulate material having particles between .01 microns and 100 microns of such number and concentration that the contrast between the population of these particles to nearby particulate affects visibility, light reflection and scattering. As defined, smoke may be composed of soot particles, dust particles or almost any small particulate matter suspended in the airmass. Consequently, in this program the two methods of providing smoke were to let a pyrotechnic develop the smoke during the combustion process, such as a phosphorus-oxygen type smoke, or to provide a dust material contained in a sabot which is dispensed into the air, by burning a small amount of pyrotechnic powder behind the sabot.

Tests show that pyrotechnic smoke performs better than ejected-dust smokes, however, the general fire hazard involved in a pyrotechnic smoke and the usually detrimental by-products of the burning substance which forms the smoke made pyrotechnic smokes a less desirable choice than the ejected dust for the FBS unit. In addition, ejected-dust smokes of the type of sodium bicarbonate, potassium bicarbonate and calcium carbonate are water soluable and what little dust of these types that actually gets into lung areas will be dissolved by lung fluids and subsequently be ejected with other waste material.

Bang and Smoke Ignition

Analysis indicated that the best solution to ignition of the bang and smoke section of the FBS unit was to utilize the caloric output of the Magicube (TM, Sylvania) flash generator. The zirconium oxide which is the product of combustion within the Magicube bulb boils at 5000° Kelvin. The boiling process tends to stabilize temperature and hence limits the peak temperature that is achieved. The radiating temperature is therefore 5000°, and the bulb can transfer only about one to two calories of energy into its surroudings. Ignition with this system is achieved by coating the inner faces of the Magicube bulbs (four per flash cube) with a rubber-based cement which holds an ignition compound in close proximity to the surface of the bulb for most realiable ignition. The "powdered-bulb" method of bang and smoke ignition has several advantages over others tried. In particular, realiability is increased because any one of the four flashbulbs in the Magicube can ignite the ignition compound and thereby result in detonation of the bang and smoke portion of the FBS unit. Testing of Magicubes has yielded a small number of bulbs which were defective for one reason or another, therefore, this redundant reliability factor is warranted. A further advantage is that the ignition compound burns within the plastic housing of the Magicube; this tends to minimize the chance of hot gases escaping into the atmosphere and causing a fire.

The bang and smoke section of the FBS unit is housed in a 16 gauge shotgun shell as shown in Figure 1. This portion of the FBS unit is herme-

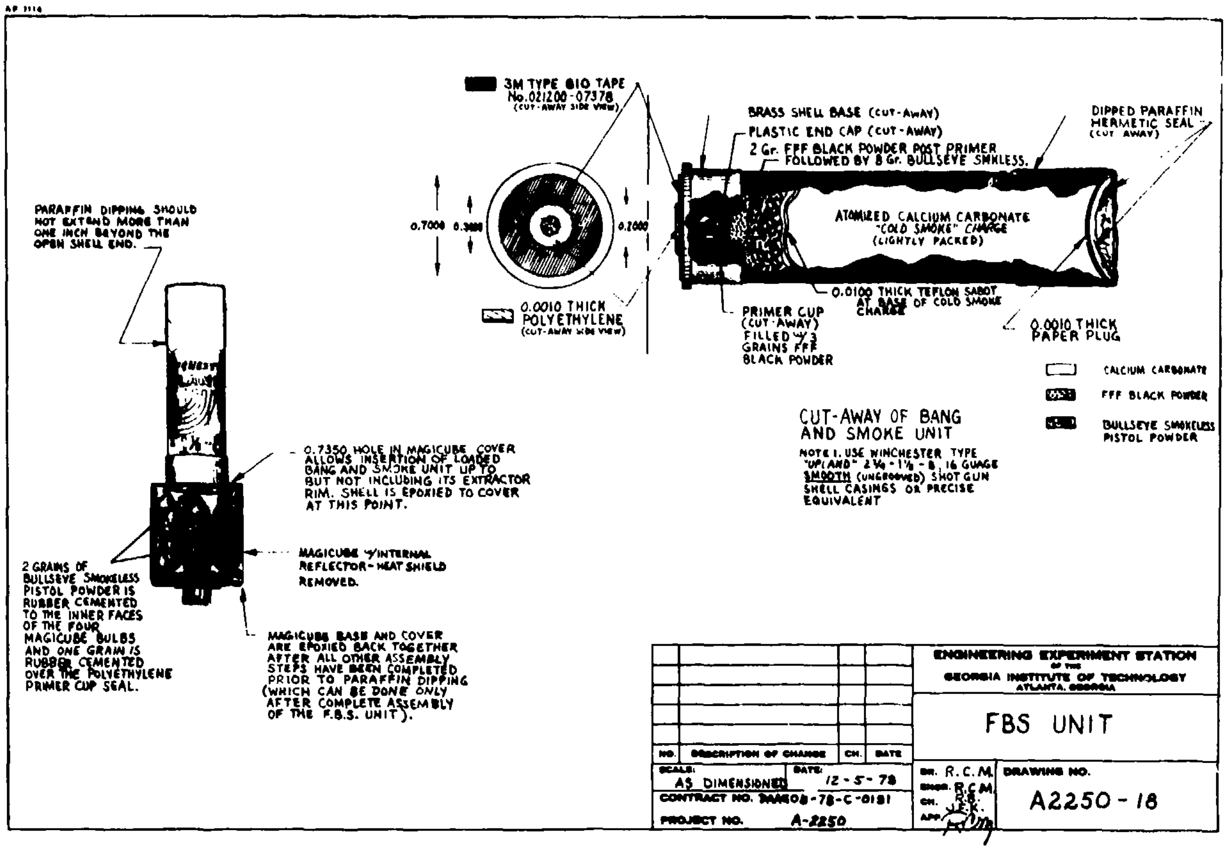

Figure 1. Flash/Bang/Smoke Unit

tically sealed since the bang and smoke charge primer is hygroscopic and the atomized calcium carbonate "cold smoke" must be moisture free for correct dispersion when deployed. As shown in the figure, the bang and smoke charge is placed through an opening in the top of the Magicube housing. Upon projectile impact, the Magicube bulbs are actuated, and this in turn ignites the ignition compound painted on the bulbs. The flash of the Magicube bulbs and the ignition compound constitutes the flash signature. The hot gasses produced by the burning of the ignition compound penetrate the hermetic seal over the primer charge on the bang and smoke unit.

These hot gases continue into the black powder shotgun shell primer causing it to flash through the flash hole in the primer cup of the shotgun shell and ignite the smokeless bang charge contained on the other side. When the smokeless bang charge detonates, it creates rapidly expanding gases which serve 1) to cause a bang and 2) to blow the calcium carbonate "cold smoke" charge out the back of the shell (and through the weak polystyrene tail section of the projectile), thereby deploying the smoke signature. Since the smoke is a cold smoke, the fire hazard is diminished. The rapidly expanding gases which drive the smoke charge out cool quickly and are dissipated upon reaching the atmosphere. The calcium carbonate also serves to lessen the chances of fire by acting as a chemical fire extinguisher. The FBS unit is doubly shielded against fire hazard by confining the hot gases evolved during ignition to the inner Magicube plastic housing and the outer flash housing of the feasibility model projectile fuselage (to be discussed).

Empirical Findings About the FBS Unit

Many firings of the feasibility model FBS unit were made both in the projectile and on a test stand. Each time an FBS unit was ignited, it was rated as to its effectiveness as a cue. The flash intensity is sufficient to be seen at a 200 meter range in bright sunlight. The flash of the FBS unit is striking in low light level conditions such as night, early evening or an extremely overcast day; in very bright sunlight conditions, a projectile landing some distance from an individual would not necessarily catch his attention via the flash unless it happened to fall within his direct field of vision.

The deployed smoke cloud produced by the ejected calcium carbonate is quite noticeable at a 200 meter range immediately after it is deployed (while the cloud has a cross sectional dimension of 1 square meter). Under calm wind conditions, the cloud is still entirely visible and stands out against its background when it has bloomed to a two square meter cross sectional area. This cross section is about maximum for the "cold smoke" cloud. Beyond this cross sectional area, the cloud begins to fade. In addition, wind will tend to disperse the cloud, particularly if the wind is turbulent. The cloud produced by the feasibility model FBS unit should be entirely useable by forward observers with a clear field of view up to 300 meters. Larger and more visible smoke clouds can be produced by combustion techniques within the same projectile delivery system, but are less player safe and present a greater fire hazard.

The sound level of the FBS unit is on the order of 108 dB (measured 3 meters from the point of impact). At a range of 200 meters, the FBS unit is clearly audible, though at this range the presence of any ambient noise in close proximity to the player (e.g., truck motor, gunfire, close talking) may totally obscure the sound signature of the FBS unit.

The deployment of an FBS unit at a range of 200 meters is adequate to cue a player engaged in a war game to the presence of incoming indirect fire. The effect is greatly enhanced if the cues are dropping within 100 meters of the players. Certain features in the FBS unit could be improved if the man safety requirements were to be less restrictive. A smoke cloud visible at 2 kilometers is well within reason if a pyrotechnic rather than cold ejected smoke could be used. A bang in excess of 108 dB is easily achieveable, and would result in a more noticeable cue for projectiles dropped at maximum range from a war game player. The flash intensity is the one item that is difficult to increase safely. The safety concern is not one of man safety but of fire safety. Since the eye has a logarithmic response merely doubling the flash intensity does not have a profound effect. The flash intensity would have to be increased by a factor of eight or sixteen to make a significant difference. A pyrotechnic flash would have to be used to achieve this level of intensity with the current feasibility model projectile. Some question exists as to whether the hot gases associated with such a flash could be easily contained within the flash housing of the projectile.

PROJECTILE

The basic design of the projectile for the indirect fire simulator/cue depended upon two performance factors; flight stability and man safety from the standpoint of impact blunt trauma to an individual. Tests were performed on a baseline projectile to determine its flight characteristics. This baseline projectile was a simple cylindrical object with an ogive nose section. Wind tunnel tests were used to determine the stability of the projectile in terms of roll, pitch, yaw, and effects of drag in the air mass.

Man safety of the projectile impact is directly related to impact momentum. Impact momentum (P) is a function of impact velocity (V) and projectile mass (M).

$$P = MV$$

One must reduce either the impact velocity, the projectile mass, or both to reduce the impact momentum.

A possible scheme to reduce the impact velocity is to use a variable drag technique, which employs air brakes that are deployed late into the flight of the projectile so as to achieve maximum range with a low drag profile and then, at a predetermined point in the flight, increase the drag to significantly reduce projectile velocity.

Another method to reach maximum range with minimum impact momentum is through the use of a variable mass projectile. A variable mass projectile can jettison mass during flight. A convenient source of discardable mass is fluid; however, powders and even gases can be allowed to escape. One possible mode of operation involves the use of a pressurized gas compartment and a fluid filled compartment within the projectile which are separated by a flexible balloon-like diaphram. The fluid compartment is vented to the outside through a narrow tube leading to the aft portion of the projectile. Upon launch, fluid is forced through the orifice at the end of the projectile by the expanding pressurized gas compartment acting through the flexible diaphram. Mass is therefore continually lost by the projectile throughout the flight. By careful timing of the fluid release, the projectile can be made to achieve the maximum desired range by the time the entire fluid charge has been expended. The projectile then falls to the ground with a mass that is significantly less than the launch mass, thereby imparting less momentum to any object that it strikes. Combinations of variable mass and variable drag are also possible. Both the variable mass and variable drag concepts are valid methods for reducing impact momentum, but the complexity and cost of the projectile is increased, while the timing of these final momentum-reducing schemes introduces an additional source of error into the launch system.

A constant mass projectile is one having a final impact mass that is the same as its launch mass, and a final velocity that is proportional to its launch velocity (where the constant of proportionality relates to the aerodynamic drag coefficient of the projectile shape). In any of the projectile configurations mentioned, terminal momentum must be low enough to allow impact upon an individual without causing bodily harm. (Note however that harm to an individual is possible by any practical projectile regardless of configuration if the impact is sustained upon certain areas of the body (e.g., eyes)). One major advantage of a constant mass projectile arises from its inherent reliability. Both variable mass and variable drag schemes could fail to deploy their final momentum-reducing mechanisms after launch, resulting in an unsafe impact momentum. Such a condition cannot occur with a man-safe constant mass projectile.

Constant Mass Final Velocity Tests and Man Safety

Early in the development of the pneumatic launcher, reuseable constant mass non-variable drag balsa wood test projectiles were used to test the launcher. These projectiles weighed anywhere from two to five ounces. When conducting tests at the 150 to 200 meter range, technicians standing nearby noted that the impact velocity of the projectile appeared sufficiently slow such that they were willing to try to catch them in midflight. Final velocity tests were then conducted to determine the man safety of the projectile if neither variable mass nor variable drag techniques were employed.

Three basic tests were performed to assess the final velocity of the projectiles. First, a projectile with a calibrated momentum sensor was used to measure the terminal momentum and hence velocity in situ. A second method involved high speed photography of the projectile upon impact, and the third, a standard police radar was used to measure the velocity just prior to impact.

All three methods yielded corresponding final velocity information. For the feasibility model projectile, the measured final velocity was on the order of 64 kph upon impact. Other objects were investigated that might also have a 64 kph impact velocity to obtain a feel for the damage that might be incurred by a human struck by such a projectile. In particular, a tennis serve was studied because the weight of a tennis ball was within grams of the feasibility model projectile, and therefore, would be a good indicator. Using the police radar, a tennis ball was served numerous times directly at the radar antenna. Spectrum analysis showed that the tennis serve also yielded a velocity of approximately 64 kph. This means that the danger of human damage due to a strike by the feasibility model projectile would correspond to that expected of a strike by a tennis ball being served. Various other sports activities were found to involve greater danger of damage due to strikes by the playing implements. For example, a fly baseball presents a greater danger to an outfielder than does the feasibility model projectile.

After reducing the impact momentum data and finding that the final velocity was 64 kph for the feasibility model projectile, the technicians were allowed to attempt to catch dummy projectiles in flight. The picture sequence in Figure 2 shows one such successful catch.

Figure 2. Impact Safety Demonstration

The Feasibility Model Constant Mass Projectile

Once it was demonstrated that projectiles were relatively impact safe to humans, a decision was made that variable drag and variable mass techniques would not be necessary to achieve the contract goals since constant mass projectiles could be launched to ranges in excess of 200 meters and still be man safe from an impact standpoint.

Figure 3 shows the components used to construct the feasibility model projectile. These components include a polystyrene tail section, rubber hemispherial nose section, two piece epoxy arming mechanism and guide mechanism, and Lexan flash housing. Each of these components was carefully designed as to size and weight to result in a feasibility model projectile of precise center of gravity and mass. The tail section is made from fused polystyrene beads. A smooth finish and a rough finish is possible depending on the size beads used in the manufacturing. Polystyrene beads that will result in a rough finish for the tail section are necessary because minor turbulance is formed over the surface of the tail section to break the laminar air flow in much the same way that the dimples on a golfball provide stability by breaking the laminar flow. The minor turbulance causes an increased drag in the tail section which results in projectile stability by assuring a greater side drag behind the center of gravity than in front. All portions of the projectile from the tail section forward must be kept as smooth as possible for the stabilizing effect of the rough tail section to be effective.

The Lexan flash housing is made of 10 mil Lexan tubing. Lexan was chosen as a flash housing material because it is self-extinguishing and does not shatter during impact. The use of Lexan assures that there will be no shrapnel upon impact and also prevents the high temperature gases evolved within the FBS unit from burning through to the outside.

The arming mechanism has four firing pins which are forced up through the base of the FBS unit upon impact, and result in FBS unit ignition. In the unarmed position, these pins are physically misaligned with the FBS unit ignition system. When placed in the armed position by manually rotating the arming mechanism relative to the projectile fuselage, the pins are aligned with holes in the base of the FBS unit, thereby allowing a forward impact to force the firing pins into the holes causing FBS unit detona-

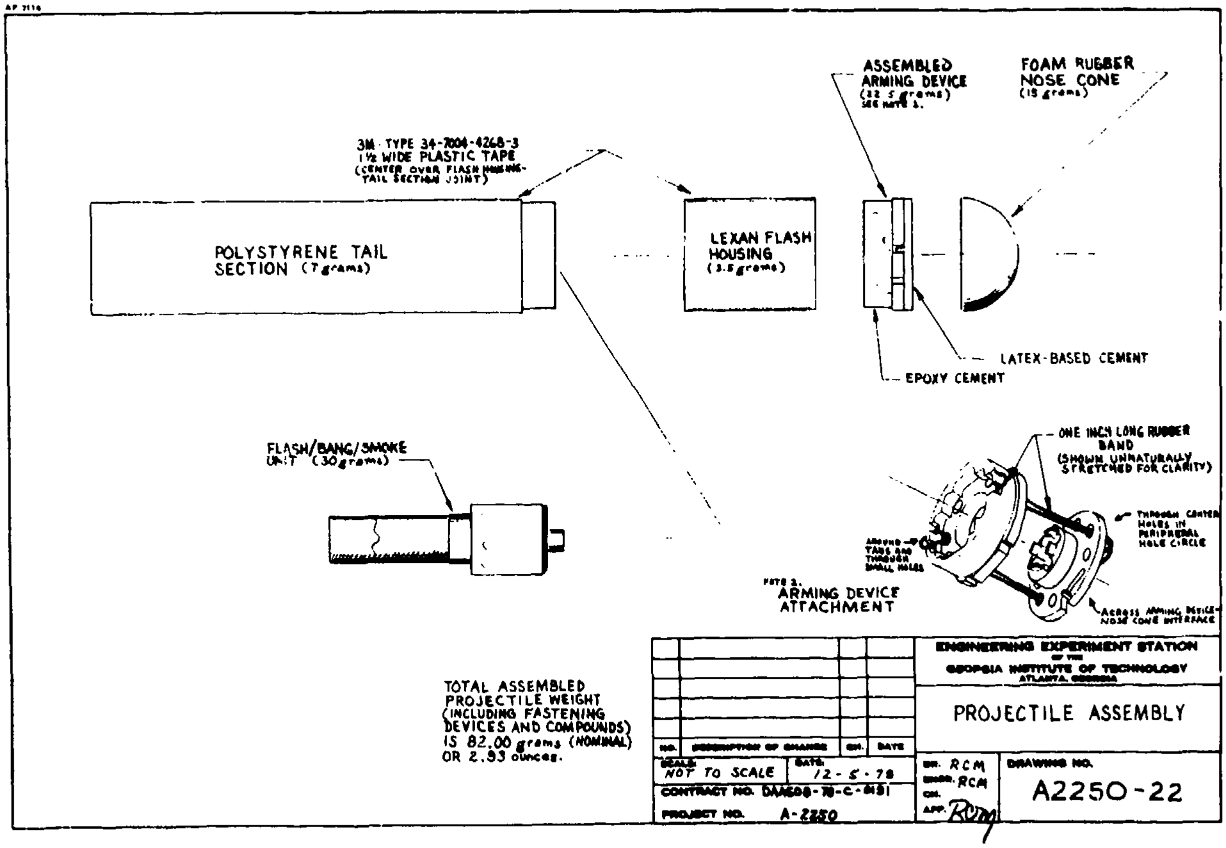

Figure 3. Projectile Assembly

tion. Tests have shown that an unarmed projectile can be handled rather roughly and even dropped without danger of igniting the FBS unit; however, when armed, dropping of the projectile on the nose from a height of as little as 1 foot can set off the FBS unit.

The nose cone of the feasibility model projectile is hemispherical, and is made of a foam rubber compound. This nose cone adds the weight necessary to bring the center of gravity to the very front of the flash housing. From an aerodynamic standpoint the hemispherical nose shape is a 73% drag improvement over a simple flat ended projectile nose. A fully assembled feasibility model projectile is shown in Figure 4.

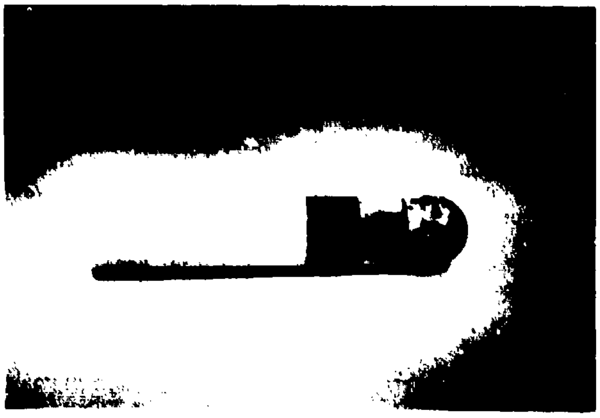

Figure 4. Final Feasibility Model Projectile With FBS Unit

PNEUMATIC LAUNCHER

Early attempts to test a pneumatic launcher employed a freon tank, a two inch brass ball valve, and a length of Polyvinal Chloride (PVC) plastic pipe, as shown in Figure 5a. Figures 5b through 5d show the pneumatic launcher that was ultimately developed. Figure 6 identifies the major components which comprise this feasibility model pneumatic launcher. It operates on the pneumatic principle of a blow gun using vaporized liquid CO_2 as a propellant. An explosive flapper valve is used to transfer pressurized CO_2 gas from an intermediate holding reservoir to the barrel of the launcher in which a projectile has been placed. The expanding CO_2 gas is capable of ejecting a two to three ounce projectile from the barrel and hurling it in excess of 200 meters using CO_2 reservoir pressures as low as 30 psig (see Figure 7).

Valve Considerations and Pressure Rise Time Within the Barrel

The early pneumatic launcher used a large diameter ball valve which was activated through a spring mechanism to achieve as fast an opening as possible. After extensive testing, data showed that at higher pressures increased range was not appreciable. Analysis indicated that the valve opening speed played an important role in achieving maximum range at these higher pressures due to the pressure rise time within the barrel. When the valve is initially opened, the pressure in the reservoir begins to drop, and the pressure within the barrel behind the projectile begins to rise. Immediately upon overcoming static friction, the projectile moves down the barrel in front of the increasing pressure wave front. Tests involving the ball valve and high pressures, demonstrated that the projectile could move down the barrel and, in fact, leave the barrel before the complete build-up of barrel pressure had taken place. As reservoir pressure was increased beyond this point, it had little effect because the pressure front could not fully transfer its energy to the projectile once the projectile had cleared the end of the barrel.

An improved valve design emerged wherein a flapper valve was used to explosively transfer pressure from the reservoir to the barrel. A significant increase in performance was immediately noticed. By using the pressure in the reservoir to blast the valve open, it was possible to obtain a reservoir-to-barrel pressure transfer in much less time than previously achievable with the ball valve/spring arrangement. The pressure in the barrel could reach a maximum before the projectile left the end of the barrel; therefore, up to 30 psig, most of the pressure stored in the reservoir could be applied to the projectile. If pressure were to be increased beyond 30 psig a limit would be reached where the reservoir pressure transfer time would exceed the projectile time-in-barrel. Other higher speed valve configurations, such as exploding diaphrams, are possible; however, these devices are not reusable and would not be suitable for automated operation of the launcher.

Muzzle Brake

A muzzle brake was designed for use with the pneumatic launcher. The purpose of this break was to minimize the effect of diffracting air currents passing from the barrel into the atmosphere. If allowed to go unchecked, these diffracting air currents can deflect the tail of the projectile as it clears the end of the barrel (high speed motion pictures of test projectiles leaving the barrel without the muzzle brake have visually confirmed this deflection). These initial tail deflections result in undesired trajectory perturbations. Placement of parallel plates at the end of the barrel which have holes that are slightly larger than the inner barrel diameter passing through the center of each plate, allows the projectile to move from the barrel, through the plates, and into the atmosphere under the direct force of the planar pressure front that drives the projectile up the barrel. Any pressure wave fronts which are off-axis impinge upon the parallel plates and are redirected perpendicular to the flow direction of the main wave front. Several plates were employed to increase the efficiency of the muzzle brake (see Figure 5e). Photographic, CEP, and range data analyses all confirmed the effectiveness of the muzzle brake.

The Creation of the Air Bearing

During launch, the pressure front formed behind the projectile forces it down the barrel. Initially, there is contact between the

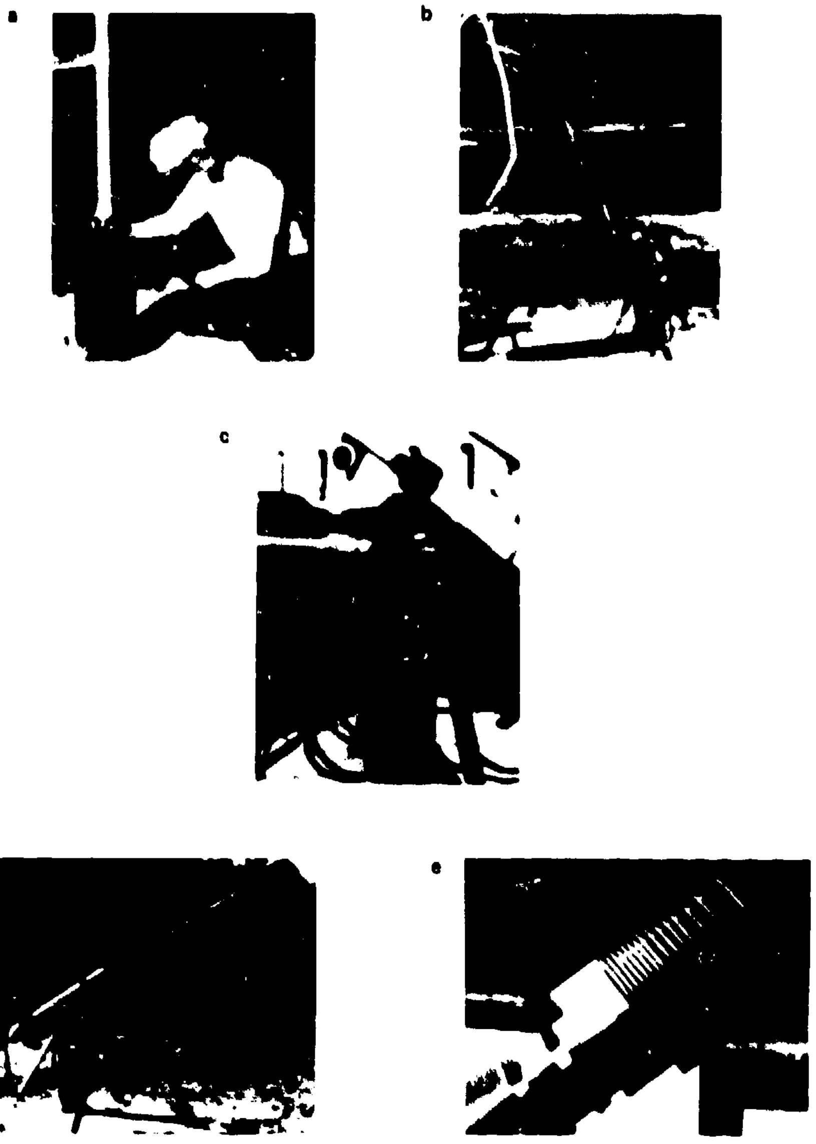

Figure 5. Pneumatic Launcher

projectile and the barrel. As the projectile begins to move down the barrel, however, it rides on a cushion of air as the pressure from behind escapes along the narrow projectile/barrel-wall interface. This air bearing is not formed at low launch pressures (e.g., five psig). Only when the launch pressure is of sufficient magnitude to force gas past the projectile, does the air bearing form. The movement of the projectile can also enhance the formation of the air bearing. There is a point at which the projectile will begin to move up the barrel at low pressures (after having overcome static friction) while maintaining significant barrel contact. After obtaining a certain barrel velocity at these low pressures, leakage occurs around the projectile which eventually forms an air bearing. The production of the air bearing is essential for efficient operation of the pneumatic launcher. Best results are achieved at pressures above 8 psig due to the formation of the air bearing. Short range launches are therefore best achieved through the increase of quadrant elevation, rather than the continual decrease in reservoir pressure.

Wide Area Coverage Considerations

Consideration was given to the question of maximum range attainable versus launcher cost. Either a single launcher must be capable of 360° operation at a range sufficient to cover an area, or a number of shorter range 360°-operable launchers must be employed in a matrix to achieve maximum coverage of a given area. Figure 8 shows the geometry used to determine the spacing of

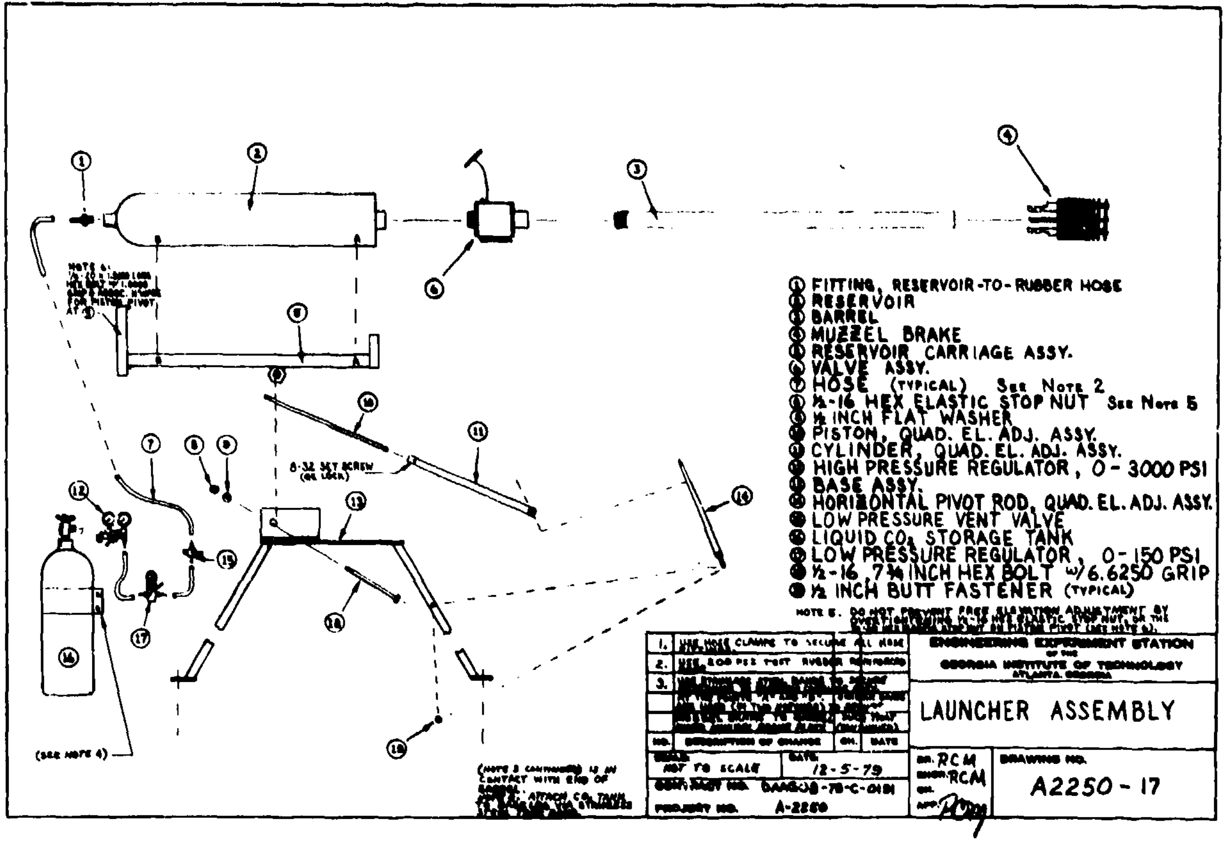

Figure 6. Launcher Assembly

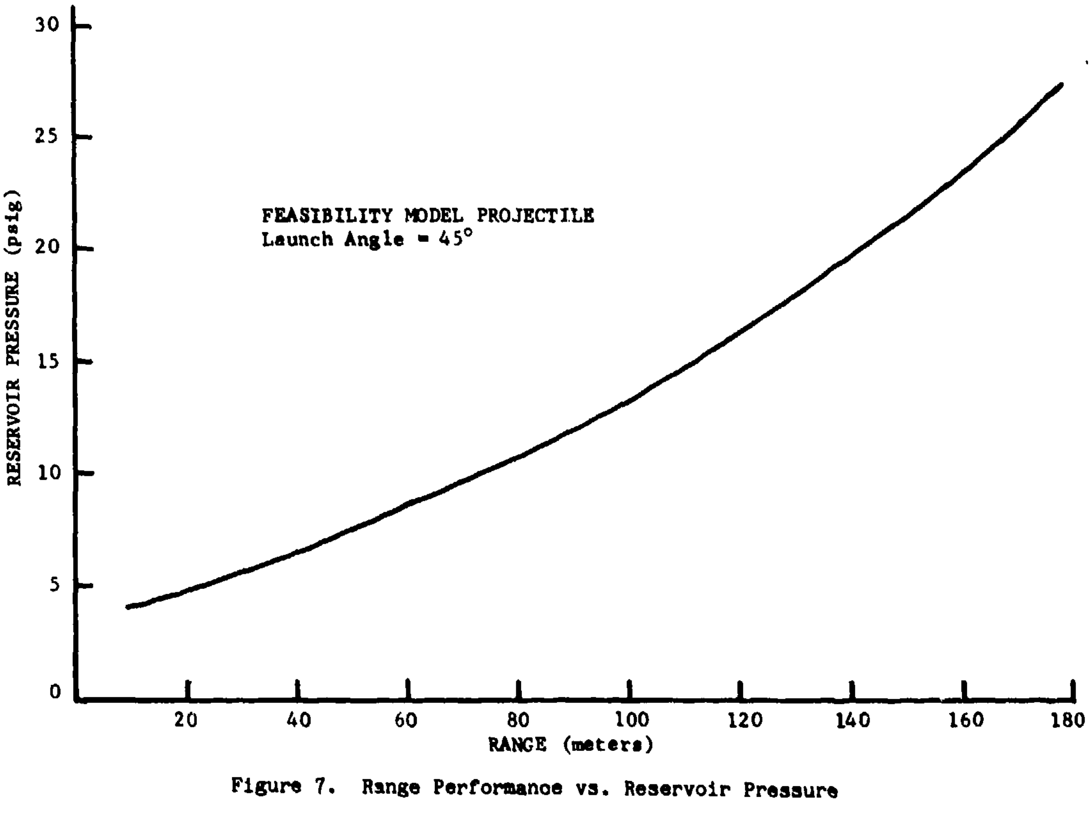

Figure 7. Range Performance vs. Reservoir Pressure

launchers of a maximum launch range (R) within the matrix. The separation (D) necessary for these launchers is related to the maximum range of the launcher by the curve shown in the graph of Figure 8. Note that this curve is exponential and that the average number of launchers decreases drastically as range capability is increased. Currently the feasibility model launcher can attain a maximum range of approximately 200 meters using reservoir pressures that do not exceed 30 psig. Additional research will be necessary to determine if significantly greater ranges can be achieved through either launcher modification (e.g., increased reservoir pressure or advanced valve design) or modification of the feasibility model projectile (computer simulations have recently shown that maximum launch ranges of 500 meters (1 km circular coverage) are possible using increased launch pressures coupled with a reduced diameter projectile that has a launch weight two and one half times greater than that of the feasibility model projectile. Verification of these computer simulated results is forthcoming). A performance constraint is placed on the maximum achievable range however. As the maximum range capability of the launcher is increased, so is the projectile time-of-flight. The projectile trajectory is subject to wind-induced perturbations as long as the projectile is in flight, and therefore the CEP of the indirect fire cueing system will degrade with increased range capability.

Man-Safety Aspects of the Launcher

Since the launcher normally achieves muzzle velocities on the order of 145 to 160 kph (see Figure 9), care should be taken to avoid direct impact by the projectile at point blank range since the projectile is moving at its highest velocity immediately after leaving the barrel of the launcher. Use of the feasibility model requires only that operators and onlookers remain out of the field directly in front of the muzzle. All other aspects of the launcher are man-safe. The propellant used is carbon dioxide, and the amount expelled per shot is not significant when expulsion is into the open atmosphere. The sound level of a launch is about 98 dB as measured three meters in front of the launcher and is well within the Surgeon General's guidelines.

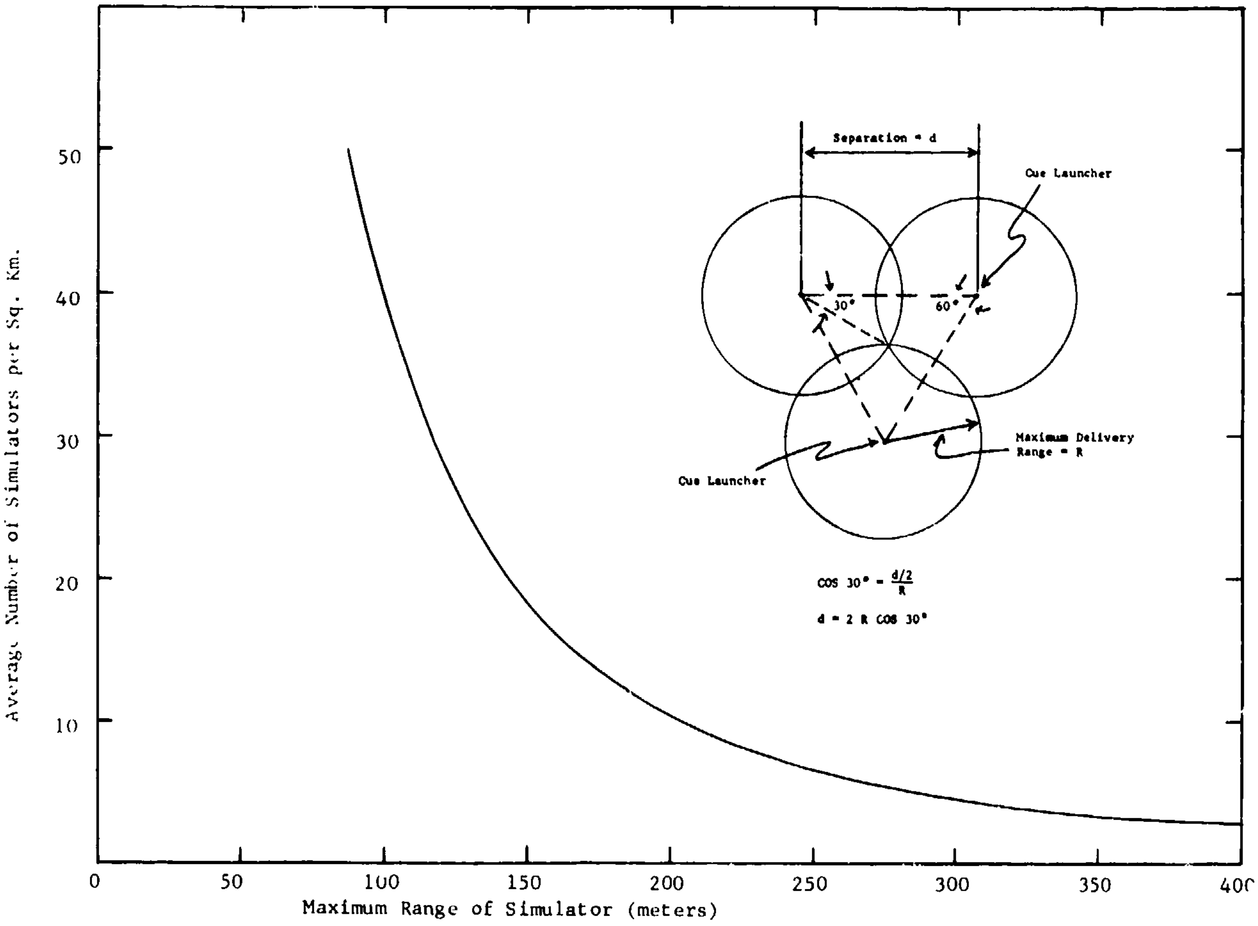

Figure 8. Number of Simulators vs. Maximum Simulator Range

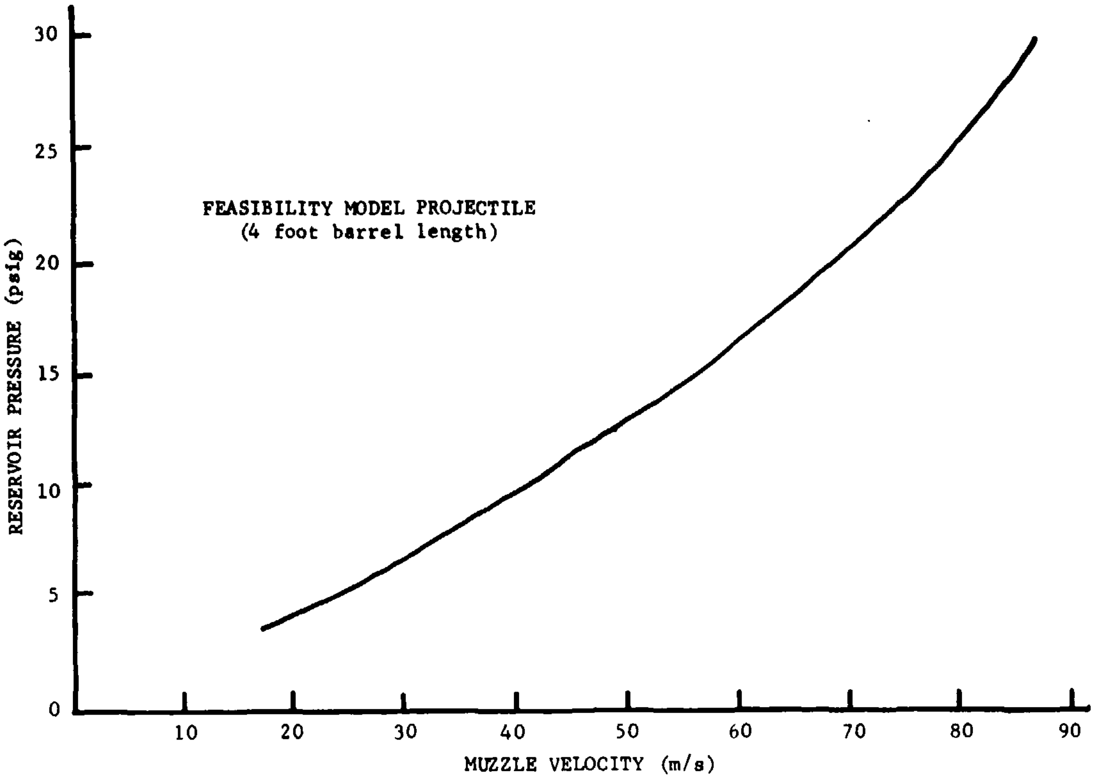

Figure 9. Muzzle Velocity vs. Reservoir Pressure

OVERALL SYSTEM PERFORMANCE

The performance of the system was ultimately determined through a number of experiments in the field which were geared toward measuring the accuracy with which a cue could be successfully delivered to a predetermined location and detonated upon impact. The accuracy of ballistic objects is usually described by the elliptical probable error (EPE) of their impact points about their corporate controid. For convenience, the major and minor axes of the typically elliptical impact pattern are normalized to yield a circle of the same area as the original ellipse which is called the circular error probable (CEP).

Circular error probable is defined as the radial distance from the center of impact which is as likely to be exceeded as not. This means that it is a circle whose center is at the impact area centroid and includes 50% of all the points of impact. The radius of this circle equals 1 CEP (1).

Circular error probable tests were conducted on the feasibility model system by firing a sequence of shots without changing QE or reservoir pressure from shot to shot. A theodolite mounted downrange from the launcher was used to accurately plot the relative angle of each impact. In addition, a measurement of the impact distance from the theodolite was made. Wind direction and velocity were simultaneously measured (at a height of 10 meters) to assure that the shots were occuring under minimal wind conditions.

The measurement of each impact point yielded polar information which was transferred to set of cartesian coordinates as shown in the graph of Figure 10. The CEP of 17.35 meters derived for these tests indicates performance far exceeding that required by the Army (25 m requirement). In fact 100% of the impacts fell within the 25 meter required CEP.

The effects of upper level winds on the trajectory can be severe. An upper level wind shear would, on numerous occasions, cause the projectile to move significantly off course. These upper level winds are difficult to predict over the entire test range. The CEP impact graph of Figure 10 was constructed from data taken during the final acceptance tests. On other occassions, similar tests yielded CEP's as low as 6.1 meters which is likely due to differences in upper level wind turbulance.

A projectile fire hazard assessment was also conducted during the final acceptance tests wherein a standard projectile was ignited in the presence of gasoline saturated paper. The projectile was ignited successfully, deploying its FBS unit without igniting the surrounding gasoline saturated papers or the gasoline vapor in the air. Recognition must be given to the fact that this test is not conclusive proof that the feasibility model projectile would not cause grass fires under normal use. However, the fact that the gasoline saturated paper (considered to

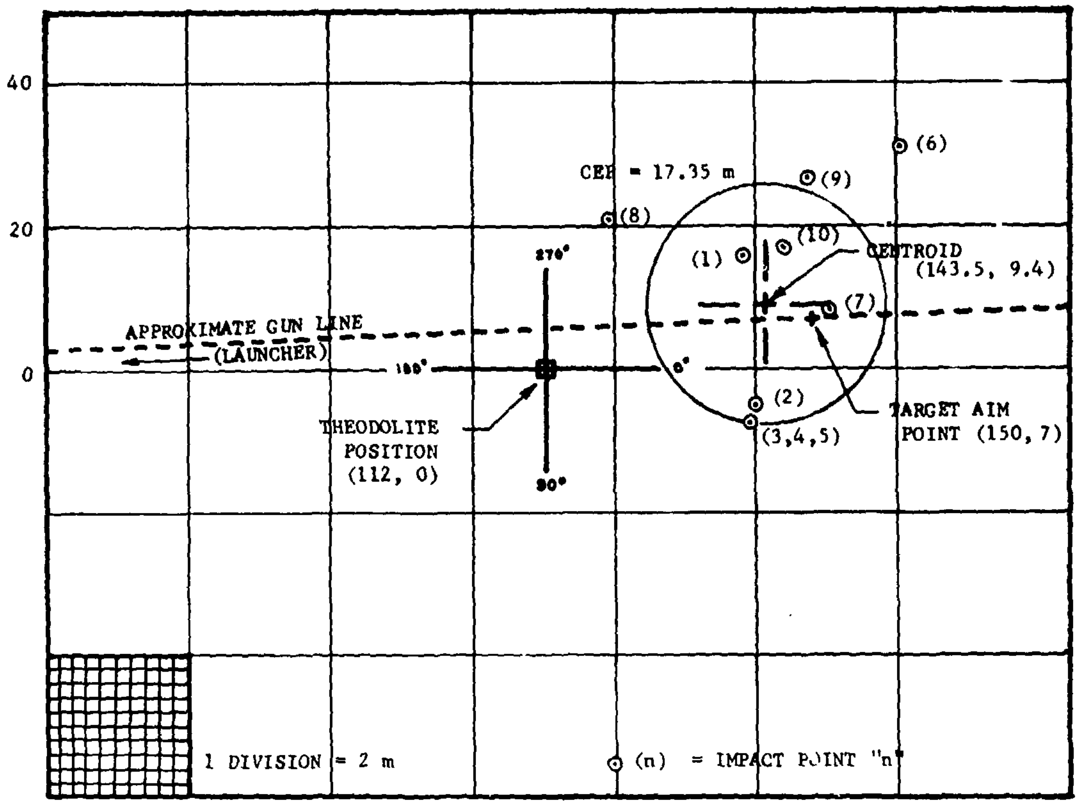

Figure 10. CEP Acceptance Test Results

be more flammable than dry grass) did not ignite indicates that the projectile can be deployed in the presence of highly flammable material without necessarily igniting that material.

Another set of measurements conducted during the final acceptance test consisted of maximum range tests. These tests were designed to evaluate the maximum achievable range of the feasibility model system. Projectiles launched with pressures of 25 psig and launcher QEs of 45 degrees had impact points in excess of 200 meters from the launch site. These projectiles ignited correctly upon impact deploying a visible smoke cloud and audible bang at the 200+ meter ranges.

CONCLUSIONS

FBS Unit Determinations

Many ignition techniques, sound generators, smoke generators, and light sources were investigated for use in the FBS unit. The FBS unit was developed around a Magicube primer and a shotgun shell loaded with a cold particulate smoke generator. Pyrotechnic generators were found to be more effective cues than cold particulate smokes; however, they were less man-safe and a greater fire hazard. The sound level of the shotgun shell approach is easily adjustable and lies within the acceptable ranges as set forth by the Surgeon General of the United States. The light output from the Magicube is very intense but brief. The use of the Magicube as a primer for the shotgun shell yields a small lightweight package that is highly stable and man-safe.

Projectile Determinations

Variable mass, variable drag, constant mass, and hybrid configurations of projectiles were investigated. A baseline projectile was hypothesized and modified numerous times to obtain the feasibility model projectile. These modifications were based on simulations by both computer and direct wind tunnel experiments, in addition to empirical data derived from actual field tests.

Flight stability is a function of two major factors. First, a hemispherical nose cone is used which decreases the forward drag. Second, a rough finish is used on the tail section to create minor turbulence which causes increased drag in the tail section resulting in projectile stability by assuring a greater side drag behind the center of gravity than in front. All portions of the projectile, from the tail section forward, must therefore be kept as smooth as possible for the stabilizing effects of the rough tail section to be effective.

Launcher Determinations

Several launcher schemes were investigated during the indirect fire simulation/cueing program. Of those investigated three were implemented; of these three, the pneumatic launcher was chosen for development.

A fast acting valve was found to be essential to efficient operation of the pneumatic launcher. The valve design chosen was an explosive flapper valve.

Barrel length also affects launcher efficiency. Of those tested, the four foot barrel length was chosen because of its tractability. As pressures are increased in later prototype models, the barrel should be increased in length.

During the course of pneumatic launcher evaluation, an air bearing was found to be created between the projectile and the barrel wall for pressures above 8 psig. The creation of the air bearing is essential to efficient operation and maximum range.

Projectile fish-tailing immediately upon launch lead to the development of a muzzle brake which channeled off-axis gas flow away from the tail section of the newly airborne projectile. The addition of the muzzle brake improved impact groupings.

Extensive testing indicates that upper level winds are a dominant factor in biasing impact centroids. QEs of less than 60 degrees were found to be desirable in order to avoid these upper level winds. Observance of the 60 degree limit becomes more important in future prototype launchers where maximum ranges will be increased.

Production Conclusions

All expendable components of the feasibility model system are designed to be conducive to mass production techniques. Whenever possible, components are cast or molded from specific types of plastics. The choice of plastic for use in a given component is dictated by its weight, tinsel strength, or elasticity. The tail sections are made from expanded polystyrene because of its extremely low density. The arming device is made from two types of plastic; one being very rigid and the other being elastic. Rigidity was important in the Magicube receiver section of the arming device since this section provided the major structural strength for the front half of the flash housing. The upper section of the arming device contains machined plastic leaf springs which must be able to flex without breaking, so a different, more elastic kind of plastic was necessary to implement this component. Other parts of the system must be fire proof or self-extinguishing. The flash housing is one example, being made out of Lexan, a self-extinguishing polycarbonate material. The nose section must be able to maintain its hemispherical shape under the acceleration of launch, but also must be able to deform upon impact with a human to increase the level of man-safeness of the projectile. For this application, a cast foam rubber compound was employed.

Man-Safety Inferences

The feasibility model projectile was demonstrated to be impact safe for individuals in visual contact with the incoming round. Fully outfitted soldiers engaged in war games should be as safe from a direct impact given that the impact does not occur on the eye or in general, the facial region. Adequate eye protection would effectively render a facial impact harmless. The sound and light level outputs from the FBS unit are within acceptable medical standards. The cold particulate smoke is soluble in the lungs and is non-toxic in the quantities to be encountered during an actual war game engagement.

General Conclusion

Extensive experimentation has shown that the feasibility model system performs in accordance with theory and meets or exceeds all contract requirements. The feasibility model system, as delivered, proves the indirect fire cueing system concept to be valid. Further research is necessary to improve upon this system, however.

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MICROPROCESSORS APPLIED TO TRAINING DEVICES

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ABSTRACT

Computer Controlled Trainer Simulation traditionally has been done with minicomputer class processors. Instruction, speed and flexibility, as well as good hardware and software support, are some of the reasons for the domination of the minicomputer in the area of simulation. However, over the past decade, microprocessor performance has improved to such an extent that microprocessors may rival some of the best minicomputers currently available. Microprocessors may be used to offload the mini in areas such as complex real time handling of I/O and number crunching, as well as monitoring hardware status. Distributed processors allow the mini to process more data, with less hardware needed to perform the simulation task. Microprocessors may also replace minicomputers completely in systems requiring real time number crunching with limited precision calculations, such as radar simulation or part task trainers. Additionally, software support has become quite extensive with many of the leading microcomputers, including ANSI FORTRAN, Basic and Pascal, making the micro a viable candidate to replace the minicomputer for simulation of military or commercial equipment. Such a system offers reduction in costs, weight, and power consumption with increased reliability and flexibility.

INTRODUCTION

The emergence, in the late 50's and early 60's, of the digital computer in training devices provided significant advancements in training capability. Reprogrammability, improved accuracy, ability to develop hardware and software independently and ability to use the digital computer to test the entire training device were all favorable characteristics which led to the evolvement of the digital computer as the heart of the modern training device.

Since it was first introduced in training simulation, improvements in the computer's abilities such as more instructions, faster speed, and larger word sizes have strengthened the role of the digital computer. Between November '65 and January '77 the number of digital computers inventoried by NTEC rose from 51 to 587.(1) However, framing time crunch and discrete system anomalies associated with models of analog systems continue to be a problem. As system complexity increases, it becomes more and more difficult for digital computers to provide realistic outputs to the student in real time. Often enough there are complaints that it doesn't "feel", "look" or "sound" like the real system. Microprocessors have evolved to the point today where they can perform many of the tasks normally associated with a minicomputer. Because total mission training constraints are requiring much larger computers and because microprocessors can easily handle data manipulation and number crunching, a marriage of microcomputers and minicomputers in a distributed processing environment is called for. Lower costs of microprocessor systems and significantly less development time are also factors which make the microprocessor an ideal addition to training devices. Additionally, the power of the microprocessor makes it a viable candidate for smaller systems such as radar simulation and part task trainers instead of the minicomputer.

Of the 587 computers inventoried in January '77 there were 40 different languages in use. Present requirements for standardized languages, such as PASCAL, to provide software transportability, are hoped to maximize use of programs between training devices and computers. Many of the leading microprocessor manufacturers offer development systems and software support packages which allow programing in FORTRAN, Basic, Pascal and assembly languages.

The main objectives for microprocessor utilization are:

Peripheral Processing

- scaling from engineering values to binary values
- curve fitting for non-linear devices
- packing and unpacking of digital data
- self-checking on-line background programs and off-line automatic test capability
- state change detection of input data
- relocatable I/O

Stand Alone Trainer

- complete standard trainer electronic package
- standard peripherals
- maintenance trainers, part task trainers.

The benefits derived from microprocessor usage are:

- production cost savings due to fewer parts and wiring
- increased system reliability

- unburdens main processor
- unburdens processor channel
- eliminates need for mini in small systems
- permits a more rugged trainer.

Some disadvantages of micro based systems are:

- the initial costs of the development system are high
- lack of built-in control panel for operator control
- most 16-bit micros do not support floating point operations.

The advantages and disadvantages have to be evaluated up front when applying microprocessors to training simulators. In the sections that follow, it is shown how the microprocessor could have provided significant benefits in the development of the C5A-Cockpit Procedures Trainer (CPT). The design philosophy of using microprocessors in stand alone radar trainers is also presented. The performance benefits of using a microprocessor to offload tasks from a minicomputer are shown.

MICROPROCESSORS AND PERIPHERAL PROCESSING

Computer memory size requirements are continually increasing. Faster iteration rates, quantity of I/O and complexity of simulated systems, such as experienced in Weapon System Trainers, all contribute to the need for more and more computer power. Multiple computer systems are not uncommon. Microprocessor systems can relieve the minicomputer of many of the time consuming tasks. The total I/O time required for Device A/F-37A-T65, the C5A Cockpit Procedures Trainer, averages 18% of real time. Digital data is processed at a 5-Hz rate and analog data is processed at a 10-Hz rate and uses a Harris Slash 5 computer with an Automatic Block Controller (ABC) for I/O transfer.

The following paragraphs illustrate some typical I/O handling requirements and how they relate to the C5A-CPT I/O processing tasks.

These tasks include:

- Polling of I/O
- Packing and unpacking of discrete data
- Scaling and curve fitting of analog data
  - Inputting analog data
  - Curve fitting
  - Sine/cosine conversion.

Polling of I/O

Polling techniques for transferring data between the computer memory and the I/O equipment use valuable time, especially at higher iteration rates. The central processor reserves a storage area in memory separate from the memory being used for processing. This reserve storage area is required to buffer all input and output data. All data being transmitted to the I/O device is first placed in the buffer before being transmitted. Similarly all data received from the I/O device is first placed in the storage area. In the C5-CPT trainer, digital data is transferred at 5 times per second and analog data is transferred at 10 times per second.

Table 1, C5-CPT Cycle Time Required for I/O Transfers, identifies the quantities of I/O channels required and the quantity of CPU instruction cycles required. These figures do not include the set up time required by the CPU to initiate each block transfer. A microprocessor would save time by transferring only that data which has changed from the previous value, at rates consistent with the particular type of input or output.

Table 1. C5-CPT Cycle Time Required for I/O Transfers

I/O TYPE	QUANTITY 16-BIT CHANNELS	MAX I/O RATE	MAX DMA RATE	CPU CYCLES	
				PER SEC	TOTAL
DO	124	3 μs/chan.	1 transfers ea. 3 cycles	5	620
DI	160	3 μs/chan.	2 transfers ea. 3 cycles	5	800
CO	344	3 μs/chan.	1 transfer ea. 3 cycles	10	3440
CI	64	75 μs/chan.	2 transfers ea. 3 cycles	10	640
					5.5K

Packing and Unpacking

Another task which is directly related to the quantity of data words being transferred is the procedure of packing and unpacking I/O, and applies to digital data. This procedure involves storing each bit of a data word as a complete word in memory as shown in Figure 1. The unpacked format allows the DI's and DO's to be in a form more palatable to most FORTRAN based programs. This requirement is based on the fact that most minis do not have good bit testing capability.

It is a simple task to check the sign bit of a data word in a real time operating program; therefore it takes much less time to use unpacked data than it would take to perform bit testing. This frees up the main computer program from bit testing and data manipulation. Extra time is required to perform this packing and unpacking during I/O transfers. To keep this time at a minimum, the CPU compares new input data to the previous data. This requires two areas in memory, one to store the data being transferred as identified under polling, and a second one to store the previous data for comparison purposes. If, during the comparison process, the CPU detects a difference between the old and the new data, the CPU will then unpack the input data, a bit at a time, into the working memory. Table 2 summarizes the Harris Slash 5 iterative instructions required for each DI word and shows the total computer cycles required for the C5A trainer. All output data is packed into a 16-bit word. Table 3 is a summary of instruction cycles required to pack all DO words for the C5A-CPT. The number of total cycles required is

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Bit #
1	1	0	0	0									1	1	0	

PACKED I/O DATA

Bit 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Mem Add N
Bit 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Mem Add N + 1
Bit 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Mem Add N + 2
Bit 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Mem Add N + 3
Bit 15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Mem Add N + 14
Bit 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Mem Add N + 15

UNPACKED I/O DATA

Figure 1. Data Formats for Packed and Unpacked Data.

Table 2. Instruction Cycles Required to Compare Input Data

INSTRUCTION	NUMBER OF CYCLES
TME Transfer memory to E Reg.	2 Load DI word
CME Compare memory to E Reg.	2 Compare last input to present input
B02 Branch on 0	1 Branch if not different
AOJ Increment buffer address	1
AOI Increment memory address	1
AOK Load reg.	1
CMJ Compare for last DI word	2
BON Branch on non total	1
	11 cycles x 160 DI words = 1760 cycles X 5 per second 8800 cycles/sec.

Table 3. Instruction Cycles Required to Pack Output Data

INSTRUCTION	NUMBER OF CYCLES	
TNJ Load # bits (16)	1 16 bits per word	X16
12A Transfer zero to A	1 Zero A register	
TME Transfer memory to E reg.	3 Load data from memory	
LRD Left rotate double	2 Shifts sign bit into A Register	
AOI Increment to next memory	1 Add 1	
BWJ Return for next bit	1 Do all 16 bits	
TAM Transfer word to memory	2 Transfer work to RTI buffer	X1
AOK Increment K	1	
CMK All words done?	2	
BNK Branch if not zero to top	1	
	((9x16) + 6) 124 DO words = 18600 cycles X 5 per sec. 93000 cycles/sec.	

1760 for a DI compare and 18600 for DO packing, for each iteration. This requires over 100K instruction cycles per second. Faster iteration rates obviously require more time.

Since digital data normally represents manual functions, significant CPU time can be saved by transferring only unpacked data. At first glance this would seem to require a significantly greater I/O time for polling purposes. However, there are two important factors to be considered: first, I/O time takes less time than comparing and unpacking, and second, the microprocessor can be programed to transfer only changed data as follows.

The transfer of data which contains no new information is a loss of valuable time. A smart I/O would transfer information only when there is new data. Because of the continuous nature of analog data, the arguments for transmitting only changed data would be applicable primarily to digital data.

This task, combined with the capability of transmitting unpacked data, would result in minimal processor cycles each second. Transmitting of unpacked data could be accomplished in either of two ways; a block of data preceded by a single address or an address transmitted for each data word. The Harris External Block Controller (XBC) provides a means for automatic data transfer between memory and a selected peripheral device on a random access, cycle-stealing basis. This device would allow transfers directly with the memory location used by the operating program, saving time and memory. Table 4 shows the I/O buffer space savings because of the elimination of intermediate storage requirements and the number of CPU cycles saved by elimination of packing and unpacking requirements. State change detection is an integral part of data transfer reduction. American Micro Devices has announced a new integrated circuit, P/N AM29837, which is called a Bit Mapped I/O Port and is shown in Figure 2.

Table 4. Benefits of Eliminating
Packing and Unpacking

I/O BUFFER SPACE SAVINGS	CPU CYCLES SAVED	
DO = 124 x 2 = 248	Polling time	5500 cycles/sec
DI = 160 x 2 = 320	Input unpacking	8800 cycles/sec
568 words	Output packing	93000 cycles/sec
		107300 cycles/sec

This part would simplify the microprocessor tasks of determining if there are changes on inputs by providing information regarding changes without the overhead of comparing to previous data in the processor.

Scaling and Curve Fitting

Scaling and curve fitting are additional tasks which may be relegated to the microprocessor peripheral. These tasks relate to the conversion between normalized values for equation solving purposes in the computer and engineering values required for the I/O system. Each analog input in the C5-CPT trainer goes through the following process and requires the indicated number of computer cycles:

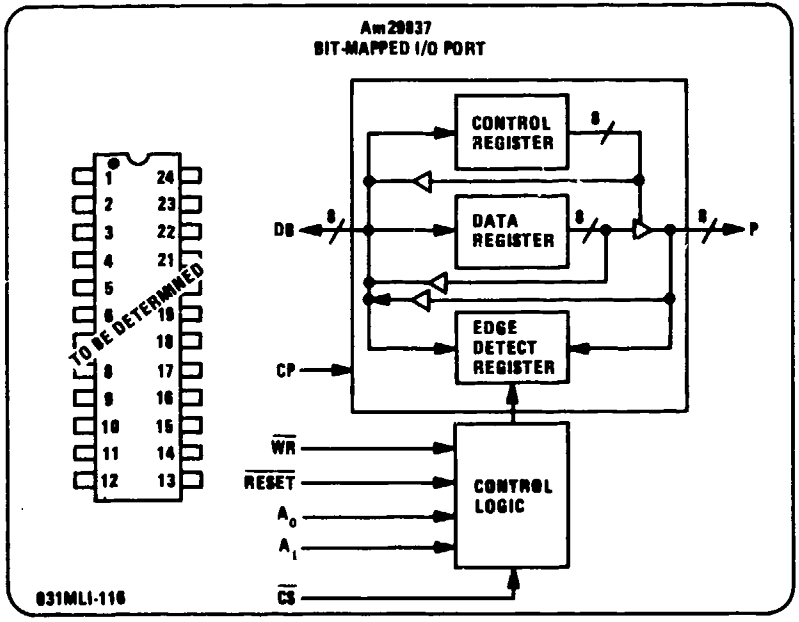

Figure 2. Bit-Mapped I/O Port

	Number of Cycles
TMA Load accumulator with analog input	2
LLA Left shift to left justify for sign bit	3
RRA Right shift to right justify with sign bit	3
MYM Multiply to a normalized value of ± 1	6
	14 cycles
Times quantity of analog inputs	x 64
	896 processor cycles
	x 10 per second
	8960 cycles/sec.

Each analog output requires a conversion from a normalized value to an engineering value. For the simplest of analog outputs this requires solving the following equation:

$$y = mx+b$$

where:

y = engineering value

m = slope of the line

x = normalized value

b = y intercept

The following conversion routine is typical for solving the previous equation:

	Number of Cycles
Load accumulator with value of "x"	2
Multiply by the value of "m"	6
Add the value of "b"	2
Shift to 12-bit format	3
	13
Times the quantity of analog outputs	x 344
	4472 cycles
	x 10 per second
	44720 cycles/sec.

As mentioned earlier, this represents the simplest conversion of analog outputs and is required for each output. Some cockpit flight instruments, because of nonlinearities, require several straight line segments to cover the range of engineering values. This requires additional checking routines to first determine which segment of the curve the value falls into and also requires additional memory to store the associated constants. For a single straight line curve, two constants must be stored; the values of m and b.

Instruments which require dual continuous outputs, such as compasses and two speed devices including altimeters and attitude direction indicators, require additional handling to convert the output data into sine and cosine format. To calculate this value involves solving a polynomial equation in the following form:

$$y = C_1x^3 + C_2x^2 + C_3x + C_4$$

Typical conversion time for an equation of this form requires 200 µs for each conversion in the Harris Computer. In the C5-CPT trainer there are (23x2) sine/cosine conversion routines which require:

46x200 = 9.2 ms (9.2K instruction cycles)
x 10 per sec. = 92000 cycles/sec.

Summary of I/O Tasks

The previous tasks associated with I/O handling require an appreciable amount of time. For the basic tasks identified, total CPU time is summarized as follows:

Polling	5500 cycles/sec.
Packing and unpacking	101800 cycles/sec.
Analog inputs	8960 cycles/sec.
Curve fitting	44720 cycles/sec.
Sine/cosine conversion	92000 cycles/sec.
	252980 cycles/sec.

At 1 µs per instruction cycle this represents 25.3% of each second of processing time. It should be pointed out that the tasks defined here do not include overhead of set-up time required nor do they include the additional time for those analog outputs which must be tested for multi-segment curve fitting. Also not included is the actual time required to unpack a changed DI input. Another factor which increases the total time is that all channels are not contiguous and are split between four separate devices.

The previous examples of tasks which could be off-loaded to a peripheral processor may not seem too significant once a computer, such as the Harris, is selected for a specific trainer, such as the C-5 CPT. In the beginning there is always plenty of spare memory and time available to meet specification requirements. However, because of additional requirements and ECP add-on, this particular trainer ran out of memory space and required a second Slash 5 minicomputer to handle all the processing tasks. Once the original design used the minicomputer as the sole processing device, the best solution to add-on requirements was another mini in order to minimize system design changes.

MICROPROCESSORS IN RADAR SIMULATION

Microprocessors are increasingly taking on the tasks once performed only by minicomputers in the area of radar simulation. Many of the more recent 16/32-bit microprocessors equal or exceed present day minicomputer capabilities in speed and calculation precision, at less cost. However, the approach to a solution using microprocessors may not be simply supplanting the minicomputer. Concepts of parallel vector and multiprocessing are much more easily and cheaply realized using microprocessors than using minicomputers.

The design approach for radar simulation systems using microprocessors must be optimized to achieve greatest cost/performance yield. Each hardware and software subsystem must be evaluated for the individual application as well as the future applications to increase the hardware/software life cycle of the final product. Hardware tradeoffs such as multiprocessor/shared resource designs, as well as off-the-shelf approaches to specific subsystems, must be evaluated. Software tradeoffs, such as selection of important instruction set features as well as selecting the most efficient software language mix, must be contemplated.

Simulation of a radar system containing large numbers of targets or multiple gaming areas requires multiprocessing and shared resources. This simulation requires multiple semaphore switching of shared memory and peripherals. Semaphore switching may be accomplished directly by the microprocessor itself, or indirectly via an intelligent resource controller. The advantage of a resource controller is that a processor can make a request for a shared resource, then continue processing. The resource controller would continue to poll the status of the resource until it is free for use, then hold possession of the resource while signaling the requesting processor. This saves processor time and allows efficient use of system resources.

Hardware subsystems producing clutter, jamming and weather effects must be evaluated for general design approach. Software generation of these effects is quite time consuming. It is more prudent to free up the target generator processor by dedicating a separate microcomputer to the task of generating these effects. Since setup selection (display) or de-selection (blanking) of these phenomena occurs infrequently during the course of simulation, a 'slow' serial RS-232 link to the target processor may be used. This link makes the clutter/weather generator usable with any processor. The target processor would down-load set-up information such as type, intensity, wind boundary, speed, etc. to the clutter/weather processor. The peripheral processor would then execute the appropriate algorithms and output the raw video via a video generator port. This port would be designed to accommodate expected variations in sweep speed, video level, etc. The goal of this design approach is to have off-the-shelf hardware/software for clutter/weather generation, independent of target processor type, with a savings of target processor time.

Radar simulation requires a specific set of demands on computing systems. Since all calculations of targets and radar clutter/jamming must be done in real time, a fast instruction set is essential. Key areas of performance within the instruction set are fast multiply-divide with number crunching of at least 32 bits, context switching during interrupt vectoring, looping primitives, and flexible addressing modes. In addition, instruction execution speed is greatly enhanced with a large directly addressable memory capability due to the minimization of memory management overhead.

Radar simulation also requires an efficient mix of software languages to achieve the required performance level for the specific system. High performance systems require calculations for target dynamics, radar sorting, radar conditioning effects, and routines for I/O handling to be written in assembly language. In addition, the executive should be written in assembly language to quickly assign new tabs. Utilization of assembly language allows software functional entities that are time constrained and iterative to be processed at the highest speed of the microprocessor. Use of assembly language has the added advantage of being compact, thus saving memory and recurring hardware costs.

Software functions that are not time constrained may be more quickly written using higher level languages, which are also more 'portable'. Low priority functions, including data entry/display and scenario generation, should be written in higher level languages such as Pascal, FORTRAN or ADA. Portable programs may be written for general use as off-the-shelf software, thus reducing costs and time for each new simulator.

Low performance systems should have the entire radar model and control functions written in a higher level language. The I/O handler would be the only function written in assembly language. The advantage of this approach is "portability" of software that is more likely to be off-the-shelf. The disadvantages are greater memory consumption, higher recurring hardware costs, and a lower number of targets that may be handled by an individual processor.

The following paragraphs discuss significant features of microprocessors as applied to radar trainers and summarize the distinct advantages of the microprocessor.

Microprocessor Applications in Radar Trainers

Tables 5 and 6 compare minicomputer and microprocessor based training devices.

Table 5, CPU Internal Structure, summarizes the basic structure of the CPU devices used on various radar training devices. These devices range from the Harris Slash 5 minicomputer used in 1971-2 on the Forward Area Alert Radar trainer for the Army and the 15G19 radar trainer for the Navy to the present Motorola 68000 microprocessor being designed for the AN/GPN-T4(V) Air Force trainer.

An earlier T4 device delivered in the late 70's to the Air Force used an IMP16-L microprocessor as did the 15G20 which has been delivered to the Navy and the Marines. Table 6, CPU Development Facilities, shows the features available with each of the CPU systems for the radar trainers referenced above.

Table 5. CPU Internal Structure

CPU	HARRIS 6024/5(MINI)	IMP16-L(MICRO)	68000 (MICRO)
DEVICE	FAAR, ARMY 15G19 NAVY	AN/GPN-T4, AIR FORCE 15G20, NAVY, MARINES	AN/GPN-T4(V), AIR FORCE
	Byte-word (24 bit) long word	16 bit word, limited byte and long word operations	Byte, word, and long word instructions with little restriction
	6 registers (24 bit)	2 working registers 2 address registers	8 data registers (32 bits) 7 address registers (32 bits)
	No stack	16 word internal stack	Stack in external memory without restriction
	65K address space	65K address space	8M direct address space
	Vectored interrupts only	Nonvectored interrupts only	Vectored or autovectored interrupts or both
	Data transfers controlled by Harris data channel; no user connection to bus	Time shared address and data lines	Separate address and data lines

Table 6. CPU Development Facilities

1971-72 MINICOMPUTER HARRIS 6024/5	1974 MICROPROCESSOR NATIONAL SEMICONDUCTOR IMP-162	1980 MICROPROCESSOR MOTOROLA 68000
Programer's control panel, no CRT	Programer's control panel, no CRT	CRT-Keyboard terminal
Punch cards or paper tape	Punch cards or paper tape	Floppy disk handlers
Own assembly language plus FORTRAN IV	Own assembly language only (FORTRAN required external processor)	Own assembly language, FORTRAN 77, Pascal
Assembler and editor	'Conversational' assembler as limited editor	Assembler and editor (word processing, CRT oriented)
Debugger but no incircuit emulator	Debugger but no incircuit emulator	Debugger plus incircuit emulator
No memory space protection	No memory space protection	Optional memory space protection
User mode only	User mode only	Supervisory and user modes, privileged and nonprivileged instructions

Computers in Radar Simulation in 1973 and 1980

A $30,000 minicomputer, standing as high as the programer, seemed like a reasonable solution to a real time radar simulation development in 1973. This punch card based system easily computed dynamics of 16 targets at 25 discrete ranges, although system integration with our hardware was sometimes baffling and usually very slow. There were no logic analyzers then. In addition, the required card reader, tape handler, chain printer, I/O channel boards, cables, other hardware, and software support pushed the total development package to nearly triple that of the computer alone, yet only the computer and a paper tape reader needed to be delivered with the simulator.

In 1980, the same $30,000 bought a 16-bit microprocessor development system and a software package for another radar simulation. The system included a processor, a keyboard-CRT terminal, a printer, a dual floppy disk handler, and an in-circuit emulator pod. The software package included a word processing-oriented editor and a debugger. No more keypunch machine or punch card files. The new printer was slower than the old chain printer but was the size of a typewriter instead of a small refrigerator.

The job for which this microprocessor system was bought required delivery of only a processor, some memory, and a DMA controller. Each was to be put on a 9 x 10-inch printed circuit board. Each delivered radar simulation system then included only about $3,000 worth of computation hardware, about one-tenth of that required in 1973. Since the program and all diagnostics were resident in ROM on the memory board, no other peripherals were needed in the delivered system.

Hardware integration wasn't so baffling. Now we could plug the development system into the socket where our microprocessor chip was to go, rather than connect a mini via a peripheral channel as before. Single step execution, break points, register examination, traps, and data manipulation all took place at a terminal with the flexibility of a keyboard and CRT display, rather than at a control panel with switches and lamps.

Of course, minicomputer development hasn't stood still since 1973. But for us, the contrast in development of a computer-based system for radar simulation between 1973 and 1980 reflects work in two different worlds.

MICROPROCESSOR PERFORMANCE

The performance of the microprocessor, including speed, instruction set, I/O rate and software, is an important factor when considering offloading tasks from a minicomputer. If a task becomes more difficult or time consuming to handle in the micro, then very little has been gained unless production savings offset development costs. Benchmarking provides a means for evaluating a processor's performance of certain tasks. A group at Carnegie Mellon University compiled a set of programs in 1976 for benchmarking minicomputers.(2) EDN magazine(3) published the results of a comprehensive benchmark study of four major 16-bit microprocessors: the Digital Equipment Corp LSI 11/23, Intel 8086, Motorola 68000 and Zilog Z8000. EDN's tests, while being a subset of the Carnegie-Mellon set, specifically exclude benchmarks dealing with floating point math or virtual-memory handling because most 16-bit microprocessors do not support floating point operations or virtual memory. Also excluded were two benchmarks that require extensive number crunching capability (Fourier transforms and Runga-Kutta integration). The results of the seven remaining microprocessor benchmarks are shown in Table 7.

Table 7. Microprocessor Benchmark Execution Times

	EXECUTION TIME IN MILLISECONDS			
BENCHMARK	LSI 11/23	8086	68000	Z8000
A. I/O Interrupt Kernel	114	126	33	42
B. I/O Kernel with FIFO Processing	1196	348	390	436
E. Character String Search	996	193	244	237
F. Bit Set, Reset, Test	799	122	70	123
H. Linked-List Insertion	592	-	153	237
I. Quicksort	-	115,669	33,527	115,500
K. Bit-Matrix Transposition	1517	820	368	646

The following clock speeds were used.

LSI - 11/23	3.33 MHZ
8086	10.00 MHZ
68000	10.00 MHZ
Z8000	6.00 MHZ

Table 8 tabularizes the benchmark code bytes required for the same microprocessors and compares them to the Interdata 8/32 mincomputer which was the superior device of the Carnegie Mellon tests.

Table 8. Benchmark Code Bytes

	CODE BYTES				INTER-DATA
BENCHMARK	LSI 11/23	8086	68000	Z8000	8/32
A. I/O Interrupt Kernel	20	55	24	18	26
B. I/O Kernel with FIFO Processing	86	85	118	106	98
E. Character String Search	76	70	44	66	120
F. Bit Set, Reset, Test	70	46	36	44	82
H. Linked-List Insertion	138	94	106	96	148
I. Quicksort	-	347	266	386	426
K. Bit-Matrix Transposition	152	88	74	110	130

From Table 7 and 8 we note that all microprocessors are not equal in performance. It is therefore up to the individual user to compare his particular requirements against the various micros and perform a trade off evaluation. It should be noted that the fastest clock speed is not necessarily the device with the best performance. For instance, the Z8000 at a clock speed of 6.00 MHz performs benchmark K (bit-matrix transposition) faster than the 68000 with a clock speed of 10.0 MHz; however, it requires more bytes of code. From Table 8 we note a significant savings in the number of code bytes required for most of the microprocessor benchmarks as compared to the Interdata 8/32 minicomputer.

CONCLUSIONS

It has been shown how the microprocessors can be used to enhance the performance of a training simulator. Specific tasks can now be performed on the microprocessor at much greater speeds and economy than on the minicomputer; for example, routine iterative tasks of data handling, number crunching, hardware monitoring and radar target generators.

With the current technological development of microprocessors, we can expect these benefits to increase and that more and more tasks may be offloaded onto the microprocessor. It is thus incumbent upon the simulator systems designers to economically incorporate microprocessors into their particular application.

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VOICE-AIDED TRAINING

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ABSTRACT

Computer voice response and computer speech recognition can provide a valuable supplementary training aid for military training systems. For training devices based on media or software which is hard to change, voice can provide supplementary information and allow spoken amendments to course information. For simulators which attempt physical fidelity to a particular defense system, speech provides a medium which can communicate information to and from the student without interfering with the defense system displays or controls.

It is feasible to add computer voice response of telephone quality to most training systems. Such voice response can be entered and changed by simply speaking into a microphone. At least thirty minutes of such speech can be stored and retrieved digitally in a simple hardware implementation.

Speech recognition capability can add a further dimension to a voice training aid, allowing the trainee to make requests or to answer multiple-choice questions.

INTRODUCTION

In this paper, we will look at two major categories of training situations which arise: 1) with simulators or part-task trainers, and 2) with training devices, such as videodisc or computer-aided instruction systems. This paper will discuss where we believe that computer-voice response, i.e., the ability of the computer to communicate with the student by voice, can be an important supplement to these training technologies, making these technologies more effective. It will also discuss how speech-recognition capabilities, i.e., the ability of the student to respond to the computer by voice, can be a valuable supplement to computer voice response in some situations. We will discuss how current state-of-the-art hardware and software can be used to meet the requirements generated by these applications.

There have been more specialized discussions elsewhere of the role of speech technology in training, particularly in situations where the response to be trained is a vocal response and in which the specific syntax and words used are part of the training (1,3-5).

SIMULATORS AND PART-TASK TRAINERS

There is a wide range of training systems being developed for military and other applications. These devices include very complex weapon system trainers. Weapon system trainers simulate in real time the response of the operational weapon system to the trainee's actions. At the other end of the spectrum are more simple familiarization trainers where the device responds to a limited number of console actions to give the trainee experience with a particular set of switches and controls.

Simulators and Computer-Aided Instruction

The major characteristic of such trainers is that they attempt to simulate to varying degrees the actual system for which the training is being undertaken. Thus, the displays, switches, and other means of communication between the trainee and the system are those present in the actual weapon system. If we wish to automate such a system to provide computer-aided instruction as a supplement to the instructor, we are faced with the difficulty that we do not wish to interfere with the fidelity of the student-system interaction. We do not wish for there to appear on the CRT screen of the weapon system a question or a prompt that would not be available in the actual weapon system. Misuse of a simulator/trainer as a computer-aided instruction device could too easily result in confusing the trainee between what he can expect in an operational situation and the training situation. We would therefore like to have such machine-based instruction occur without interference with the operation of the training system.

Having the computer-based instruction be delivered by spoken messages is probably the ideal alternative for this type of system, particularly since the student is used to receiving vocal instructions from the instructor while he is operating the training system.

Let's consider a more specific example. Suppose we wished to teach emergency procedures with a part-task trainer. The system might be such that, when a particular weapon system panel failed, the procedure was to use keyboard entry. Because the major part of the training will be for normal operation, training in the emergency procedures can be a poor use of time for an instructor, particularly if these procedures are complex enough to require many repetitions for familiarization. Yet, no one would argue against the importance of training in these procedures.

An example of the interaction with a speaking computer-aided- instruction (CAI) system might be as follows. The CAI system might say, "Suppose the firing panel has failed. What would you do in order to initialize your missile battery for firing?" The user responds as he would in an operational situation, typing in his response. If the system is implemented such that the CAI system is aware of what response was typed in, the machine can respond to a correct answer by saying, "That is correct." and proceeding to the next step in the instruction. If the answer is incorrect, the CAI system might indicate the nature of the error; for example, it might say "You transposed a C and an A in the command. Please try again," or "You used the command appropriate for a failure of the navigation panel instead of the firing panel. Please try again."

If the CAI system is not set up in such a way that it can read the specific response of the trainee, it may simply state the correct response and ask him if he requires further explanation. This approach requires that the student be able to interact directly with the CAI system to indicate that he or she needs more help or a repetition of the instructions. For the reasons previously discussed, it would be useful if the student's responses could be vocal. It would be useful if he or she could state what the response was and have the computer comment upon it, as if the CAI system were aware of the keys pressed.

Even in a situation where the CAI system is aware of the key presses, there should be a mechanism for the student to communicate with the system to request help, a hint, or more detailed explanation.

Speech Technology Requirements

Let us discuss the voice response and recognition technology which would be desirable for voice-aided training as we have described it.

Voice response. A highly desirable requirement is that the speech be easily intelligible and natural speech. The student is learning a difficult task and it is inappropriate for him to also be learning to understand unnatural speech. We would like the speech to be as if it were coming from a recording.

It would also be useful if the speech response system could produce sounds as well; for example, it might be useful to explain to the student that when he had pressed a particular sequence of buttons, he would hear a particular sound and have the system replicate that sound. Similarly, having different voices would be useful; for example, one could use a female voice for instructions about the CAI procedure and a male voice for the instructional material.

Another requirement is that the vocabulary of the speech response system be essentially unlimited to allow instruction to be designed and changed without artificial constraints.

A third requirement is that there be no significant delay in the beginning of a vocal response, even if the content of that response depends upon the student's actions. If there is a differing response for a correct answer than an incorrect answer, the machine must immediately present the appropriate response. This is also the case if the student requests a review, more detail, or a hint.

We must also require that there be a capability for storing sufficient speech to carry the whole training session. This would probably require that a minimum of fifteen minutes of speech be stored in the speech response system. It is unlikely that more than an hour of speech would be required for any single training session, considering time allowed for student response and for repetition of material. A subsidiary requirement is that the speech/material be changeable by reloading the system in some way from some off-line storage medium, such as tape, so that the course content could be easily changed to another hour of speech.

A highly desirable capability is that the system allow the speech content of the course material to be easily changed. Because speech is such a natural medium in which to teach, the full advantage of the speech response technology will not be realized unless the instructor or course designer can readily change portions of the spoken material. This can be required for a number of valid reasons:

1) The instructor may discover that the students have difficulty with a certain portion of the course and require additional instructions that are not in the present course material.

2) The weapon system itself may change, requiring that the course material be changed to reflect this. (It is particularly advantageous when the course material can compensate for an incorrect response of the weapon

system trainer, due to a late change in the operational weapon system.)

3) An instructor may discover that a certain portion of the instructional material is wrong or confusing.

It would be ideal if the instructor could change the course material simply by indicating the portion of the course to be changed and then simply dictate vocally the change or addition.

A final requirement is that the addition of the voice response have a minimum impact, if any, on the hardware and software of the training system. Given the difficulty of developing training systems, any significant increase in the complexity added to that task by a CAI adjunct would be a severe impediment to the addition of such capability. For this reason, it is probably inadvisable to integrate the voice-response capability into the weapon-system hardware and software.

It is modern design philosophy for computer-based systems to modularize as much as possible to simplify the software development. The implications for the computer-voice response in this context is that it would be appropriate for the device to be a stand-alone device where changes in the spoken material were made independently. The communication with the training system could be through simple identifiers without requiring the training system to store the speech material.

The speech response requirements are summarized in Table I.

Speech Recognition. We have discussed the requirements for the voice-response capability of the CAI system. The requirements on the speech-recognition side are less substantial. Speech-recognition capability in combination with voice response would be very powerful if the speech-recognition capability could distinguish the following commands:

"Repeat" --
The student could use this to request that course material or a question be repeated.

"Hint" or "Help" --
The student could use this to request further information or a hint to the correct response.

"Yes" and "No" --
To allow the student to respond to questions.

"Stop" and "Ready" --
To allow the student to stop the CAI process or to inform that he or she is ready to proceed again after an interruption.

In addition, in specific applications, it might be useful for the student to respond by a series of digits or by other specific responses to inquiries by the voice-response unit.

If these requirements could be met at a price commensurate with the cost of the trainer and justified by the service provided, it is quite likely that the device would provide an effective aid in assisting the instructor in training for certain types of skills.

TRAINING DEVICES

Another type of training which is receiving growing interest in the military and elsewhere is the use of dedicated general-purpose training devices. Such devices include the following: (1) general CAI systems based upon minicomputers or microcomputers, and (2) interactive video systems, both videotape and videodisc. In particular, microcomputer-controlled videodisc systems hold great promise for highly powerful interactive training systems at a moderate cost. A major disadvantage, however, of CAI systems in general, and of videodisc systems in particular, is the difficulty of changing such systems once the program is designed. To change a videodisc, for example, may require creating a new master.

This problem could be minimized through the use of an adjunct voice-response system controlled by the same microcomputer that controls the CAI or videodisc system. Thus, while a given frame is on the screen, the speech-response system could be instructed by the microcomputer to speak a given section of material. The speech material could differ depending on the trainee's response.

The same considerations, with respect to being able to change the material easily, apply to this type of system as they did to the simulators and part-task trainers in the previous section. It is almost an axiom that there will be errors in a given set of courseware no matter how often it is checked before being committed to software or to videodisc; a related postulate is that the course material will become outdated in part as soon as it is finalized. Thus, the voice-response system requirements of Table I are relevant to the present section.

In the area of the supportive speech recognition devices, however, there are different considerations. We do not have the requirement in most cases of physical fidelity. Therefore, there is no difficulty in allowing the trainee to communicate with the CAI system through the use of a keyboard or other means such as a touch-sensitive screen, minimizing the need for speech recognition.

Table I:
Requirements for
Computer-to-Trainee
Voice Response

A. Easy-to-understand speech

B. Easily changed speech material

C. Unconstrained vocabulary and syntax

D. Different spoken material depending on student action, with no significant time delay before response starts

E. At least fifteen minutes of speech, one hour desirable; course material changed by reloading from off-line storage (e.g., tape)

F. Sound effects and different voices possible (useful, but not important)

G. Minimal impact on training system hardware and software

There would be a significant motivation for using a speech-recognition system as a response mechanism if the response of the user required a minimum of familiarization by the trainee with the speech system; that is, if the speech system took advantage of the naturalness of speech to the user as a means of communication, it might make the interaction with the CAI system less intimidating. It would be nice, for example, if the videodisc or CAI system could display a multiple-choice question on the screen and ask the user to repeat the correct response. The response choices would ideally be lengthy phrases with no vocabulary constraints. If the system could distinguish the correct from the incorrect responses, this would be a very natural means of interacting with the students. It would have the added value of having the student repeat the correct answer orally, rather than simply press a button marked A,B,C, or D. It is reasonable to assume that a student would better retain an answer which required oral repetition. This would seem on the face of it to be an easy task for a speech-recognition system, since the phrasing of the multiple-choice answers, particularly the wrong answers, is very much under the control of the designer. It would therefore seem to be easy to select choices which are distinctly different.

In the next section, we discuss the implications for speech-recognition technology of the requirements of this section and the previous section.

IMPLICATIONS FOR SPEECH-RESPONSE AND SPEECH-RECOGNITION TECHNOLOGY

There are two distinct technologies involved in this discussion: 1) voice response, and 2)speech recognition.

Voice Response

There are four major approaches to speech synthesis: (1) analog recording, (2) off-line encoding, (3) phoneme synthesis, and (4) waveform coding. In this section, we will discuss these technologies and the degree to which they can meet the requirements of Table I.

Analog Recording. Because they are not well-suited for allowing interactive responses, analog (tape- or drum-based approaches) are not attractive for voice-interactive systems. However, if one wishes to sacrifice voice interaction, one can use a standard cassette system with tones indicating the next CAI or videodisc segment. For some applications, this may be cost-effective; as a general-purpose interactive speech-response system, it is not.

Off-Line Parameter Encoding. Techniques such as linear predictive coding (LPC) are used to analyze a spoken word or phrase and reduce the storage requirements for storing that word digitally. The encoding is done off-line, one word or phrase at a time, on a system different from the system which synthesizes the speech. The synthesis system can be inexpensive. The resulting speech quality is related to the amount of data reduction produced by the coding, but, in general, the result is easy to understand. This technology is suitable for short responses and material which does not require changes; but the difficulty of changing the speech and the large amount of speech required eliminate this approach from practical consideration for the applications of this paper.

Phoneme synthesis. One can describe a phoneme synthesis system roughly as a device which pronounces each letter of a word which is spelled out. The speech can be entered as a string of "phonemes" (analogous to letters) and will be pronounced as entered. A great deal of effort is required to enter phonemes, pauses, and stresses so that the resulting speech sounds reasonably natural; even with effort, the speech is "robot-sounding," and the listener must expend some effort to understand it. It is feasible to use phoneme synthesis for the training applications of this paper; but this technology places a burden on the trainee in understanding the speech, and changing the material can be difficult and time-consuming. Text-to-speech systems under development may ease this latter difficulty (2). This approach conserves computer memory more than any other approach, so a great amount of material could be stored. Rapid retrieval of any part of the material is easily possible. This could be a relatively low-cost approach to voice-aided training with the disadvantages noted.

Waveform coding. This technology basically stores a replica of the speech waveform in real time as the speech is spoken. Coding techniques used in communications, such as Pulse Code Modulation (PCM) coding, can be used to reduce memory storage requirements. It is theoretically possible to use techniques such as LPC computed in real time to reduce storage even further. With PCM coding, speech data can be stored at about 4,000 bytes per second to create highly intelligible telephone-quality speech. The speech can be generated and changed by simply speaking into a microphone.

Waveform coding satisfies all the requirements we outlined for voice-aided training in Table I. It has the further advantage that it is a well-developed technology. Unfortunately, the large memory requirements make this one of the more costly solutions; one half-hour of speech requires over seven megabytes of storage. On the other hand, Winchester disc drives of ten to twenty megabyte capacity are readily available and becoming increasingly inexpensive. Waveform coding is a full solution to the voice-aided training requirements for voice response in Table I -- although not an inexpensive solution.

Speech Recognition

The simple control words required by the simulator application can be implemented with any commercial isolated word recognition device. Distinguishing words such as "help," "repeat," etc., is not difficult.

An isolated word recognizer is not so suitable for distinguishing multiple-choice questions of essentially unlimited vocabulary. The isolated word recognizers require each word or phrase to be less than two seconds or so; each such word/phrase to be used must be individually spoken several times by the trainee to "train" the recognizer; and a long multiple-choice reponse which is a series of shorter word/phrases requires a distinct pause between word/phrases. Isolated word recognition is a complicated way to solve what, in this case, is a simple problem.

Because of the flexibility we have in choosing the multiple-choice responses, we can choose them to be different in the number of "syllables" (more accurately, in the number of energy pulses). By simply monitoring the energy envelope of the trainee's response, the speech recognition system can distinguish trainee responses which differ in energy pulses. Since no spectral information is required, the system is speaker-independent and requires no training. Since this approach cannot distinguish "yes" from "no," it does not replace isolated word recognizers where distinctions between words of equal syllable count are required.

The problem of counting energy pulses consistently over many users is more difficult than implied here, but has been demonstrated. In particular, adding this type of recognition capability to a microcomputer-based speech response system requires a minimum of additional hardware.

SUMMARY AND CONCLUSIONS

If one wishes to use CAI with training systems which replicate part of a weapons system,, voice response and speech recognition allow the trainee to interact with the CAI system without interfering with the fidelity of the trainer.

For training devices, voice response can allow changes to the training material to be made easily by dictating into a microphone. Speech recognition allows trainees to respond to the system in a manner more comfortable to them than a keyboard and in a way which may improve retention of course material.

It is feasible to have all the key characteristics implied by these applications in a voice-response system with current waveform-coding technology. Because of the memory storage required by this approach, a system with a hard disk drive is required; although such devices are becoming smaller and declining in cost, this approach is relatively costly. The cost, however, is low compared to the cost of simulators, part-task trainers, and their instructors' salaries. The cost is not so low compared with the cost of a single low-cost training device, but perhaps acceptable if a single speech response system serves some ten to twenty training devices.

A possible lower-cost alternative is a text-to-speech system using phoneme synthesis. Currently the quality of the resulting speech is questionable; but research continues.

Speech recognition has been discussed in this paper as a supplement to voice response rather than as an end in itself. This approach is motivated by the realization that it is fairly easy and inexpensive to add both isolated word recognition (using board-level systems) and speaker-independent phrase recognition (syllable-counting) to a microcomputer-based, voice-response system. Except for multi-user environments, the speech response/recognition system should never be talking while it is listening, or vice versa; thus, a single microcomputer can control both voice response and recognition. The microcomputer can also handle communications with the training system through a standard serial interface to minimize any impact on the trainer hardware and software.

In implementing a total system (voice response, two types of speech recognition, and communications with the trainer computer), one accomplishes more than a cost reduction. The speech recognition and response capabilities complement one another and yield a highly versatile system. For example, the system may interact with the trainee by giving vocal instruction and requesting a multiple-choice response which is interpreted by the syllable-counter. The voice-response system can then ask a question which requires a numerical response; that response can be interpreted with the isolated word recognizer. The isolated word recognizer can accept control words such as "help," "repeat," or "wait."

The technology for effective voice-aided training is available; it has the potential to make computer-aided instruction more practical in many applications.

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GUIDES FOR

VOICE TECHNOLOGY IN NAVY TRAINING SYSTEMS

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ABSTRACT

Computer speech recognition provides the enabling technology for the use of automated performance measurement and instructor support features to allow "instructorless" training for those tasks which are primarily speech in nature. The design guides take the approach that automated, "instructorless" training is achievable through the use of computer software models of the instructor and the task. Human factors design guidelines are provided for the integration of speech technology with the software models. The Navy has built two prototype training systems using voice technology to capture student behavior, evaluated one of them, and is in the process of evaluating another. Further, the training implications for airborne applications of voice technology have been developed. The emergence of voice technology as one solution to the manpower shortage has provided justification for these efforts. This paper describes how voice technology can make the transition from R&D to application.

INTRODUCTION

Background

For several years, the Human Factors Laboratory at the Naval Training Equipment Center has been developing techniques for the application of voice technology to training systems. There has emerged from that work an identification of three areas of expertise which will be required in future efforts to apply voice technology to Navy training systems.

The first area is Systems Engineering. Obviously, knowledge is required in hardware capability and in programming requirements of voice technology subsystems. The second is Human Factors. Obviously, too, knowledge is required in man-machine interface design requirements. The third area is relatively new, the Voice Technology Specialist. Knowledge is required in the integration of Systems concepts with Human Factors design concepts. What makes the Voice Technology Specialist separate is the requirement to recognize the unique characteristics of Voice Technology. Talking to a machine with today's technology is not like talking to another person. Special skills are required to properly integrate a voice subsystem, and this paper will address what those skills are.

Each of the three areas of expertise has a critical role to play in the design and implementation of the training system using voice technology. This paper seeks to define those roles in terms of the tasks which must be performed. It is proposed that the first two roles will merge to form the third as more and more voice subsystems are applied to training systems. The method of this merger is described in the conclusion of this paper.

Growing Popularity

Science fiction has identified numerous applications for voice technology, but the technology will have to be able to converse as smoothly as the conversation between two people for those applications to be feasible. Industry has shown cost payoffs with today's technology with applications in the data entry and the secure access areas. So, we can expect to see a slow but growing development from current technology capabilities to "natural" communication with machines. The length of time that it takes for the growth will depend upon the speed at which voice technology is popularized by reduced cost and upon the speed at which need is created for more sophisticated applications of man-machine dialogue. The Navy is shaping this development by its applications of voice technology.

This paper will briefly describe two Navy training prototypes. They have taught us much about the unique characteristics of voice subsystems and have allowed development of the voice technology design principles discussed here.

The two prototypes are for controller training. The Navy has built (1) and evaluated (2) a system for training a portion of the task of the Air Traffic Controller, and has built (report in preparation) and is evaluating (work in progress) a second system for a portion of the task of the tactical controller, the Air Intercept Controller. In each case, voice technology is used within a package of instructional features. Voice technology serves to capture the vocal behavior of the trainee so that other automated subsystems can evaluate the performance of the trainee. Other subsystems then select the next task so as to teach the trainee the required next logical skill. This package of instructional features is both the reason why voice technology can be made to work, as well as why the application principles are so complicated. That is, a non-trivial dialogue between a person and a machine requires an intelligent person and an intelligent machine.

Future Payoffs

The Navy's cost payoff from voice technology is currently in the area of Manpower, Personnel and Training. Voice technology as part of an instructional features package can serve to substitute for personnel actions and in some cases for personnel themselves. Thus, fewer people can perform more tasks in less time because technology is performing the functions once done by people. In the 1990's, voice technology combined with artificial intelligence (AI) is expected to pay off additionally in terms of reducing the complexity of operating sophisticated training devices so that training tasks such as tactics or gaming are instructionally manageable and performance is measureable. This will be important in the 1990's, even if the manpower shortage is reduced.

Organization of Remainder of Paper

In the three sections which follow, the discussion will be concerned with tasks required of the Systems Engineer, the Human Factors Engineer and the Voice Technology Specialist. The Systems Engineer will be required to design systems in terms of two dynamic, interactive models. The task model generates events to be presented to the trainee. The instructor model delivers instruction. The voice technology subsystem must then be designed to pass sufficient data to the models to allow the student to interact with them. Of course, a model can be composed of submodels, depending upon requirements.

The Human Factors Engineer will be required to design the feedback subsystem. For example, people can use a simple frown during conversation to indicate a word wasn't understood. However, a training system using voice recognition must provide a functionally equivalent source of feedback that doesn't distract the trainee from the task.

The Voice Technology Specialist must integrate these two systems. Voice technology data capabilities such as indications of potentially confusing phrases or hesitant speech must be matched with an appropriate instructionally relevant encouragement from the system so that the trainee receives functionally the same type instruction a teacher would deliver in a similiar situation.

THE SYSTEMS ENGINEER

The Role of Models

Supporting software models will be required when a speech recognition device is included in a complex Navy training system. Models are not needed when voice is merely a data entry device: a keyboard replacement. The real power in a training system with voice, however is achieved through the relationship between voice recognition and two major models: the model of the task and the model of the instructor. As an example, consider the Ground Controlled Approach Controller Training System (GCA-CTS), designed to provide automated instruction of Precision Approach Radar (1, 2). The task model is the pilot/aircraft model which simulates the responses to the student controller's verbal transmissions, such as "Turn right heading 160." A closed-loop system is achieved by the student observing the simulated radar scope and making appropriate transmissions which are "understood" by the voice recognition system, resulting in the appropriate changes in the radar display. In this case, the integration of voice recognition with the pilot/aircraft model has enabled a real-time interactive simulation. An added benefit is that no human "pseudo pilot" is required to manually simulate the pilot responses. Therefore, the combination of voice recognition and pilot/aircraft modeling has achieved a more controlled response of the simulated pilot while eliminating the need for one support person for each trainee. In a similar development, a pilot/aircraft model has been designed by Hooks (3) in support of automated training for the Landing Signal Officer (LSO).

Another type of model which is closely related to the use of voice technology for training is the instructor model. Several studies have dealt with the issue of how to move toward "instructorless" training through the use of software models of the instructor and the task (4, 5). Instructor model functions for an LSO training system will soon be completed (6). Advances in the field of artificial intelligence (AI) promise to enhance the development of "intelligent" instructor models (7), and the NAVTRAEQUIPCEN currently is initiating work on this issue.

Instructor models will never totally replace a human instructor for long periods of training, but instructorless (or nearly instructorless) training is feasible now and can provide the capability both to relieve instructor manpower shortages and to promote effective, objective, consistent training. Instructor models in voice-interactive training systems must be capable of several functions, including the following:

- Provide Instruction
- Measure and Evaluate Performance
- Provide Performance Feedback to the Student
- Decide on the Appropriate Individualized Instruction (remediation, task difficulty, etc.)
- Keep Records of Students' Progress
- Communicate Relevant Information to the Human Instructor.

These functions are not limited to training systems with voice technology, but the voice capability carries with it a special set of considerations for the design of the instructor model. For example, automated instruction can take full advantage of voice interaction by using speech generation as well as video display to demonstrate proper and improper procedures. Speech recognition and speech generation can provide the basis for a natural language interface between the student and the simulated instructor. The student can use voice to query the system, and ask for review or additional information. Voice interaction with the automated instructor is a natural communication medium. The focus here is to make the student an active part of the instructional process, rather than a passive recipient of information.

The performance measurement and evaluation function in a voice interactive training system for verbal tasks will be critically dependent on the accuracy of voice recognition. Accurate performance measurement for air traffic controller training, for example, can be severely degraded by speech recognition errors. Careful design of the supporting software is required to assist in the discrimination between a student's performance error and a speech recognition error. The importance of accurate discrimination between these two types of errors is obvious when one realizes that incorrectly attributing a speech recognition error to a student error can be carried through to faulty performance feedback, syllabus decisions, and record keeping. Task oriented software based on AI principles appears to be a promising approach to this problem.

The instructor model also may be assigned the responsibility of managing the support requirements of the voice recognition subsystem, such as collecting voice reference patterns, providing instruction on "how to talk to the system," monitoring confusion matrices to prompt voice retraining, and supporting voice retraining when requested by the student. These functions must be accomplished through the coordination of the instructor model and the voice subsystem. The design goals are to: minimize the time required for the student to learn to use the voice system; avoid long and tedious voice training (data collection) sessions; and assist the student in maintaining high recognition accuracy over time. This topic is discussed later under Reference Pattern Formation.

A student model is another candidate for inclusion in an automated training system. The function of the student model is to generate inferences about the changing state of knowledge/skill of the student. These inferences are used to select appropriate individualized instruction. Adaptive training in the form of either multiple syllabus branches or variable task difficulty can be supported by a student model, as discussed in several NAVTRAEQUIPCEN reports (4, 5, 8). The design of the student model in a voice-interactive system is not particularly unique, other than its dependence on the voice recognition system (and the performance measurement system) to provide the input data regarding the students' current level of (verbal) performance.

Voice Recognition Issues Affecting Training System Design

A number of voice technology issues will be encountered by the systems engineer during implementation of voice recognition technology. Although there may not be simple answers to these issues, Table 1 is presented in the belief that identifying some of the potential problems can be beneficial.

Clearly, the list of issues in Table 1 is not exhaustive. It is merely a sample. In general, a major category of issues to be confronted is speaker variability (fatigue, sore throat, lip-smacking, non-meaningful sounds such as "ah," amplitude variation with situational stress, etc.). In short, all the variabilities that make speech more interesting (to the human listener) than a predictable monotone are what make automated speech recognition a challenge. In addition to speaker variabilities, there will be environmental conditions to be confronted, depending on the training application. Ambient noise, particularly of the impulsive type, may be a factor. Consistent microphone placement is important. Motion and vibration in an

Table 1

Issues and Suggestions for Implementing Voice Recognition

ISSUES	POTENTIAL SOLUTIONS/SUGGESTIONS
Vocabulary Definition	Do it early, ideally during a full ISD process. Consider stylization requirements and natural pauses. Avoid confusible items. Consider word/phrase lengths and time required for speaking.
Voice System Selection	Consider objectives/requirements of training system, e.g., "real-time" vocabulary size, isolated vs. connected speech, and sampling requirements. (See 9)
Speech Sampling (Voice Data Collection)	More research is needed on opposing viewpoints: (1) Train (sample) in random order. Seek consistency and sampling in context of task. (2) Sample repetitively on the same word/phrase seeking variability in reference patterns. Double-map difficult or alternative words (e.g., "nine" and "niner").
New Users	A "voice recognition test" mode should be available. Increasing competence (and recognition accuracy) is to be expected over time for a new user.
Recognition Feedback	Essential. Alpha numeric, audio or situational feedback information should be provided immediately, ideally without interfering with the speaker's primary task.
Maintenance of Recognition Accuracy	Automatic or manual procedures are needed to facilitate accuracy maintenance. Voice test function is needed. Access to "retraining" is needed. A confusion index is recommended.
"Understanding" Software	Supporting software (AI?) is recommended to enhance speech recognition through the use of syntactic, semantic, and task information.
Training System Integration	All software "downstream" of speech recognition, such as performance measurement and adaptive syllabus control, must be designed to minimize the impact of speech recognition errors.

operational training environment could introduce additional sources of variance.

Navy Training Systems

The two prototype Navy training systems that have included voice technology have been relatively sophisticated, featuring real-time interactive simulation, automated performance measurement, and automated instruction. However, simpler voice applications in training also may be quite worthwhile, such as a voice-interactive CAI system. One can envision a simple CAI system with a very limited vocabulary, perhaps consisting of eight words such as "ALPHA, BRAVO, CHARLIE, DELTA, NEXT, YES, NO, and REVIEW." Advances in the technology of integrated circuits reportedly will enable a single-chip recognition device with an eight word vocabulary to be marketed within the next year for less than $100.00 (10). These advances in hardware technology may reduce costs to the point of popularizing voice technology in a wide variety of entertainment and consumer products. This presents both a challenge and a benefit to the designer of training systems oriented to complex, technological jobs within the Navy. The benefit will come by the very "demystification" of automated speech recognition. Just as today's recruits find hand calculators commonplace, nearly every Navy recruit in 1990 will have operated some sort of voice system. This will tend to facilitate user acceptance and prevent the equivalent of "mike fright" for new users. The challenge for the training system designer will be to select the appropriate voice recognition device from the projected large number available, and adroitly to integrate it into the training system.

Design Guideline Development

In addition to the implementation of models, the systems engineer must integrate data flow between the models and the voice technology subsystem. Some of the issues to be considered in that include strengths and weaknesses of various features of speech recognition systems, such as:

- Isolated Word Recognition (IWR) or Connected Speech Recognition (CSR)
- Speech Stylization Requirements
- Speaker Dependence/Independence
- Vocabulary Size

- Voice Data Collection
    - Number of Samples
    - Procedures for
- Voice Test and Retraining
- Confusion Matrices
- Recognition Accuracy
    - Misrecognition
    - Non-recognition
- Recognition Speed
- "Understanding" Software.

The promised advantages to be gained from voice technology, however, can only be gained by careful design of the entire training system to be compatible with the capabilities and limitations of the trainee and the voice subsystem. The design guidelines currently under development (11) are intended to consolidate the lessons learned from previous prototype system developments, to project the trends of voice technology, and serve as a sourcebook for specifying design options and choosing among them, based on the objectives of the particular training system being developed.

There are numerous physical, environmental, and human factors issues in the training applications of voice technology. An "up front" Instructional Systems Development (ISD) process is necessary, and, at the other end, a generous allocation of time for system test and "debugging" is required to achieve an effective voice-interactive training system. The systems engineer must therefore work closely with ISD personnel in order to consider all relevant issues.

HUMAN FACTORS CONSIDERATIONS

The Task Analysis

The development of a training device, especially a major device for hands-on training, must be based on an analysis of the tasks or skills to be trained. This training task analysis provides the basic data for determination of training objectives and resulting training system performance requirements. In a training task analysis, the emphasis should be on relating system functions to trainee perceptions and responses, determining special skill requirements, and making certain that each system output critical to task performance is linked to an operator response.

One of the recommendations from a recent study of the training implications of airborne applications of voice technology (12) was that task analyses and other front-end analyses for training systems employing voice technology should be performed by professional personnel who thoroughly understand the human factors of voice-interactive technology. Furthermore, personal hands-on experience with voice-interactive systems was recommended as a means of assuring familiarity with the human factors of voice technology. Without such personal experience, there is a danger that some important factors in learning to use automated speech recognition and synthesis will not be reflected in the development of instructional objectives.

In the design of voice technology for systems to train speech-based tasks that do not themselves use voice technology --that is, in using voice technology as a training medium-- particular care must be taken that the constraints imposed by voice technology do not cause the training tasks to misrepresent the speech-based tasks being trained. Personal voice technology experience can help instructional designers to use training media based on voice technology in ways that foster rather than hinder accomplishment of training objectives.

Reference Pattern Formation

Most of the presently available automated speech recognition systems are "speaker-dependent", that is, they require that each operator "train" the system by providing examples of that speaker's pronunciation of the words to be understood. This voice reference pattern formation process is not required for speaker-independent systems, but such systems can generally recognize only within a vocabulary limited to a very few items.

The pattern registration process in speaker-dependent systems requires a speaker to pronounce several times any word or phrase to be recognized. A composite of the several pronunciations is stored and the recognizer system can then compare future utterances with stored composites as the basis of its recognition magic. The formation of reference patterns is extremely important to recognition accuracy, since word or phrase recognition occurs when an utterance is judged by the computer to match one reference pattern better than any other.

It is to be expected, then, that if a word or phrase is spoken in a particular way during reference pattern formation, and then spoken differently later, it may not be recognized correctly. The subtlety of differences which can interfere with recognition becomes clear only after one has attempted to use an automated speech recognition device using today's technology. Differences which are not at all apparent to the speaker may result in non-recognition or misrecognition by the system, leading to considerable frustration on the part of the user.

Differences between the context in which reference pattern formation occurs and in which recognition is attempted can result from changes in physical conditions, such as noise, vibration, G-forces, and other factors. The substantial research on the effects of physical context has been summarized by Coler (13) and others. Although not as well studied, differences resulting from changes in psychological context have often been noted informally by many researchers (14, 15).

Among the most widespread observations are 1) that words trained individually may not be recognized when later embedded in longer utterances, and 2) that a speaker is often misrecognized when speaking in a stressful situation if the voice reference patterns have been entered in a non-stressful setting. Such misrecognition may be self-perpetuating, since it induces additional stress, which leads to further misrecognition. If speech recognition is to work well in a variety of psychological contexts, it is probably necessary to perform voice reference pattern formation under conditions that effectively simulate the range of operational situations to be encountered. It may be possible to obtain speech samples which are sufficiently typical of the trainee's normal voicing by collecting them during the practice of correct terminology during training, as was done for parts of the GCA-CTS vocabulary (1).

It is desirable that trainees spend as little time as possible in speaking for the sole purpose of registering voice reference patterns, an activity with little training value to the trainee. However, if voice reference pattern registration is well integrated into the training program, it can occupy considerable time, and that time will also be beneficial to the trainee. It is essential that this be done to avoid wasteful use of trainee time, and also to avoid trainee boredom or loss of interest. Fortunately, such integration of reference pattern registration into substantive training exercises also serves to increase the likelihood of proper psychological context for reference pattern registration.

Recognition and Re-training

All currently available Automated Speech Recognition systems have performance limitations which render them less efficient and less adaptable than a human listener. Although some limitations are not easily surmounted, others stem from conditions which can be controlled to minimize their detrimental effects on recognition.

We have already discussed what is perhaps the most important of these controllable factors, which is the context in which voice reference pattern formation occurs. Another factor known to affect recognition accuracy is variability among individual users in their ability to "talk to a machine." Some users are consistently well understood by Automated Speech Recognition devices, while others have persistent problems, probably in part because their speech is more variable (16).

If we acknowledge that currently available Automated Speech Recognition systems, and systems likely to be fielded in the near future, do not always recognize speech with high accuracy, it becomes necessary to assess the effects of non-recognition or misrecognition on the performance of man-machine systems. In particular, we are interested in the effects on the user and on interactions with the speech recognition system.

In the design of training systems using voice technology, the design of system feedback on recognition accuracy is critical, requiring exacting human factors analysis for each specific application. This is necessary because recognition failure induces frustration and stress in the user, increasing the probability that the next utterance will be misrecognized, producing further frustration and stress in a vicious cycle. To break this cycle, we must provide the user with easily interpretable feedback concerning recognition accuracy and with natural ways of responding to misrecognitions. A well-designed system will notify the operator that it has not understood, or will display what was understood to have been said, thus giving the speaker a chance to detect and cope with a misrecognition problem. The speaker can repeat the utterance, or retrain the system if necessary. A system which merely fails to respond appropriately to an utterance will leave the speaker not knowing what has gone wrong, nor what can be done to set it right. This extremely frustrating experience can have a strong negative influence on the user's acceptance of the training system and attitude toward training. Thus the effectiveness of training systems using voice technology may be expected to vary directly not only with recognition accuracy but also with the usefulness of the feedback on recognition accuracy.

The voice reference pattern updating or re-training capability of training systems using voice technology must be designed with reference to human factors. Because an effective training program for a speech-based task will lead to constant improvements and changes in a trainee's speech behaviors, frequent updating of reference patterns may be expected. This process may be performed openly, in such a way that the trainee knows that it is taking place (and giving the trainee a measure of control over the process), or it may be integrated into the training so as to be transparent or unnoticed by the trainee. If the updating is transparent, there must also be a provision whereby the trainee can deliberately test and update the voice reference patterns if poor automated speech recognition performance occurs at any time during training. A convenient test and update capability will aid in preventing the frustration which arises from incorrect recognition, and will foster trainee perceptions of control over the training process. It will help prevent an adversary relationship from developing between the trainee and the training system.

Human-machine Interface for Voice Technology--Alice's Doorway

In the report on training implications of airborne applications of voice technology (12), an analogy was made between the user of voice technology and Alice in Wonderland. In one adventure, Alice is trapped behind a small door through which she can see a marvelous garden with bright flowers and cool fountains, just out of reach beyond a narrow passageway. Reaching the full benefits of voice technology may also be seen as requiring a user to traverse a narrow passageway, a channel restricted by the human factors peculiar to current speaker-dependent voice-interactive systems, as suggested by Figure 1. Human engineering of the man-machine interface can provide the "magic" to allow the user access to the garden of benefits.

As Figure 1 shows, the human factors that must be reflected in the design of the man-machine interface for voice technology are not limited to speech control factors resulting from the characteristics of present-day automated speech recognition systems. They also include general factors resulting from use of auditory and voice channels for information exchange characteristic of artificially intelligent systems.

In the category of general factors, one of the more difficult problems to deal with is likely to be resistance by experienced training designers and users to changes induced by the introduction of voice technology in training. Heavy involvement in the design of the instructor interface by personnel who will use the system for instruction, coupled with thorough training in its use, can help combat this resistance.

Other difficult problems stem from teaching users the reality of dealing with limited intelligence machines, and from tendencies to view the machine as an adversary. These problems can be especially troublesome because voice technology systems usually do not provide feedback and verification of the sorts people expect in interaction with another intelligent entity. Simply stated, users may attribute too much intelligence to a machine just because it talks and listens, and they can become angry when it fails to live up to their expectations, especially if the basis for its misbehavior is not readily apparent. The human-machine interface must be designed to help the user suppress inappropriate responses that might be directed toward another human and to strengthen appropriate responses that take into account the limitations of the machine.

In the category of speech control factors, the human- machine interface must be designed to aid the user in dealing with any constraints on user speech patterns peculiar to that automated speech recognition system. For example, it has been pointed out that recognition accuracy can be critically dependent upon characteristics of speech utterances that are not usually attended to by a speaker. Feedback on user inputs may have to be structured to help speakers attend to such subtle characteristics.

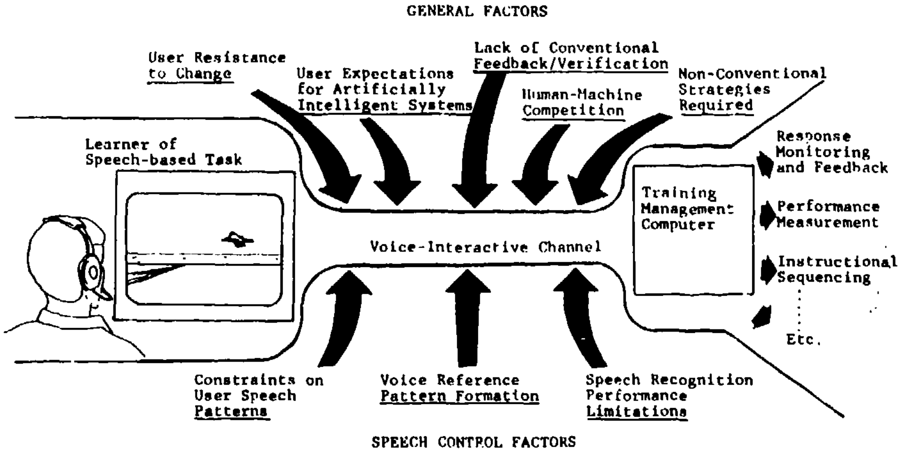

Figure 1. Human factors constraints resulting from use of the voice-interactive channel in training systems.

Voice reference pattern formation/updating and speech recognition performance limitations also have an impact on the design of the human-machine interface. Even for a system in which voice reference pattern formation and updating are sequenced within training program content so that little or no trainee time is spent solely for those activities, recognition failures may be perceived by the trainee as correctible by better reference pattern formation. To maintain user acceptability, the system must permit a user the option at frequent intervals or at will of voice recognition test and reference pattern update.

If the human-machine interface for voice technology in training systems is engineered with the user's capabilities and limitations as a guide, the restrictiveness of the voice-interactive channel can be minimized. Human factors engineering and a well-designed training program can provide the "magic" to allow the user access to the garden of benefits made possible by creative application of voice technology.

VOICE TECHNOLOGY SPECIALIST

The emergence of a Voice Technology Specialist is required for success in complex applications and high payoff in voice technology. To encourage that trend, a short course is being developed at the Naval Training Equipment Center, Human Factors Laboratory, to provide hands-on experience with voice technology. It is expected to be ready for evaluation early in 1982 by a select group of Naval Training Equipment Center instructional systems design personnel, then to be offered Government-wide.

Skills of the Voice Technology Specialist

Models. Training tasks to which voice technology can be applied are characterized by requirements for the trainee to process information, manage data, and make decisions. The model of the task which must generate the data required for proper training is characterized by requirements for generation of variability. For example, a pilot/aircraft model for a controller trainee must be capable of flying various approach profiles which exhibit typical situations. The voice technology specialist must ensure that the model is properly integrated with the voice subsystem so that the decisions of the trainee as spoken to the system are accurately reflected in the response of the model. For example, voice recognition systems often confuse "port" with "four" (they may sound different to you and me, but electronic ears hear things differently). Thus, the integration task of the voice technology specialist requires identification of potential recognition confusions unique to the particular hardware and vocabulary being used. Then, logical substitutions can be made by the system itself when a trainee's decision doesn't make sense.

Similarly, the instructor model must evaluate decisions of the trainee and provide appropriate feedback, remedial training, and critique. The voice technology specialist must ensure that the model is properly integrated with both the task model and speech subsystem so that the trainee doesn't become confused or frustrated. For example, confusion resulted in the GCA-CTS prototype system during a particular two-part maneuver. The first part required a number of decisions in a relatively short time. If any were not recognized precisely, the trainee was not told why and also could not proceed. Since the task was timed, there occurred a build-up of stress which reduced further the trainee's chance of being understood. Thus, the integration task of the voice technology specialist requires identification of potentially stressful situations. Then, the voice recognition subsystem can be designed to relax recognition accuracy requirements until the trainee becomes proficient at the task.

Voice Technology. Certain areas within voice technology are constantly improving and changing. The voice technology specialist must keep abreast of developments in speaker dependent/independent systems, isolated/connected word recognition, vocabulary size vs. system cost trade-offs, accuracy of recognition, and software access to voice recognition parameters such as a confusion matrix, threshold values, and timing of incoming speech.

Human Factors. One area of human factors has been concerned with training panel layout design. In the voice technology area, however, the other design criteria, discussed earlier in this paper, become important. In particular, there is a learning-to-talk-to-the-machine phenomenon in which most people can achieve 99.9% recognition accuracy with a few hours practice. What appears to happen is that a person develops consistency in speaking a particular phrase and develops uniqueness in how that one is said versus how another acoustically similar phrase is said. Exaggeration of consonants is the simplest technique.

The voice technology specialist must analyze the application for critical voice technology features, then optimize the man-machine interface design for user friendliness. Stress is particularly important to consider in training system design. The higher the stress, the lower the likelihood of recognition. In training, stress often comes about from poor, erroneous, or no feedback, or from too fast-paced responding. The voice technology specialist must design a system that combines the "intelligence" of the task and instructor models with the recognition parameters of the voice subsystem to produce a dynamic, interactive, voice-based training system.

CONCLUSION

This paper has concerned itself with technology transfer. An emerging technology, computer voice technology, has been described in terms of the skills required to apply the technology to real-world training situations. Transfer to engineering is being conducted via development of design guides for system models and subsystems. Transfer to instructional systems development is being conducted by development of Human Factors principles of feedback and exploitation of available voice quality data from the system. A Voice Technology Specialty appears to be emerging from a combination of the System Engineering skills and Human Factors skills. This emergence is required for continued application of voice technology.

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INTERACTIVE MULTI-MEDIA SYSTEM

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ABSTRACT

Increasing systems sophistication and limited personnel resources are dramatically demonstrating the need for cost effective training, operations and maintenance assistance at the work site. The Interactive Multi-Media System (IMMS) addresses these needs by providing training, technical documentation, and operations information in a highly interactive format using advanced microcomputer and optical videodisc design. IMMS uses Spatial Data Management as a means to provide users with rapid and natural access to varied types of information in an easy-to-use and unified format. There are no languages to learn or typing required with IMMS. Optical videodiscs are used in IMMS to provide users with immediate access to interactive video-based information. Some of the interactive videodisc functions supported by IMMS include diagnostic procedures, step-by-step assembly, maintenance, and operations activities, and technical information support. Other multi-media aspects of IMMS include the use of variable data sources such as microfiche, videotape, remote data systems, and teleconferencing to support changes in technical information and procedures as well as off-site instruction. Finally, embedded subsidiary incentives in IMMS stimulate the learning and usage of IMMS by users.

INTRODUCTION

The productivity limits of our current training technology may have been reached. Massive efforts to improve "stand-up" lectures, printed training materials, and "hands-on" laboratory experience have begun to yield too few significant returns. We need revolutionary new techniques that will break through the constraints posed by existing training technologies and allow us to beat the current tradeoffs that must be made among costs, quantity and quality. Videodisc technology is one of the most promising sources of these new techniques.

Videodisc technology is creating opportunities for new kinds and forms of training devices at surprisingly low cost. At the heart of this technology is the capability to access tens of thousands of color images, including stereo sound, in seconds of fractions thereof. When coupled with the new uniquitous microprocessor, videodisc technology offers new opportunities for training applications as well as new issues for the training specialist.

In this paper we share some of our ideas and experiences in the application of IMMS to training. Specifically, we will examine three new ideas for training applications which use videodisc technology. We then consider issues relevant to these applications and their implications for training. We begin a brief review of the characteristics and capabilities of the optical videodisc.

OPTICAL VIDEODISC TECHNOLOGY

A videodisc is similar to an audio record except that each side of a 12-inch disc contains 30 minutes of television. Since television is the rapid presentation of pictures at a rate of 30 images per second, each side of a videodisc contains 54,000 still pictures in color.

The player for a videodisc is much like a turntable except that under computer control the player can rapidly find any particular part of the videodisc. Specifically, any one of the 54,000 images, or any part of the 30 minutes of television on a videodisc, can be located typically in a fraction of a second. A videodisc provides a combination of moving and still images, any part of which can be quickly located.

Videodiscs are made like audio records using original materials that can be movies, videotapes, pages of text, tables of numbers, graphs, charts, maps, drawings, diagrams, or photographs. From the original materials, a master disc is produced that in turn is used to "press" multiple copies speedily and at low cost.

Three types of videodiscs and videodisc players are now available. The players are characterized by the market they are targeted for: general consumer usage and industrial/educational applications. Various potential manufacturers such as JVC, IBM, Xerox, Zenith, to name a few, are waiting in the wings, but only six are now marketing videodisc players.

- Magnavox, a wholly owned subsidiary of Philips, began selling a consumer model player for about $800 in December 1978.

- Discovision (DVA), under license by MCA, began general sales of an industrial player for about $3,000 in June 1979.

- Thompson-CSF began sales of an industrial player for about $3,500 early in 1980.

- Pioneer began sales of a consumer player for about $700 late in 1980.

- RCA began sales of their consumer videodisc player early in 1981.

- Sony began limited sales of an industrial videodisc player in mid-1981.

Some of the aforementioned companies have announced marketing plans for their videodisc systems. Matsushita (which markets under brand names such as JVC, Panasonic, and National) and several other Japanese companies have announced marketing dates of first quarter 1982 for their consumer videodisc systems.

The differences between consumer and industrial systems are significant as Table I shows. For instructional settings, the industrial players incorporate microprocessor control for fast random access, pre-programmed branching, and frame selection. Microprocessors have also been installed in the less expensive consumer players to provide random access, branching, and frame selection. However, the servo-mechanism in these players requires from 15 to 20 seconds to locate a frame in the worst case. Maximum access times for the industrial players are under four seconds. The consumer players lend themselves to instructional application, but the functional capabilities of the industrial players may be sufficiently greater than their higher cost is justified. With experience, we should discover what various videodisc features buy in terms of instructional achievement and will thereby be able to recommend commercial or industrial players depending on instructional settings.

laser focused on the track and thereby generate a signal that is processed and passed to a standard video monitor (i.e., to the antenna terminals of a TV set).

One video frame is stored on each track and there are 54,000 tracks per disc. Video, audio, and still photographic information can all be intermingled on these discs. These videodisc systems effectively provide rapid access to 30 minutes of video information, 30 minutes of analogue audio information, 54,000 still photographs, well in excess of 400 hours of digitized audio information, 30 minutes of motion picture information, or various combinations of the above. The point to be made is that videodiscs provide rapid random access to a lot of information which can be inexpensively stored and replicated. Table II presents a summary comparison of the videodiscs discussed in this section.

There are at least two important differences between the DVA/Sony/Philips and the Thompson-CSF videodisc systems. First, the Thompson Disc is "transmissive" while the others are "reflective". Light from a laser passes through the Thompson-CSF disc and is picked up on the other side. On a DVA, Sony, or Philips system, the disc reflects light back up so that light is sent from and received on the same side of the disc. Three implications of this difference in technical approach are: (1) the Thompson-CSF disc is "floppy", it can be rolled up in magazines and newspapers, and the reflective disc is rigid; (2) by adjusting the focus of the laser, either side of the Thompson-CSF disc can be read without physically turning the disc over. If both sides of the reflective disc are to be used, it must be physically turned over-- or there must be a light source for each side; and (3) the Thompson-CSF disc is more sensitive to dust and dirt than the reflective disc.

Features	Consumer Players	Industrial/Educational Players
Cost	$800	$2500-$3500
Still frame	Manual or automatic	Manual or programmed*
Frame random access	Manual Visual idensitication	Manual or programmed Visual, keyboard selection, or programmed
Frame-by-frame "stepping"	Manual	Manual or programmed
Variable speed motion (forward or reverse)	Manual	Manual or programmed
Two discrete sound channels	Yes	Yes

*Programmed control may be through an on-board video disc player microprocessor or an external computer.

Table I. Comparison of Consumer With Industrial Video Discs

With the exception of the RCA system, the videodisc players discussed above are all optical, laser-based systems. They use a 12-inch disc with a spiral track. The track is pitted with oblong depressions or micropits about 1 micron deep that vary in accordance with the audio or video information they represent. During playback the disc spins at 1,800 revolutions per minute while these micropits modulate a low power helium-neon

The second important difference between the two discs is that the Thompson-CSF disc systems observe European PAL/SECAM television standards as well as U.S. standard NTSC. The reflective disc observes only American NTSC television standards. When used in PAL/SECAM mode, the Thompson-CSF disc therefore provides more lines per display. The major instructional implication of this difference seems to be that because of the better resolution

	Magnavox/Phillips	Discovision DVA	Thompson-CSF
Cost	$800	$2,600	$3,500
Market	Consumer	Industrial/Educational	Industrial/Educational
Cost of Master	$1,500[a]	$1,500[a]	$1,500[a]
Cost of Copies	$5-$10[c]	$5-$10[c]	$18[b]
Technology	Optical-reflective (two-sided aluminum disc)	Optical-reflective (sided aluminum disc)	Optical-transmissive (two-sided plastic disc)
Standard	NTSC	NTSC	NTSC, PAL/SECAM

[a] Cost per side

[b] Cost includes $1.00 for protective plastic cover

[c] Depends on quantity.

Table II. Summary Comparison of Three Video Disc Systems

with PAL/SECAM standards, programs that display large amounts of text may be better suited to the Thompson disc. On the other hand, if instruction designers want to take advantage of the millions of already purchased television sets in American homes, schools, and industries, they may be well advised to use NTSC encoded videodiscs.

Second Generation Disc Technology

Two second generation developments in videodisc technology appear to be particularly notable for instructional applications.

First is the anticipated appearance of direct read after write, or DRAW, technology. The important aspects of the DRAW disc is that it stores 10^{10}-10^{12} bits of digital information on each side of the disc. This development is being undertaken by both RCA and Phillips. In the near term, videodisc systems using DRAW technology are likely to be very expensive. However, DRAW disc systems may be better suited for the small volume experimental development that is characteristic of many instructional settings.

Second is the development of still frame sound. All currently available disc systems only provide sound when the disc is played at 30 frames per second. Unfortunately, this detracts considerably from the disc's instructional value during slide-type presentations. DVA and Sony have both indicated that some form of compressed audio providing 3 to 30 seconds of sound per frame is under development.

Videodisc Versus Videotape

A brief comparison of videotape capabilities with those of videodiscs may be in order at this point. After all, videotapes represent a rapidly maturing technology, and they can offer many of the features of videodiscs such as random access, variable speed play, and reverse motion. Three points appear to be salient:

1. Tapes can be edited and current videodiscs cannot. This difference is likely to be removed with the appearance of the DRAW technology discussed above. DRAW technology will, of course, provide editable videodiscs quickly and relatively inexpensively.

2. Random access to arbitrary points on a videodisc is much faster than similar access using videotape. Random access on industrial videodiscs is less than 4 seconds compared with 20-100 seconds on videotape. Moreover, accuracy of random access on videotape leaves something to be desired.

3. Still frames are possible using either videodisc or videotape, but it is exceedingly expensive and cumbersome on videotape and single stepping through a series of still frames is essentially impossible. A far more comprehensive and detailed comparison of videotape and videodisc has been prepared by Heuston (2).

APPLICATIONS OF IMMS TO TRAINING

One of the most exciting aspects of IMMS is that it makes possible an entirely new set of training experiences. This section describes such new applications ranging from new kinds of training movies to low-cost simulators.

Interactive Movies

Interactive Movies, illustrated in Figure 1, translate movie viewing into an active participatory process. In effect, the viewer becomes the director and controls many features of the movie. A sampling of feature controls available to the viewer is the following:

1. Perspective. The movie can be seen from different directions. In effect, the viewer can "walk around" ongoing action in the movie or view it from above or below.

2. Detail. The viewer can "zoom in" to see selected, detailed aspects of the ongoing action or can "back off" to gain more perspective on the action and simultaneous activity elsewhere.

3. Level of Instruction. In some cases, the ongoing action may be too rich in detail or it may include too much irrelevant detail. The viewer can hear more or less about the ongoing process by so instructing the Interactive Movie System.

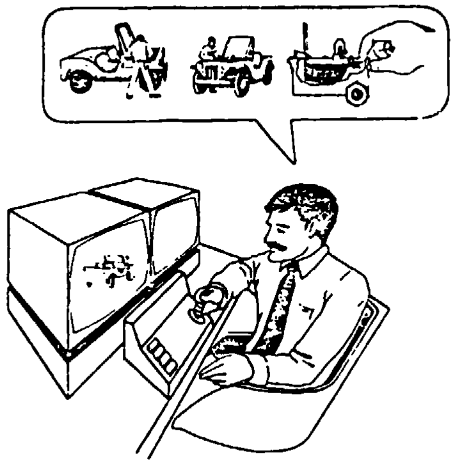

Fig. 1. Illustration of an Interactive Movie.

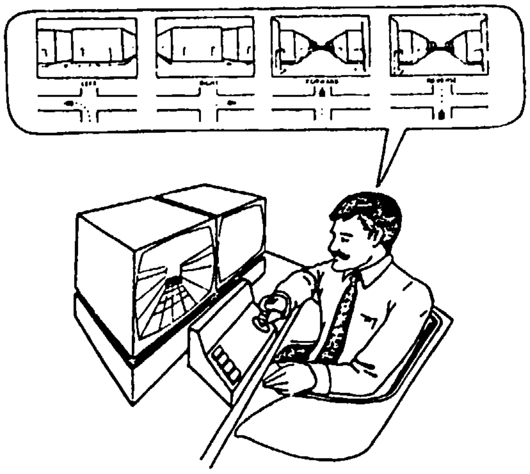

Fig. 2. Illustration of Surrogate Travel.

4. Level of abstraction. In some instances the viewer may wish to see the process being described in an entirely different form. For example, the viewer might choose to see an animated line drawing of an engine's operation to get a clearer understanding of what is going on. In some cases, elements being shown in the line drawings may be invisible in the ongoing action-- for instance, electrons or force fields can be shown.
5. Speed. Viewers can, of course, view the ongoing action at a wide continuous range of speed-- including reverse action and no action (still frame).
6. Plot. Viewers can change the "plot" to see the results of different decisions made at selected times during the movie.

A typical application for Interactive Movies would be in training (and aiding) equipment technicians. The technician could not only see how a particular part is located and installed from several points of view (e.g. top versus bottom) but could interactively control how detailed a description is either seen or heard regarding that maintenance activity.

Several Interactive Movie videodiscs have been completed using hand to hand combat (i.e., karate) as the subject area. These discs let the viewer not only control playing a particular karate move backward and forward at any rate, but also include multiple views and closeup views following every move from four different positions. In progress are several interactive Movies that focus on equipment maintenance tasks.

Surrogate Travel

Surrogate Travel, illustrated in Figure 2, forms a new approach to local familiarization and low cost trainers. The basic principle is simple. On videodiscs are stored up to 108,000 images showing discontinuous motion along a large number of paths in an area. Under microprocessor control, the user accesses different sections of the disc, simulating movement over the selected path.

The user sees with photographic realism the area of interest. Unlike a travel movie, the user is able to both choose the path and control the speed of advance through the area using simple controls. The videodisc frames the viewer sees originate as filmed views to what one would actually see in the area. To allow coverage of very large areas, the frames are taken at periodic intervals that may range from every foot inside a building, to every ten feet down a city street, to hundreds of feet in a large open area (e.g., a harbor).

The rate of frame playback, which is the number of times each video is displayed before the next frame is shown, determines the apparent speed of travel. Free choice in what routes may be taken is obtained by filming all possible paths in the area as well as all possible turns through all intersections. While it might first appear that this would be a time consuming and expensive technology, it is in fact relatively efficient because of the design of special equipment and procedures for doing the filming.

Demonstrations of this technology have been developed for building interiors (MIT, National Gallery of Art), a small town (Aspen, Colorado), an indusrial facility (nuclear power plant), a weapon site, and San Francisco Harbor. In progress is the production of a prototype video mapping library of broader scope for selected areas worldwide.

To provide training in reading and understanding maps, the photograph-based Surrogate Travel is linked to different sorts of maps of the area. In effect, the viewer can travel across a map, can fly into it getting greater and greater detail from what can be presented by standard map symbology, and then "fall through" the map to see photographically what the map depicts. In addition, the viewer can switch among different types of maps (e.g., topographic, infrared, etc.) to develop an understanding of how different map symbologies and representations interact.

In addition to ground level travel, including the inside and outside of buildings, aerial flight experience can be produced and used for flight training and airport familiarization. Similarly, other forms of travel experience, such as anchorage piloting and low level nap of the earth flying, are also easily accomodated.

Surrogate travel can also be used to provide training on routine and emergency procedures, physical plant maintenance, safety, security as well as other training requirements found in ships, military and industrial facilities. In these applications blueprints, floor plans, procedures, and up-to-date reference materials are linked with the photography of the site to provide a powerful and easy-to-use training system.

Electronic Libraries

Electronic libraries, illustrated in Figure 3, in the form of Spatial Data Management Systems (SDMS) provide students and instructors with quick and easy access to an assortment of multi-source and multi-media information (3). Users literally "fly over" information and select what they want by simply pointing. Spatiality is use to group materials into lesson plans so that different information spaces represent course concepts, additional instruction, and assessment procedures.

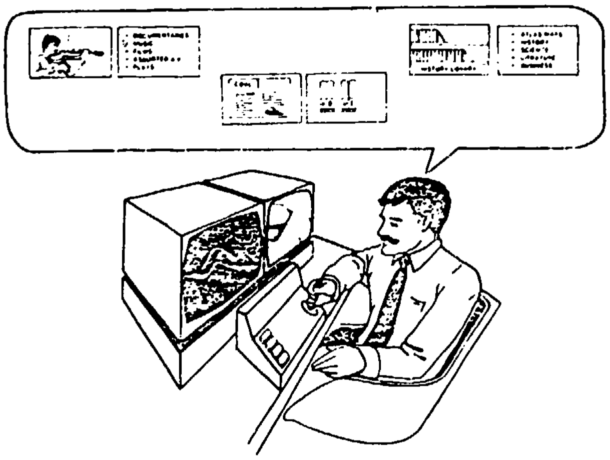

Fig. 3. Illustration of an Electronic Library.

Stored on a videodisc are tens of thousands of frames consisting of photographs, diagrams, charts, texts, movies, spoken speeches, music, graphs, etc. The pages can be organized, reassembled, segmented, and/or duplicated in accordance with the user's need and growing sophistication with the subject matter. The pages can be annotated, highlighted, drawn-on, underlined, etc., at the user's convenience and pleasure.

For the instructor, the SDMS provides ready access to a wealth of material which might otherwise be unaccessible. Instructors can access the SDMS to create their own information spaces (i.e., courses or lectures) and subsequently present such materials to large audiences in single locations via large screen television projection or to multiple locations through cable distribution systems.

Students can independently use the SDMS for self paced instruction by either working through previously designed information spaces or by browsing on their own. When students and instructors are in remote locations, offsite instruction is facilitated by linking two or more SDMSs together using regular telephone lines. In this manner, a student or instructor can literally fly the other to a topic of interest, sharing at geographically remote sites a large library of information.

The same video materials can be used for hundreds of different users. The only thing that must be changed from user to user is the magnetic storage medium which serves as the user's private librarian for the videodisc.

The U.S. Marine Corps Education Center is using the videodisc and SDMS technology to create the electronic library which we have discussed. The low cost replication characteristics of the videodisc make this medium an attractive alternative for the distribution of previously archived information.

ISSUES

Development and use of training applications employing the videodisc such as those discussed in the previous section raise a set of issues to be considered by the training community. A few of these issues are briefly discussed below:

1. What are the authoring requirements in producing videodisc based training systems? Probably the most important requirement is the need to work freely with the capability of storing and almost instantaneously accessing over 50,000 frames of information. Our experience is that many videodisc first-timers make only incremental use of the technology because they do not take advantage of its random access characteristics. Missing from the videodisc milieu are inexpensive authoring systems that would enable authors to put together and try out new videodisc program concepts. Bunderson and Campbell (1) have prepared a more complete discussion of this issue.
2. What is the role of digitized sound and synthesized speech in videodisc applications? Currently, several groups are experimenting with a number of means to overcome the lack of still sound in videodisc systems. Future videodisc systems will almost certainly incorporate still sound capabilities. However, synthesized speech may have an important place in videodisc applications given the rapid, random access capabilities of videodiscs. For example, in the Surrogate Travel application discussed earlier, the controlling computer also generates narrative descriptions that accompany the viewer's travel. Speech synthesis is used as the audio channel because it is not reasonable to prestore all things that could be said for all possible routes that the viewer might take.
3. How does videodisc technology affect the accessibility of training devices? A lot. With the videodisc, the training device designer gets a comparatively low cost (potentially less than $1,000) system that brings together an array of media (slides, text, graphs, movies, sound) in a compact and robust form. In some instances, very expensive computer graphics based systems may be replaced by inexpensive videodisc players.
4. How "smart" a videodisc training device is needed? Smart, yes, but not brilliant. The applications discussed earlier all use videodisc players controlled by small, inexpensive microcomputers. Future videodisc players may incorporate sufficiently capable microprocesor systems to allow the necessary functions to be

completely on board. While it is true that the players available today include a small microprocessor which can support branched instruction-- usage in this mode is far removed from the real potential of the videodisc as a training device.

5. How can training take advantage of the "super realism" offered by videodiscs? In the Surrogate Travel and low cost trainer applications, the viewer sees the real place (e.g., a real tank and, if appropriate, a real explosion). This is all made possible by storing a fascimile version of events and materials on the video disc. Thus, instead of seeing a simplification (although at times this may be beneficial), the user interacts with the object or process as it will be encountered in the work place.

6. Are videodisc training devices inherently "fun"? Stated in another form, since television is fun, will videodisc training devices find greater acceptance? Without attempting a full analysis we state our experience: Users enjoy working with these systems. We cannot say if this is because the systems are well designed, because they include color, sound, and motion, because they are a familiar medium (television), or because of something else. Nonetheless, the overwhelming impression we and others have gained from working with videodisc systems is that users like them.

The list of issues above is in no way complete. What we have attempted to do is alert the reader to some of the questions which have arisen through our own experiences. We feel that the area of videodisc based training devices is extremely promising and deserves considerable attention by the training community.

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ON THE USE OF A FLIGHT SIMULATOR'S FREEZE FEATURE DURING ACQUISITION OF A CARRIER LANDING TASK

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ABSTRACT

Performance errors committed during the acquisition of a carrier landing task in the simulator resulted in the occurrence of a freeze. Pilot subjects exposed to the freeze developed control strategies which were distinguishable from those of a no-freeze control group in terms of throttle, rudder, aileron, and elevator activity. Neither rate of learning nor level of performance was affected. Use of the freeze, however, was reported as initially "frustrating" and as adding to the overall difficulty of acquiring the task. With certain applications, the freeze appears to be aversive, altering pilot motivation for learning the task. Methodologically, the study's use of a probe trial technique represents a departure from the traditional transfer of training methodology for the assessment of alternative instructional treatments.

INTRODUCTION

Error-free and trial-and-error approaches represent extreme positions with respect to the treatment of errors during learning. (6,13,14) The traditional approach to flying training lies somewhere between these extremes. Not until the recent widespread use of flight simulators did the instructor even have a choice with respect to how errors could be dealt with instructionally. Now that instructional options are available, one question that arises is the extent to which errors should be permitted to freely occur during training and the extent to which errors actually affect subsequent performance. (13)

The specific role of errors in skill acquisition is unknown. Holding has expressed the concern that frequently committed errors may be learned, or if not actually learned in the sense of being committed more frequently, that they may become embedded in the student's response repertoire. (6) This outcome appears possible in the case of the carrier landing task studied here since errors often seem to be reinforced. For example, a marginal approach, although being severely criticized by the Landing Signal Officer (LSO), can result in a safe touchdown. Although Navy pilots are consciously and explicitly concerned with technique in making carrier approaches, successful completion of a dangerous task by any means is, in a strict sense, reinforcing. Undoubtedly, the natural consequences of errors has a powerful self-correcting influence in perceptual motor learning, but the natural consequences of errors in carrier approaches may not be sufficiently negative with the required frequency to give full force to this effect.

The present study sought to address those instructional approaches to teaching the carrier approach task that are possible given the instructional environment of the flight simulator. The carrier landing task was considered ideal for the present study. Control behavior is strictly constrained by the demands of the task, and errors can be clearly specified. Navy pilots and instructors almost unanimously agree that error detection and correction are fundamental to safe and consistent carrier landings.

Specifically, the study addresses the use of the simulator's FREEZE feature to interrupt an otherwise continuous performance whenever an error is detected. The simulator environment also makes it possible following an error to either allow the errorful performance to continue or to make some correction (e.g., putting the aircraft back on course) prior to continuing the task. A potential instructional advantage of using the FREEZE is that of allowing the student to attend to instructional feedback without at the same time having to continue to fly the aircraft. A potentially negative aspect, however, is that the FREEZE may function like a Time Out (TO), a behavior modification method frequently used to suppress inappropriate or undesirable behavior.

An important methodological issue is also addressed by the present study, that of how to assess the differential effectiveness of alternative experimental treatments (in this case, instructional conditions) upon subsequent ability to perform the criterion task: the familiar transfer of training problem. One important issue in transfer of training research is related to the selection of an appropriate training period. Training to a proficiency criterion has often been used, but in a study of differential transfer, the average time for various groups to attain proficiency almost invariably differs. Thus training time tends to be confounded with the experimental effects of interest. Fixed training times resolve that problem but selection of an appropriate period can be critical, and necessarily relies heavily on the judgement and experience of the experimenter. Training times could be too short to allow differences to emerge. Alternatively, they could be so long that worthwhile training differences are worked out by subjects attaining a high level of proficiency with even the poorest training conditions. Thus training times should be extended into, but not beyond, that period in training that shows worthwhile learning differences between instructional methods.

Pre-experimental work could ascertain the most appropriate training period but it would require expenditure of a large portion of the experimental resources to obtain a reliable answer. Furthermore, in a study of more than two training conditions, the selected training time may be appropriate for only some of the comparisons. A range of times could be used, but to do so would only reduce the power of the experiment (i.e., its capability to reveal differences between conditions) to the extent that some of the selected training periods are inappropriate.

The alternative addressed in the present study is that of a "probe" technique. A probe technique in which learning trials are interspersed with test (criterion) trials could avoid the problems discussed above. This technique, which appears to have been used only once in applied transfer of training research (15), might effectively map the course of learning and thus allow an estimate of the optimum training period for each instructional method. Smith et al. (15) used a single trial probe strategy in which they alternated training and probe trials; a strategy that was probably not optimum. Presumably, an experimental session should be weighted heavily with training versus probe trials to limit dilution of the training effects. Nevertheless, probes should be frequent enough to ensure that critical differences are not missed, and sufficient data would be required at each probe to achieve worthwhile stability. Probe methodology would seem to offer distinct advantages for the initial investigation of a novel training method. However, for evaluating its savings in relation to a standard instructional paradigm, the traditional transfer of training paradigm would still be preferred.

Summary of Primary Objectives

1. To assess the relative effectiveness of three instructional methods differing in the degree to which each alters the instructional environment following an error.

2. To determine the effects of displacement-only versus displacement-displacement-plus-rate error criteria on acquisition of the approach to landing task.

3. To assess the extent to which criterion performance sampled periodically on probe trials is sensitive to what is being learned on training trials.

METHOD

Subjects

Five groups of experienced Air Force pilots were taught carrier landings in a flight simulator at the Naval Training and Equipment Center under a control or one of four experimental training conditions. Pilot subjects averaged 35 years of age, had approximately 2400 flying hours, 300 simulator hours, and approximately 20 hours in their assigned aircraft (F-4 or F-16) in the 30 days preceeding the study.

Apparatus

The Visual Technology Research Simulator (VTRS) consists of a fully instrumented T-2C Navy jet trainer cockpit, a six degree-of-freedom synergistic motion platform, a 32-element G-seat, a wide angle visual system that can project both computer generated and model board images, and an Experimenter/Operator Control Station. (5) The motion system, G-seat and model board were not used in this experiment.

Visual System

The background subtended 59^{o} above to 39^{o} below the pilots' eye level, and 80^{o} to either side of the cockpit. The carrier image, which was a representation of the Forrestal (CVA 59) was generated by computer and projected onto the background through a 1025-line video system. A carrier wake and FLOLS were also generated by this method. Both day and night carrier images could be displayed.

Average delay between control inputs and generation of the corresponding visual scene was approximately 116 msec. Calculation of new aircraft coordinates required 50 msec while calculation of the coordinates for the visual scene corresponding to the viewpoint from the new aircraft coordinates required approximately 50 msec. Generation of the new scene required 16 msec. An updated visual scene was displayed every 33 msec.

The sky brightness for the day scene was 0.85 fL (foot-Lambert) and the seascape brightness was 0.6 fL. The brightness area of the day carrier was 4.0 fL. Except for the horizon, there were no features represented in either the sky or sea. The night background luminance was 0.04 fL and the horizon and seascape were not visible. The night carrier appeared as light points of 0.8 fL brightness outlining the landing deck and other features.

Fresnel Lens Optical Landing System (FLOLS)

In contrast to a carrier FLOLS, which is generated by incandescent lights, and can therefore be much brighter than other parts of the carrier, the simulated FLOLS was generated by the same system as the carrier image. It was, therefore, only as bright as the brightest areas of the ship (e.g., the white lines on the landing deck). To compensate for its lower relative brightness, the FLOLS was enlarged by a factor of three when the distance behind the ramp was greater than 2250 ft. From 2250 ft the size of the FLOLS was linearly reduced until it attained its normal size at 750 feet. The FLOLS was centered 414 ft down the landing deck and 61 ft to the left of the centerline. It was set at a nominal 3.5^0 glideslope and with a lateral viewing wedge of 52^0.

Simulator Configuration

The simulator was initialized with the aircraft at 9000 ft from the ramp, on the glideslope and centerline, and in the approach attitude and configuration (hook and wheels down, speed brake out, 15 units AOA, and power at 83%). The T-2C is normally landed with full flaps, but flaps were set at half extension for this experiment to more closely simulate approach speeds of typical fleet aircraft. Fuel was set at 1320 lbs to give 10,000 lbs gross weight. A landing trial was flown from the initial condition to wire arrestment or, in the case of a bolter, to 1000 ft past the carrier. The carrier was set on a heading of 360^0 at 5 knots. Enviromental wind was set at $349.^0$ with a velocity of 20.1 knots. This combination of carrier speed and environment wind produced a relative wind component of 25 knots directly down the landing deck. Turbulence was used to increase the difficulty of the task. The turbulence model buffetted the simulator with a random forcing fuction.

PROCEDURE

Two subjects arrived at the simulation facility each day, Monday through Thursday, during the experiment. They viewed a video tape on carrier landings which described the FLOLS and carrier landings. They were then given detailed instructions by a Navy LSO on carrier landing techniques. This instructional period lasted approximately 45 minutes. Where convenient, subjects were given their preliminary instruction in pairs, but the remaining experimental work was undertaken with only one subject in attendance except that subjects were occasionally permitted to monitor the performance of others from outside the simulator if they had entirely completed their experimental work. Subjects were assigned to training conditions as they arrived at the simulator facility in accordance to a predetermined sequence.

Training Conditions

Two experimental training procudures in addition to a control (CONVENTIONAL) procedure were used in the experiment. For both experimental procedures, the subject pilots were frozen during the approach if their vertical deviations from the glideslope broke specific criteria. Under one procedure, known as FREEZE/RESET, when the pilots were frozen they were instructed on how they had incurred their vertical error and were then reset to the glideslope with the simulator in its optimum approach attitude. Longitudinal distance from the carrier and lateral distance from the extended centerline of the landing deck were not changed. Pilots continued their approach from the reset position. Under the other experimental procedure, known as FREEZE/FLYOUT, pilots were instructed on how they had incurred their vertical error and how to correct it once they were released. They then continued their approach from the position and attitude in which they had been frozen.

Two different experimental training conditions were derived from each FREEZE procedure by applying two different freeze criteria. The first froze the system if $|\theta_i| \geq |\theta_c|$ where

θ_i = angular displacement of the aircraft from the 3.5 degree glideslope,

$\theta_c = 0.5625 - (.3125 \times 10^{-4})$, and where

r = range in feet from the carrier ramp

This algorithm linearly increased the criterion in meatball units from 1.0 at 6000 ft from the ramp to 1.5 at the ramp. Freezes did not occur beyond 6000 ft or past the ramp.

The second criterion would result in a freeze if vertical deviation from the 3.5^0 glideslope, or decent rate error, or some combination of the two was excessive. Freezes would occur if $|M_i| \geq \theta_c$ for

$M_i = \theta_i + 0.5625\, \dot{\theta}_i \dot{\theta}_c$

$\dot{\theta}_i$ = angular rate of displacement in degrees/second from the glideslope

$\dot{\theta}_c = 0.405 - (.49 \times 10^{-4})(r + r_k)$

r_k = 524 feet, the distance of the carrier from the FLOLS origin.

This algorithm established a criterion that was a weighted sum of the previously described displacement criterion and a descent rate error limit that decreased linearly from 600 fpm at 6000 ft from the ramp to 200 fpm at the ramp.

None of the experimental training conditions permitted a freeze within 10 seconds of restarting the approach after a freeze. In adddition, a freeze would not occur if, at the end of this 10-second period, the subject was outside of the performance criterion but was descreasing his error.

In a fifth training condition, designated as CONVENTIONAL, subjects were not frozen during the approach but were given their error feedback, equivalent in nature to that given the FREEZE/FLYOUT group, during and at the end of each trial.

After preliminary instruction, subjects were familiarized with the controls of the simulator. They were then given a brief flight of approximately two minutes before they commenced their carrier landing training. The training sequence consisted of 24 approaches to the day carrier on the afternoon of their first day at the simulator facility, and 24 approaches to the night carrier on the morning of their second day. The two 24-trial blocks were divided into 6-trial sub-blocks, the first 4 trials of which were flown under the appropriate training condition. The last 2 trials of each sub-block were used as probe trials to assess the progress of learning, and were flown under the control condition. The LSO gave no instructions during or following probe trials. Subjects were given a 10-minute rest after the twelth trial of each 24-trial block.

Performance Measurement

Parameters of aircraft position and attitude were sampled at 30 Hz and used to derive altitude and lineup error scores from the desired approach path, and deviations from desired AOA (15 units). Root Mean Square (RMS) error, mean algebraic error and variability around that mean were calculated for these three dependent variables or four equal segments of the final 6000 ft of the approach.

Glideslope and lineup errors at 4500, 3000, 2000, 1000, and 0 ft from the ramp were used to derive means and standard deviations at these five points in the approach. Distance from the deck, distance from the centerline, and descent rate were measured at touchdown, and the Landing Performance Score (LPS) was calculated. (3) The LPS is a score assigned to each pass, ranging from 1.0 (technique wave off) to 6.0 (#3 wire trap).

Lateral stick, longitudinal stick, rudder pedal, and throttle positions were sampled at 30 Hz. The distance of control movement from one sampling point to the next was accumulated over one second periods and averaged over four equal segments of the final 6000 ft of the approach.

RESULTS

Day Versus Night Performance

The data showed little evidence for significant improvements in student pilot performances during the night carrier approaches. Isolated effects during the night trials included a significant reduction in aileron movement in the area of 6000-4000 ft to the ramp; a reduction in glideslope variability from 1000 ft to the ramp; and a reduction in throttle movement from 3000-1000 ft to the ramp. Since performance appears to have stabilized during the day carrier trials, results are discussed for the day trials only except as where noted otherwise (specifically, the correlational results on the probe vs. training trial performances and the discriminant function analysis).

Use of Displacement Versus Displacement-Plus-Rate Error Criteria

Neither rate of learning nor level of performance was significantly affected by the particular error criterion in effect; that is to say, whether the freeze was occasioned by deviations in vertical displacement or deviations in vertical displacement from glidepath plus rate of descent. Although Kaul et al. (8) found significant differences for experienced Navy pilots using displacement-plus-rate information displayed on the FLOLS, the Kaul study and the present study were different in several respects. (8) First, the displacement-plus-rate information in the Kaul study was presented to the pilot continuously via a modified FLOLS display. In the present study, the conventional FLOLS was displayed regardless of which error criterion was in effect. Second, the present study contained no condition which exactly paralled the displacement-plus-rate condition in the Kaul study. In the present study, there was no condition where subjects performed under the CONVENTIONAL (i.e., no freeze) criterion with feedback provided in terms of displacement plus rate. Although the subject population (experienced, carrier qualified Navy pilots versus experienced, but not carrier qualified Air Force pilots) also differed, the similarity of the glideslope maintenance portion of the task was highly similar for both groups of pilots.

Relationship Between Performance on Training Trials and Subsequent Probe Trials

Pearson product moment correlation coefficients were computed between measures of performance on training trials and subsequent probe trials for subjects in both the FREEZE/FLYOUT and CONVENTIONAL conditions. Data were combined across both day and night landing trials. No correlations are reported for the FREEZE/RESET condition since use of the RESET feature precludes use of variability data. Correlational data are not presented here due to limitations on published presentation length. Nevertheless, the following observations can be made from these data.

1. During the approach portion of the task, a high degree of consistency was observed between pilot control movements (i.e. pilot inputs to aileron, pedal, and elevator) on training trials and subsequent probe trials. This was true to a lesser extent for throttle control. This suggests that for subjects within a given instructional condition the same or similar control strategies used during training were also used during probe trials.

2. Even though control inputs appear to have been consistent across training and probe trials, the consistency of training and probe trial touchdown performances differed as a function of instructional method. The correlation between the wire caught on probe and training trials was highly correlated for the CONVENTIONAL group (r=0.60) but not for the FREEZE/FLYOUT group (r=0.17). Likewise, pitch, vertical velocity at touchdown, and angle of attack at touchdown were significantly correlated for the CONVENTIONAL group (correlations of 0.64, 0.78, and 0.53, respectively) but not for the FREEZE/FLYOUT group (correlations of -0.11, 0.32, and -0.10, respectively). The extent to which performances acquired during training transfered to the criterion conditions of the probe trial is also expressed in terms of the correlations between Landing Performance Scores (LPS) on training and probe trials. For the Conventional group this correlation was 0.35; for the Freeze/Flyout group, 0.18.

Did Learning Occur

The data showed a small but statistically significant reduction in freezes (errors) across successive blocks of probe trials, F(3,60)=3.62, p=0.018, indicating that learning did occur. Comparisons by instructional condition, however, revealed no signficant differences due to group assignment, F(4,20)=0.94, p=0.46. The learning effects are small when considered from an operational standpoint. The opportunity for measured errors to occur was bounded by the 10-second limitation imposed on the freeze as well as by not freezing when a rate error was in effect but the pilot was correcting. Neither can the effect of subjects' experience be overlooked. Based on their experience with constant airspeed, angle of attack approaches, one might expect that the carrier task differed only in close to the ship (e.g., 3000 ft to the ramp). This is supported by the data which show significant practice effects occurring most often in the 1000 ft to the ramp segment of the task. Only in the case of aileron movement did significant learning effects occur consistently in all segments of the task from 6000 ft to the ramp.

Process Versus Product Measures of Performance

A step-wise discriminant function analysis (BMPD7M) was performed on the performance measures. As the data set did not conform to rules normally required for a discriminant analysis (e.g., the size of the smallest group should exceed the number of variables), its use here should be considered as purely exploratory. (16) The cumulative proportion of total dispersion accounted for by the discriminant function was 48%, and the variables that contributed most to separation of the groups were those of control movements (pedal movement from 4500-3000 feet from the ramp, throttle movement from 1500 feet from the ramp to touchdown, and aileron movement from 4500 to 3000 feet from the ramp). The discriminant function tended to distinguish the control (CONVENTIONAL) group from the experimental groups, and in all cases the trends in the data were towards smoother control inputs for pilots in the CONVENTIONAL (no freeze) condition.

The results of the discriminant analysis agree with those of the correlational analysis in so much as they point to pilot control responses as being the dimension most significantly affected by variations in instructional approach. It appears from the data that those pilots exposed to the freeze adopted control strategies that were different than those adopted by pilots in the CONVENTIONAL instructional condition. It is hypothesized that these differences were acquired during training as part of the task of "coming-off-freeze." The probe trial procedure was sensitive to the transfer of variations in control inputs from training trials to probe trials even though customary training outcome measures of performances on probe trials were not found to differ as a function of instructional condition.

Questionnaire Responses

Following participation in the study, each pilot subject in the FREEZE/FLYOUT and FREEZE/RESET groups completed a questionnaire (see Appendix). The results are summarized below.

On the General Role of Errors in Training

Pilots generally disagreed that "errors served little purpose" as well as with the notion that "students may actually learn the errors they commit" (Item 12). Pilots also disagreed with the contention that "instructional methods that allow errors to occur are inefficient" (Item 14). Instead, pilots in the study pointed to error recognition as a basis for the development of correct performance (Item 18). Errors were seen as helping the student to focus on the critical elements of task performance (Item 13), as well as exposing the student to out-of-tolerance situations which may under later conditions result from factors such as adverse weather, visibility/ceiling limitations, etc. (Item 15). On the issue of whether correct performance is best thought of as resulting from a process of eliminating errors or from a process of shaping desired responses, pilots were undecided (Item 17).

On the Instructional Use of the Freeze Feature

Pilots agreed that it was significantly easier to attend to the LSO's feedback while the simulator was frozen than while trying to listen and fly the aircraft simultaneously (Item 3). Pilots also agreed that use of the the freeze aided in the development of error recognition (Item 5). Pilots, however, were undecided as to whether the use of the freeze might be used to significantly decrease the overall training time required to learn the landing task. On the negative side, pilots indicated that the occurrence of the freeze early in training was "frustrating" (Item 8). In fact, pilots in the FREEZE/RESET condition indicated that they were more motivated by "trying to avoid the freeze than by trying to fly the task correctly" (Item 7). Reponses of pilots in the FREEZE/FLYOUT condition to the same item did not reflect this implied aversive aspect. Regardless of the freeze condition to which subjects were assigned, all indicated that regaining control of the simulator following a freeze significantly added to the difficulty of the flying task (Item 2), and that the difficulty increased the closer the freeze occurred to actual touchdown (Item 2).

In general then the questionnaire data indicated that pilots perceived errors as contributing positively to training; that the present use of the freeze was in some instances aversive and that it served to add to the difficulty of learning the task in the simulator despite the fact that the freeze made it easier to attend to the feedback from the LSO instructor. So far as being able to potentially reduce the time needed to learn the task, pilots perceived the present applications of the freeze to have little value in this regard.

SUMMARY AND CONCLUSIONS

The view of the freeze as an opportunity to review past events and to plan for the future is consistent with an information processing approach to learning. (9) Under this view, competing information processing activities can interfere and retard acquisition of perceptual-motor skills. There was no evidence that this was the case in the present study, even though pilots indicated that it was easier to attend to the LSO's instructional feedback while frozen than to do so while continuing to perform the task simultaneously. Subjects in the present study were, however, experienced Air Force pilots even though naive with respect to the carrier landing task. Those studies which suggest that experienced pilots are better able to time share than less experienced pilots or non-pilots would suggest that differences might have emerged had subjects come from a less experienced subject population.

The specific relevance of the information processing notion to flight instruction has not been fully established. Other psychological processes may play a role in mediating the effect of the freeze. For example, the freeze could well be aversive, functioning in the same manner as a "time-out from positive reinforcement" (usually referred to simply as T.O.) has been shown to function in the control of undesirable or inappropriate behavior. (2) Pilot comments in the present study support the view that the freeze may be viewed as aversive and that some applications of the freeze (e.g., the FREEZE/RESET) may even significantly alter the nature of the student's motivation to learn the task. All agreed that use of the freeze was "frustrating" early in training. That one or more of these processes can affect the acquisition of a psychomotor task is also indicated by the work of Payne and his associates. (10, 11,12)

Furthermore, there can be no certainty that the freeze effect will facilitate learning. The interruption caused by the freeze may disrupt the integrity of the task in a manner reminiscent of part-task learning. It was clear in the present study that the use of the freeze produced differences in how pilots' performed the landing task even though analyses of customary performance measures failed to clearly discriminate between instructional treatments. Pilots were in general agreement that the freeze added to the difficulty of the task and suggested that this difficulty is, in part, traced to the task of "coming-off-freeze," a task that becomes more difficult the closer the freeze occurs to touchdown. It thus appears that the effect of the freeze is more than that of simply halting the simulation. Instead, it seems to add a new task component and to contribute, as well, to the overall difficulty of the primary task being learned.

Lastly, from a methodological standpoint, the present study is significant in that it demonstrates the utility of the probe trial technique as an alternative to the more traditional transfer of training methodology for the preliminary investigation of instructional treatment effects. In the present case, the probe technique proved to be sensitive to learning effects as well as to subtle differences in criterion performance acquired as the result of the use of the freeze.

Recommendations

1. Avoid use of the flight simulator's FREEZE feature during the performance of a continuous control task such as that involved in the approach to landing task. Other tasks to which this advice might also apply are aerial

refueling training and weapons delivery training.

2. Consider as an alternative to use of the FREEZE the use of the simulator's IN-FLIGHT CONDITION STORE feature whereby events captured at discrete points in a maneuver can be stored and later recalled for student review. Consider also use of the simulator's RECORD/PLAYBACK feature. In doing so, however, remember that in some instances the training time consumed in using the PLAYBACK may be better used to provide the student additional practice time. (7)

3. Response chaining as a training methodology is not ruled out by the findings of the present study. The data would simply suggest that once a response sequence is begun it is advisable to allow the sequence to proceed to completion. This is true whether chaining is conducted in a forward direction with termination of the sequence occurring as the result of an error, or whether chaining is conducted in a "backward" direction (2) where termination occurs with performance of the final link of the chain.

4. The probe methodology is strongly recommended as an alternative to the traditional transfer of training paradigm, especially for exploratory studies where training effectiveness may vary not only as a function of instructional approach but also as a function of amount of training.

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Appendix

Student Pilot Questionnaire

INSTRUCTIONS: Circle the number on the scale that best describes your response to each of the following items.

1. Use of the freeze feature may be used to significantly decrease the overall training time required to learn to landing task.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

2. Regaining control of the simulator following a freeze signficantly added to the difficulty of the flying task in the simulator (when responding, consider each of the following phases of the maneuver separately):

(a) "In the Middle" (first 1/3)

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

(b) "In the Groove" (second 1/3)

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

(c) "In Close" (5-10 seconds from the ramp)

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

(d) "At the Ramp"

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

4. Improvements in performance were highly correlated with a decrease in the number of freezes.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

5. Using the freeze feature to explicitly identify pilot errors during the "training" trials made it easier to detect errors on "test" trials when no feedback was given and when no freezes were in effect.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

6. Compared with the usual practice of giving detailed feedback at the conclusion of a task, providing feedback immediately following an error is more effective.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

7. In learning the task, I was more motivated by trying to avoid a freeze than by trying the fly the task correctly.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

8. The occurrence of the freeze was "frustrating" early in training.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

9. A helpful feature would be to present a "warning" signal (such as an auditory tone) prior to freezing the visual system.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

10. Night approaches were more difficult to learn than the day approaches.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

11. Errors were more difficult to detect during the night approaches than during the day approaches.

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

12. "Errors serve little purpose, since students may actually learn the errors that they commit."

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

13. "Errors help the student to focus on the critical elements of task performance."

1 2 3 4 5

Strongly Neutral Strongly
Disagree Agree

14. "Instructional methods that allow errors to freely occur are inefficient, since students spend valuable time practicing incorrect responses."

1 2 3 4 5

Strongly Disagree — Neutral — Strongly Agree

15. "In committing errors, students learn how to recover from situations which at some later time may be caused not by task-specific errors but by conditions beyond their control (for example, by adverse weather, visibility, turbulence, etc.")

1 2 3 4 5

Strongly Disagree — Neutral — Strongly Agree

16. "Pointing out 'errors' frustrates students, whereas pointing out what a student is doing 'right' is reinforcing."

1 2 3 4 5

Strongly Disagree — Neutral — Strongly Agree

17. "Correct performance results from a process of elimininating errors and not from a process of shaping desired performance."

1 2 3 4 5

Strongly Disagree — Neutral — Strongly Agree

18. "A student's recognition of what is considered correct is dependent upon his being able to recognize what is incorrrect (that is, an error)."

1 2 3 4 5

Strongly Disagree — Neutral — Strongly Agree

A COMPARATIVE ANALYSIS OF THREE APPROACHES TO THE MAN-MACHINE INTERFACE PROBLEM AT THE FLIGHT SIMULATOR INSTRUCTOR/OPERATOR STATION

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ABSTRACT

This paper analyzes the principles of instructor/operator station (IOS) design employed in three flight simulators recently produced by the same company, Sperry Systems Management - SECOR. The analysis brings out major differences among the three; comments on the reasons for the various approaches selected; examines the experience of users of each trainer, to the extent that data is available; and draws conclusions regarding the comparative merits of each approach. In addition, it discusses the problem of objectively evaluating the efficiency of IOS designs in general.

INTRODUCTION

Concurrent with other trends in flight simulator development, e.g., improving the fidelity of aerodynamic simulation, increasing the detail and realism of visual scenes, and increasing the variety and sophistication of instructional programs, there has been growing interest in improving the efficiency of the instructor/operator station (IOS). There is new awareness of the fact that a knowledgeable instructor, assisted by easy-to-interpret displays and easy-to-operate controls, is central to the effectiveness of a trainer.

In the past two years Sperry Systems Management - SECOR has produced three trainers--one is still to be delivered--whose instructor-operator stations, for various reasons, differ widely in design. These trainers are Device 2F119, the EA-6B Weapon System Trainer (WST); Device 2F122, the A-6E Night Carrier Landing Trainer (NCLT); and Device 2F132, the F/A-18 Operational Flight Trainer (OFT).

Each of these trainers has a remote IOS, i.e., one in which the instructor's console is located outside the cockpit and the instructor monitors student performance with his own displays, indicators, and instruments rather than by direct, over-the-shoulder observation. In other respects, however, each instructor station is significantly unique, and each presents a different approach to the problems of man-machine interface that occur at the IOS.

EA-6B WST

The EA-6B WST is located at NAS Whidbey Island, Washington, and achieved final Government acceptance in December, 1979. Its primary mission is to train the members of the four-man crew in all aspects of a combat mission, including pre-flight preparations, engine start, carrier launch, navigation to a target area, penetration of enemy defenses, utilization of electronic jamming equipment, defense against hostile counter-action, return to the carrier, and landing. Most of the utilization of the trainer, however, is for training pilots in emergency procedures, instrument flight, carrier landings, and such operations that do not include a full crew. In addition, the trainer is used for training ECM operators (ECMOs) alone, and supplements a part-task trainer, the 15E22A, which is available at Whidbey.

IOS Configuration

As is fitting for a trainer with a complex mission, the instructor station is quite large. With a wide wrap-around configuration (see Figure 1), it is designed to accommodate three instructors--one (designated the Flight Instructor) for monitoring the pilot, one (the ECMO-1 Instructor) for the ECMO-1, and the third (the Tactics Instructor) for the ECMO-2 and ECMO-3. In the aircraft, the ECMO-1, who sits in the right front seat, operates the navigation radar and the ALQ-92 communications jammer; the ECMO-2 and ECMO-3, who sit in the aft cockpit, operate the ALQ-99 tactical jamming system.

The instructor station is equipped with five alphanumeric-graphic CRTs and a visual monitor. Two of these CRTs and the visual monitor are intended for the Flight Instructor, and he can also use a third CRT, which is in front of the ECMO-1 Instructor position.

Each instructor has a row of control panels containing an assortment of push-button, thumbwheel and other switches. At the Flight Instructor position there are the Visual System Control Panel, with controls for initiating and varying certain visual effects (but not all); the Mission Control Panel, by which the instructor selects and enters initial conditions, demonstrations, and "programmed missions"; the Trainer Control Panel, with controls for operating the motion system, varying sound, ground roll and rough air, initiating starting air and external power, removing chocks, operating trainer freeze and crash override, and performing other similar functions; and the Aircraft/Communication Control Panel, containing controls for communicating with the students and other instructors. Miscellaneous controls for other functions not mentioned above are also included on these panels. There are, in total, 47 operative controls on the four panels.

In addition to the various control panels, each instructor has a function keyboard consisting of 32 illuminated but untitled keys. The titles

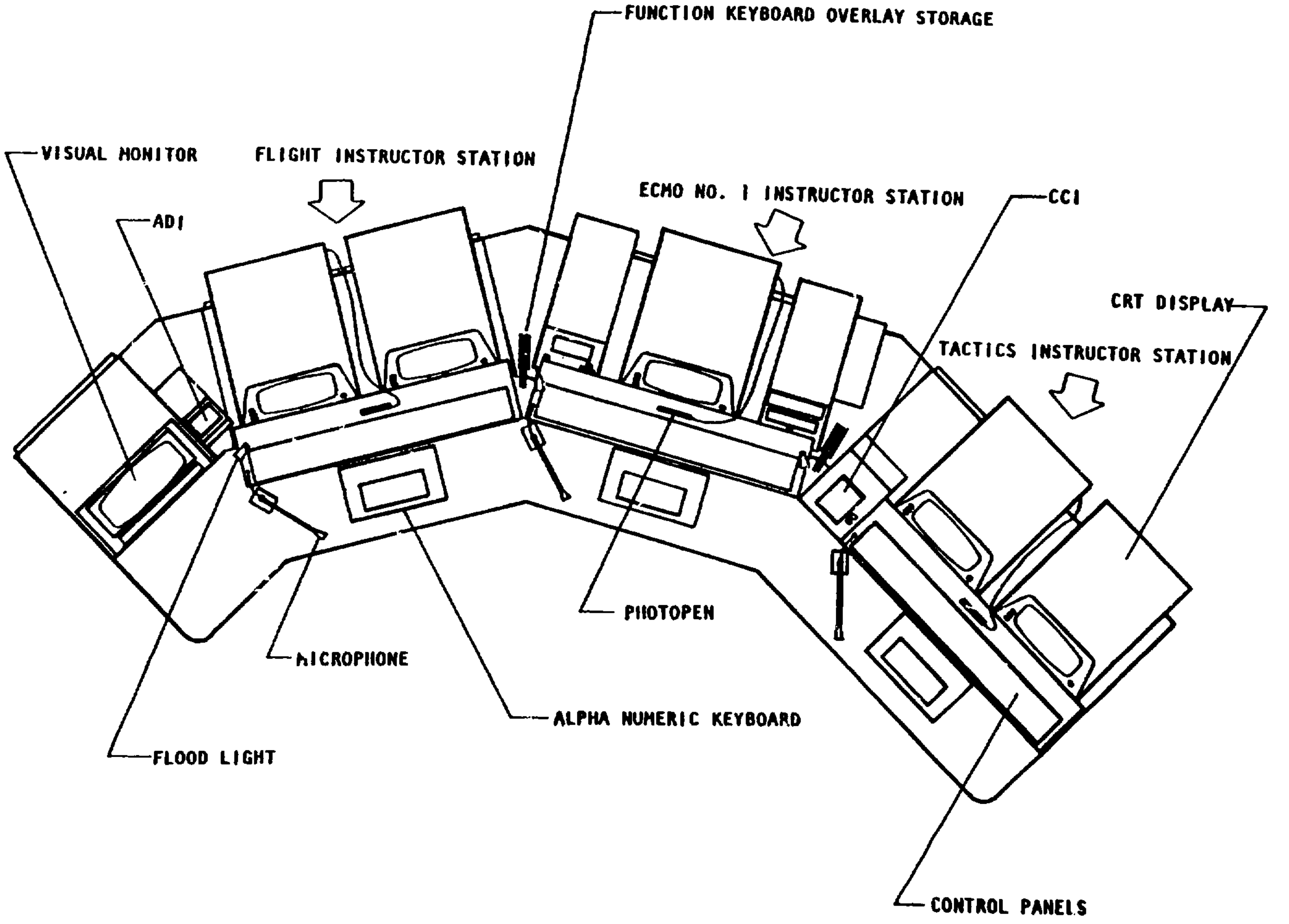

Figure 1. EA-6B WST Instructor/Operator Station

of the keys, defining their functions, are contained on an overlay which the instructor inserts at the beginning of the mission. There are six different overlays available for the Flight Instructor, one for each of the principal modes of operation: Operate, Plan (Disc File Generation), Plan (Demonstration), Display Printout, Critique, Test, and DRED (DRED is an acronym for Daily Readiness Testing). The Tactics Instructor has a unique set of overlays; the ECMO-1 Instructor uses overlays identical to those for the Flight Instructor.

When the Operate overlay is installed at the Flight Instructor's position, the keys are used for calling up displays and for performing certain control functions, such as storing CRT displays for later print-out, enabling map slew and aircraft slew (operated in conjunction with a "joystick" control), deleting the display of radio facilities not tuned in by the pilot, and overriding imminent malfunctions. Half of the keys are used directly for calling up displays; the remaining half are for control functions.

The use of overlays at the IOS is not standard in Sperry SECOR's design philosophy. The function keyboard installed in the EA-6B WST, and its attendant collection of overlays, was chosen in order to maintain commonality with the sub-contractor (the AAI Corporation) who was providing the Tactics part of the trainer, derived from their part-task ECM trainer, the 15E22A. In fact, Sperry SECOR procured the keyboard from AAI.

Because the function keyboard has a limited number of keys, it cannot accommodate all required control functions. Some are assigned to the Trainer Control Panel. Those retained on the function keyboard are ones with the closest relationship to CRT displays, since management of displays is the principal function of the function keyboard.

It would not have been practical to use an additional overlay for these "overflow" functions because of the undesirability of requiring the instructor to change overlays in mid-flight, so to speak. Changing overlays requires going off-line and interrupts the mission. On the other hand, the use of separate overlays for Plan, Display Printout, Test and the other modes is not an inconvenience because a natural interruption of the mission continuity occurs preceding those activities.

To complete the array of controls at the IOS, an alphanumeric keyboard and a light pen are provided for each instructor. Also, each instructor has a CRT Select Switch for designating the CRT where a display is to appear.

Displays

The EA-6B WST has an exceptionally extensive library of displays. There are ten displays for initial conditions sets (one for each set available), three displays depicting the instrument readings and control or switch positions in the cockpit, four types of map or map-like displays with four possible scales, 13 displays listing all of the programmable malfunctions (the trainer can simulate over 700 malfunctions, including 220 open circuit breakers), 98 displays of normal and emergency procedures, a display to initiate "parameter recording", a series of map displays for monitoring "computer-evaluated missions"*, two displays listing input codes, and several other specialized displays for programming and maintenance purposes.

The input code displays represent one of the most controversial characteristics of the trainer--the use of non-display dependent formats for data entry. All on-line parameter changes, such as increasing or decreasing the fuel load, adding or removing external stores, varying the wind direction and velocity, and changing the ceiling and visibility in the visual scene, are accomplished by entering an input code followed by a numerical value. To enter a surface wind velocity of 20 knots, for example, the instructor types WB 20 with the alphanumeric keyboard and depresses the RETURN key. Any entry can be made regardless of what displays are on the CRTs, as long as the instructor knows the proper input code.

A total of 112 input codes are listed on the two input code displays (one of the displays is shown in Figure 2). They are organized into six categories--Flight Parameters, Aircraft Configuration, Environment, Nav/Comm, Visual, and Others. Most of the codes are composed of two letters; however, there are eight one-letter codes, one three-letter code, and nine four-letter codes. The codes are designed to facilitate memorizing as much as possible; typical codes are AA for angle-of-attack, RC for rate of climb, LA for latitude, D for display, and C for carrier. Most visual codes start with V; VC is for ceiling, and VI for visibility. A number of visual codes related to intensity of lighting start with I; examples are IT for intensity of taxiway lights, and IF for intensity of flood lights. Inevitably there are instances where the best code for a parameter has already been assigned to another; the second choice is not always as logical. For example, IP had to be used for intensity of droplights since ID was already assigned to intensity of deck lights.

Most of the one-letter input codes are used in combination with the two-letter codes. For example, LA and LO, used to change the latitude and longitude of the aircraft ("ownship"), apply to the carrier when prefixed with C; and when used with G they will relocate the center of the gaming area. The letter I, when used as a prefix to a two-letter code, applies to the parameters in

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*Parameter Recording produces a continuous strip chart depicting a student's ability to maintain one or more flight parameters within specified limits--an airspeed of 140 knots + or - 10, for example; a Computer-Evaluated Mission, also called a Programmed Mission, automatically measures student performance over a preplanned flight profile containing a number of legs, or segments, designed to facilitate operation of the computer program without instructor intervention.

INPUT CODES D7

FLIGHT PARAMETERS

ANGLE OF ATTACK	AA
ANGLE OF BANK	AB
ACCELERATION	AC
ALTITUDE	AL
INDICATED AIRSPEED	AS
HEADING	HD
LATITUDE	LA
LONGITUDE	LO
MACH NUMBER	MN
PITCH ANGLE	PA
PITCH RATE	PR
RATE OF CLIMB	RC
RATE OF DESCENT	RD
ROLL RATE	RO
RPM LEFT	RL
RPM BOTH	RP
RPM RIGHT	RR
RATE OF TURN	RT
TRUE AIRSPEED	TA
YAW RATE	YR

AIRCRAFT CONFIGURATION

STATION, CENTERLINE	CL
EMERGENCY LANDING GEAR	EG
AIR REFUELING ENABLED	FE
FLAPS	FL
FUEL LOADING	FU
STATION, LEFT INBOARD	IL
STATION, RIGHT INBOARD	IR
LANDING GEAR POSITION	LG
STATION, LEFT OUTBOARD	OL
STATION, RIGHT OUTBOARD	OR
SPEEDBRAKE	SB

ENVIRONMENT

BAROMETRIC PRESSURE	BP
WIND DIRECTION AT 20000 FT	DL
ICING	IC
MANUAL MAGNETIC VARIATION	MM
MAGNETIC VARIATION	MV
RAINSHOWER DENSITY	RN
RUNWAY SURFACE	RS
SEA STATE	SS
TEMPERATURE, FREE AIR	TF
WIND DIRECTION AT SURFACE	WD
WIND VELOCITY AT 20000 FT	WL
RADAR WEATHER SET	WS
WIND VELOCITY AT SURFACE	WV

NAV/COMM

ACLS ELEVATION	AE
ADF BEARING	AF
ACLS CENTERLINE	AR
ACLS AZIMUTH	AZ
ARTCC FREQ	AT
APC FREQ	AP
NDB ON/OFF	BO
GCA/CCA AZIMUTH	GA
GCA/CCA CENTERLINE	GC
GCA/CCA ELEVATION	GE
RADIO FACILITY SET	RF
RUNWAY IN USE	RU
TACAN BEARING	TB
TACAN DME	TD
TERMINAL AREA	TE
TACAN ON/OFF	TO

Figure 2. Input Codes Display

an initial conditions set. For example, by entering ILA and ILO, followed by the appropriate numerical values, the instructor can change the latitude and longitude of the ownship as indicated on any initial conditions set being displayed.

The letter B is used to activate malfunctions. The instructor enters B followed by the number of the malfunction, which he can obtain from the displays listing all available malfunctions, unless he remembers the number or has previously determined it in his pre-mission planning. To remove the malfunction he enters R, followed again by the number.

Until development of the EA-6B WST, Sperry SECOR had never used input codes and non-display dependent formats, except for specific purposes such as entering malfunctions. The rationale for adopting input codes for the EA-6B WST was, again, to be consistent with AAI, whose Device 15E22A uses this approach (their term for an input code is "command word").

The light pen is available as an alternative input method for many IOS functions. For example, it can be used to enter malfunctions by illuminating the number of the desired malfunction on the Malfunction Display, and to remove the malfunction by illuminating the title. It is the only method for activating simulated antiaircraft fire and surface-to-air missiles via the Hostile Environment Display. It is also the most flexible method for removing the dotted aircraft track (to reduce clutter).

User Experience

The principal user of the EA-6B WST is VAQ 129, a squadron at NAS Whidbey Island whose primary mission is the training of replacement pilots and ECMOs. Currently (June 1981) there are 12 instructors (four pilots and eight ECMOs) trained in the operation of the trainer. In addition there are eight other personnel able to function as device operators.

When a full-crew mission is flown in the trainer, the instructor station is usually manned by an instructor at each of the Flight and Tactics Instructor positions, a device operator at the ECMO-1 Instructor position, and a supervisory instructor seated or standing behind the other three persons. The use of a device operator has evolved since the trainer was delivered. The original Specification for the trainer did not call for that position.

Because the ECMO-1 Instructor position does not have a full set of controls (there is no Mission Control Panel and the Trainer Control Panel is considerably abbreviated), the device operator seated there has limited utility. However, he has a function keyboard and an alphanumeric keyboard, and he can call up displays on his CRT and take actions involving use of the input codes, including entering and removing malfunctions (at the Flight Instructor's direction). Since he has a CRT Select Switch, the device operator can generate displays on the Flight Instructor's two CRTs, but in practice the Flight Instructor handles his own displays. The device operator cannot assist both the Flight and Tactics Instructors because he would have to use two Operate overlays on his function keyboard--an impractical procedure, as explained previously.

In general, the users of the EA-6B WST are satisfied with the design philosophy of the IOS. They have no significant adverse opinions regarding the function keyboard and overlays, the non-display dependent formats and input codes, and the alphanumeric keyboard. Since they expect the device operator to be the principal user of the alphanumeric keyboard, they are not concerned about the reputed antipathy of instructors, particularly pilots, toward typing. They agree with the need for consistency between the Flight and Tactics sides of the IOS, and being familiar with AAI's designs in Device 15E22A, they accept those approaches as being the appropriate ones to use.

They rarely use the light pen as an input device, except when it is the only method available. A major reason for the light pen's unpopularity is the fact that it is relatively slow and difficult to aim precisely at a desired point on the display.

Also, the users are dissatisfied with the Pilot's Instrument Monitor Display. This display depicts the various instruments in their relative positions on the aircraft instrument panel, but the readouts are digital with a one-hertz update rate. The users are considering adding a number of repeater instruments to the instructor station, or substituting for the digital display a pseudo-instrument display with analog readouts.

The Flight Instructors and Tactics Instructors who are experienced in use of the trainer do not have difficulty in coping with the complexity of the IOS. However, they are limited in number, considering the intense training program at Whidbey, and are being subjected to continual turnover. The trainer is too complex to be operated by unqualified personnel. The device operators are useful, especially during trainer turn-on and problem set-up; however, instructors must be thoroughly familiar with the trainer's capabilities in order to give effective direction to the device operator.

A-6E NCLT

Two A-6E NCLTs have been delivered, one to NAS Whidbey Island, Washington, and one to NAS Oceana, Virginia. The acceptance dates were December 1980 and March 1981, respectively. The primary mission of the NCLT is to train pilots in carrier landings. It can also provide training in launch procedures and in a limited number of emergency procedures.

IOS Configuration

The instructor station is designed to accommodate an instructor and a device operator (see Figure 3), while complying with the stipulation in the Specification that the IOS must be able to be operated by one person. There are two CRTs, one for each position, and a visual

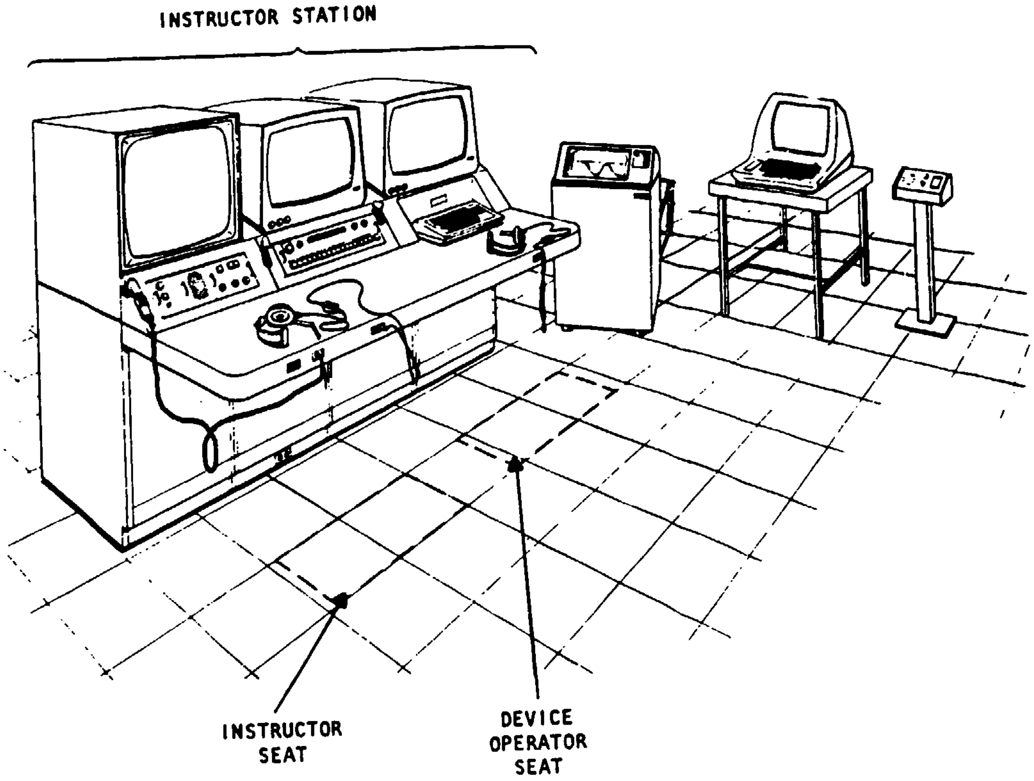


Figure 3. A-6E NCLT Instructor/Operator Station

monitor for the instructor. An alphanumeric keyboard is located in front of the device operator, and an LSO (Landing Signal Officer) hand control is provided for the instructor.

There are two control panels. One, called the Left-Hand Control Panel and located below the Visual Monitor, contains an indicator to warn of a malfunction in the simulated oxygen system in the cockpit, a "beeper" to announce an over-temperature in the computer area or at the student station, three push-button switches related to the visual system, and three rotary controls for varying the volume in two of the IOS headsets and in the intercom speaker. The other, the Function Panel, contains five switches and indicators related to the motion system, three communications switches, and eight function switches. The function switches include those for launch, freeze, reset, playback, etc. The Function Panel is located below the instructor's CRT, thus the device operator has only the alphanumeric keyboard.

Displays

The NCLT's repertoire of displays is relatively limited, containing a total of 23 displays. The first display is an index of all subsequent ones (the displays are called pages and the index page is identified as PO). The next display, P1, is the Program Mode Control Page, and it is used for entering the principal modes of operation: Mission, DRED, Display Printout, and Demo. It also enables a number of specific functions, such as previewing displays before printing, clearing stored displays from the memory, and recording for a demonstration.

P2 is the Initial Conditions Page; it lists the principal parameters for five sets of initial conditions. With the alphanumeric keyboard, the instructor can change the values of the parameters before any set is entered; he enters the desired set by depressing the proper switch on the Function Panel.

P3 is the Monitor Control Page; it enables the instructor to monitor the position of certain controls in the cockpit, such as the throttles, the air start buttons, the RAT handle, and the arresting hook. It also allows the instructor, on-line, to modify parameters, such as fuel quantity, external tank configuration, wind speed and direction, and carrier speed and heading.

Other displays (pages) include Visual System Control, Performance Evaluation, Malfunctions, Instruments, Area Map, CCA, Parameter Recording, and 13 displays for monitoring selected emergency procedures. Forty-eight malfunctions generally related to carrier launch and recovery operations are programmable.

On-line parameter changes are accomplished with display-dependent formats, which is a major difference between the A-6E NCLT and the EA-6B WST. To change the fuel quantity, for example, the instructor calls up the Monitor Control Page, if it is not already displayed on one of the two alphanumeric/graphic CRTs; insures that the CRT Select Switch is indicating the proper CRT; types the line number for FUSELAGE FUEL QTY (in this case the instructor must decide whether to increase the fuel in the fuselage tank, wing tanks, or external tanks); types a comma as a separator; and then types the desired value of the parameter. Finally he depresses the RETURN key on the alphanumeric keyboard to complete the entry. To fill the fuselage tank to 9000 lbs, the complete entry is "1,9000", plus RETURN.

There are five pages containing numbered lines enabling parameter-changing: the Program Mode Control Page, the Initial Conditions Page, the Monitor/Control Page, the Visual System Control Page, and the Performance Evaluation Page. Some of these pages also contain unnumbered lines which are for monitoring purposes only, rather than control (i.e. parameter-changing). On the Monitor/Control Page approximately half of the lines are for monitoring only (see Figure 4).

The Malfunctions Page lists the 48 available malfunctions and assigns each a number. However, the method of activating a malfunction is to type the letter A plus the appropriate number (followed by the RETURN key). To remove a malfunction, the letter R is used similarly. These actions can be taken at any time, regardless of what pages are displayed, as long as the user knows the number of the desired malfunction. This approach resembles the input codes of the EA-6B WST; the reason for such a deviation from the other, display-dependent formats of the NCLT is to give the instructor, or the device operator, more flexibility.

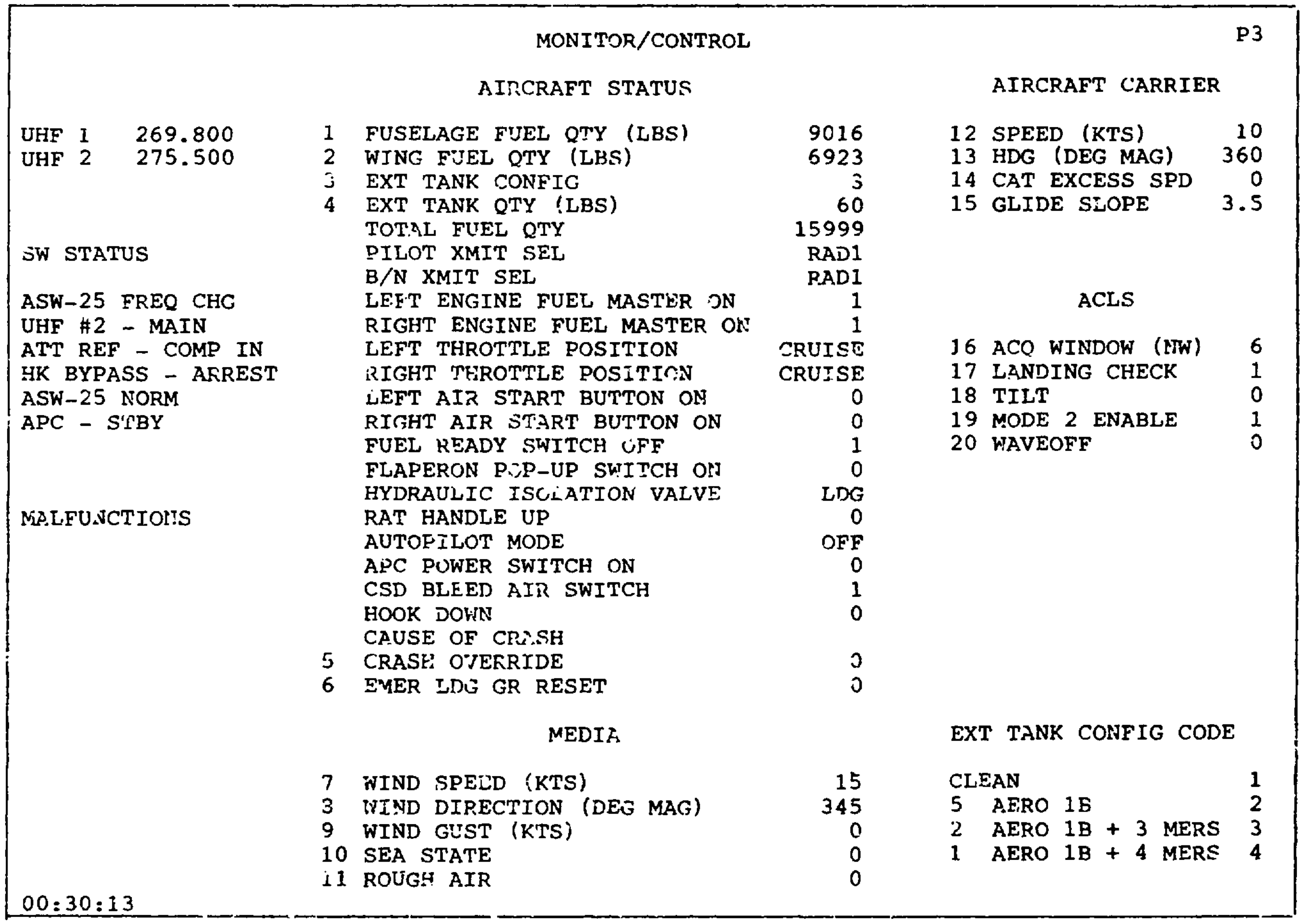
The Index Page is used in a similar way. If the instructor or device operator knows the number of the display that he wants to view, he can obtain it by typing P and the number without having the Index Page displayed.

Sperry SECOR's rationale in selecting the IOS design used in the NCLT was that it was simple and proven (a similar approach had been used by the same company on previous trainers). Also, there were no external factors influencing the choice, such as maintaining commonality with another contractor.

User Experience

The A-6E NCLT is used by a number of attack squadrons at Whidbey and Oceana. At the two stations there is currently a total of approximately 15 instructors and 15 device operators trained to operate the trainer.

Normally both an instructor and a device operator are used during trainer exercises (it should be noted that the trainer has been operational at each location a limited amount of time). The instructor is able to devote most of his attention to monitoring student performance while the device operator is concerned primarily with using the alphanumeric keyboard. The instructor also uses the switches on the Left Hand Control Panel and the Function Panel, but this responsibility is not too demanding. The motion system switches, which are on the function panel,



```
                                    MONITOR/CONTROL                                      P3

                                AIRCRAFT STATUS                          AIRCRAFT CARRIER

UHF 1    269.800     1  FUSELAGE FUEL QTY (LBS)        9016        12 SPEED (KTS)        10
UHF 2    275.500     2  WING FUEL QTY (LBS)            6923        13 HDG (DEG MAG)     360
                     3  EXT TANK CONFIG                   3        14 CAT EXCESS SPD      0
                     4  EXT TANK QTY (LBS)               60        15 GLIDE SLOPE       3.5
                        TOTAL FUEL QTY                15999
SW STATUS               PILOT XMIT SEL                 RAD1
                        B/N XMIT SEL                   RAD1
ASW-25 FREQ CHG         LEFT ENGINE FUEL MASTER ON        1               ACLS
UHF #2 - MAIN           RIGHT ENGINE FUEL MASTER ON       1
ATT REF - COMP IN       LEFT THROTTLE POSITION       CRUISE        16 ACQ WINDOW (NW)     6
HK BYPASS - ARREST      RIGHT THROTTLE POSITION      CRUISE        17 LANDING CHECK       1
ASW-25 NORM             LEFT AIR START BUTTON ON          0        18 TILT                0
APC - STBY              RIGHT AIR START BUTTON ON         0        19 MODE 2 ENABLE       1
                        FUEL READY SWITCH OFF             1        20 WAVEOFF             0
                        FLAPERON POP-UP SWITCH ON         0
                        HYDRAULIC ISOLATION VALVE       LDG
MALFUNCTIONS            RAT HANDLE UP                     0
                        AUTOPILOT MODE                  OFF
                        APC POWER SWITCH ON               0
                        CSD BLEED AIR SWITCH              1
                        HOOK DOWN                         0
                        CAUSE OF CRASH
                     5  CRASH OVERRIDE                    0
                     6  EMER LDG GR RESET                 0

                                MEDIA                              EXT TANK CONFIG CODE

                     7  WIND SPEED (KTS)                 15        CLEAN                  1
                     3  WIND DIRECTION (DEG MAG)        345        5  AERO 1B             2
                     9  WIND GUST (KTS)                   0        2  AERO 1B + 3 MERS    3
                    10  SEA STATE                         0        1  AERO 1B + 4 MERS    4
                    11  ROUGH AIR                         0
00:30:13
```

Figure 4. Monitor/Control Page

are sometimes operated by the device operator, but he can reach them easily with his left hand. While individual preferences vary, usually the instructor keeps the Instruments Page on the left-hand CRT, leaving the other CRT for all other displays.

At each location, copies of the Index Page and the Malfunctions Page have been taped to the top of the work surface. This practice may offend purists but it is an effective way of avoiding tedious display-manipulation. It can be expected, furthermore, that device operators will quickly memorize most of the page numbers.

In general, the users of the NCLT are satisfied with their IOS. They have no reason to desire non-display dependent formats, particularly since the principal disadvantage of display-dependent formats has been solved by the expedient cited above, as well as by having, in effect, input codes for entering and removing malfunctions and calling up display pages.

The users at Whidbey have a criticism of the parameter recording procedure which they intend to correct with an ECP. Parameter recording is a two-minute program for recording and graphically displaying student performance during a carrier approach.

The procedure for starting the recording requires that the CRT page be displayed while the device operator enters the line number for START RECORDING and a "1" for activation. This process occupies the CRT, although briefly, during a critical part of the exercise; the instructor normally wants other displays (the Instruments Page and the GCA/CCA Page, for example) on the two CRTs at this time. What the users want is simply a function switch to start the recording.

F/A-18 OFT

The F/A-18 OFT, Device 2F132, is scheduled to be operational at NAS Lemoore, California, in March 1982. An additional trainer will be delivered to NAS Cecil Field, Florida, approximately two years later. Typical of OFTs, the primary mission of Device 2F132 is to train pilots in all aspects of instrument and visual flight except tactics and weapon delivery (the trainer has a limited air-to-ground weapon delivery capability, however).

IOS Configuration

The instructor station is a radical departure from conventional approaches. As described in the Trainer Configuration Report, the concept of the design of the IOS is to provide the instructor "the means to conduct and monitor the training mission with visual cues that are familiar to him in the F/A-18 cockpit". With this objective specifically in mind, the F/A-18 OFT's IOS is configured so as to resemble the F/A-18 cockpit as much as practicable. The visual monitor is placed in the center and an alphanumeric/graphic CRT is located on each side (see Figure 5). A repeater of the cockpit Head-Up-Display (HUD) is superimposed on the visual monitor; and repeaters of the Master Monitor Display (MMD), the Multi-Function Display (MFD), and the Horizontal Situation Display (HSD), which are six-inch CRTs, called Digital Display Indicators (DDIs), located on the front instrument panel in the cockpit, are located at the IOS below the visual monitor. The HUD is the primary flight instrument in the aircraft, and the MMD, MFD, and HSD are the primary system and navigation displays. Thus the presentation of these displays at the IOS is optimized for the instructor, who will normally be devoting much of his attention to the visual scene.

The instructor will be seated in front of the visual monitor, and the device operator, when utilized, will be seated to the instructor's right. When the instructor is alone at the IOS, both CRTs, which are rotatable, will normally be turned inward; when the device operator is also present, the right-hand CRT will be turned so that it is facing to the front and can be more easily viewed by him.

Nine function keys are grouped around the visual monitor. They include freeze, reset, malfunction override, crash override, normal arrest, barrier arrest, and other such functions requiring rapid access by the instructor. The remaining controls, which are quite limited in number, are arranged on panels below the two alphanumeric/graphic CRTs. The instructor has three function keys for communications; the device operator has two for varying sound volume and lamp intensity. Each person has a 12-key keypad; a function key for calling up the Menu Display, which is the equivalent of an Index Display; and a function key for saving any display for later printing. The instructor has a "joystick" for control of map slew and aircraft slew.

Each alphanumeric/Graphic CRT has a light pen and the visual monitor has an LSO hand control. An alphanumeric keyboard is available at the device operator's position for non-training functions, such as activating Plan Mode and DRED and "debugging" software.

Displays

Basically, the F/A-18 OFT uses display-dependent formats activated by the light pen. The displays are designed to progress from general to specific, so that the instructor or device operator, in effect, merely follows "go to" instructions on each page. A back-up method, enabling activation via the keypad instead of the light pen, is available; it uses numbered lines and entry formats identical to those on the A-6E NCLT.

The initial display is the Menu Display (the title comes from a similar display in the F/A-18 aircraft); it is displayed automatically on both CRTs when the computer is initialized, and can be called up at any time by the Menu Display Switch, which is located on each of the panels below the two CRTs.

The Menu Display (see Figure 6) enables the instructor to call up a number of index displays: Mode Selection, Map Displays, Malfunctions, Procedures, Cockpit Monitors, Environment/Aircraft

Figure 5. F/A-18 OFT Instructor/Operator Station

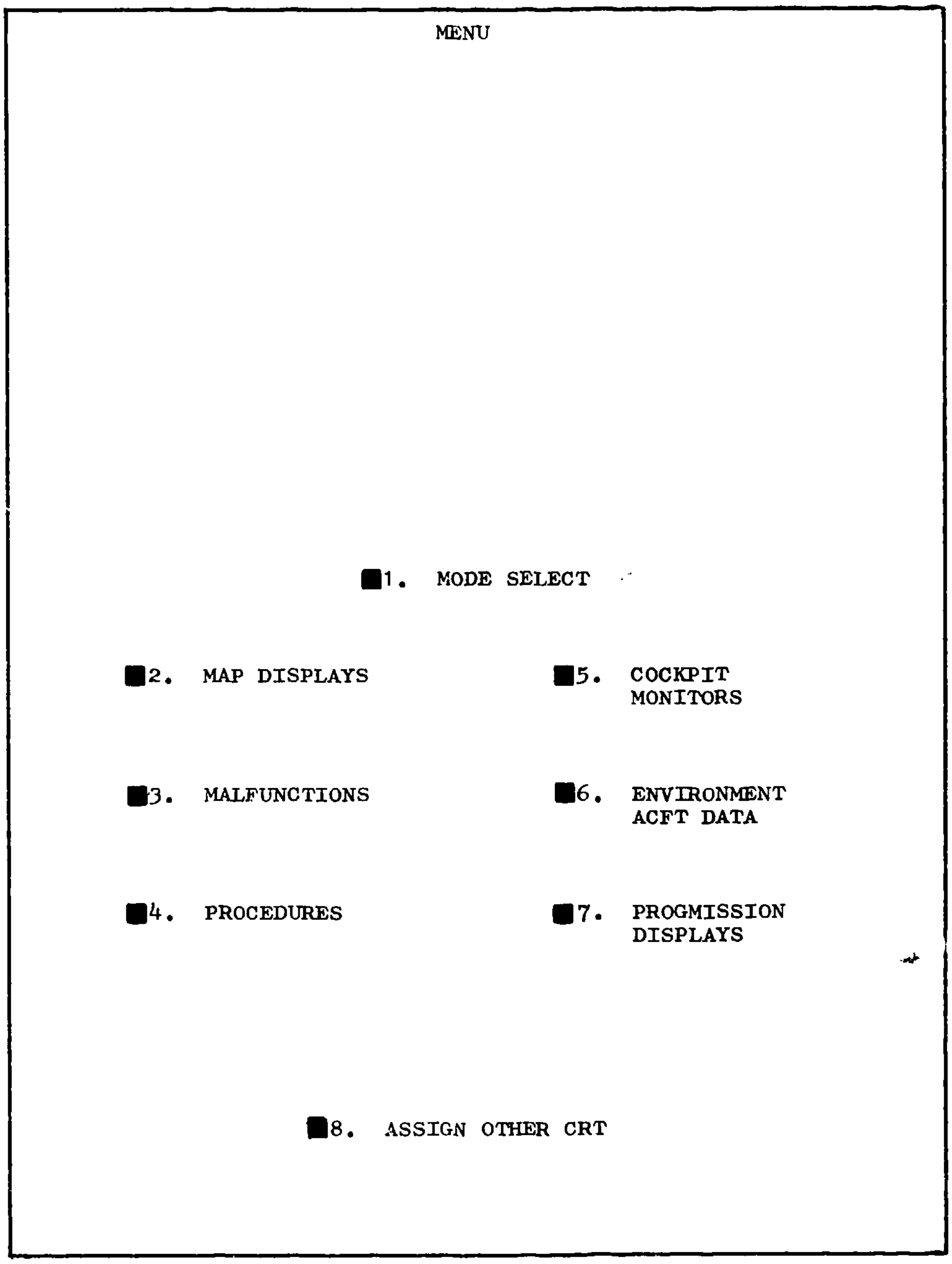


Figure 6. Menu Display

Data, and Programmed Mission. The method of operation is to "illuminate" with the light pen a small square (called the "strike area") to the left of each title. If the light pen is malfunctioning, the back-up method is to enter the line number (1 for Mode Select, 2 for Map Displays, etc.) with the keypad and depress the ENT key on the keypad. At the bottom of the page, and on most other displays, there is a line entitled ASSIGN OTHER CRT. This enables the instructor to assign the display to the device operator's CRT, and vice versa.

The organization of displays is intended to carry on the analogy with the F/A-18 aircraft. In the aircraft, the MMD, MFD, and HSD have a number of push-button switches around their peripheries. The function of each switch varies according to the display in use, and the title appears on the CRT beside the switch. This concept is repeated on the trainer displays; the strike areas are intended to represent the switches and the light pen the pilot's finger.

From the Menu Display the instructor goes to the Mode Selection Display where he chooses one of seven possible modes: Freeflight, Checkride, Automission, Dynamic Replay, Minute Replay, Demo, and Print. Selecting any of these modes leads to its own hierarchy of displays. For example, if the instructor selects the Freeflight Mode, the Freeflight Mode Initial Conditions Index is displayed. This page lists 25 sets of initial conditions and enables the instructor either to enter immediately the set desired or to call up a descriptive display of the composition of any set, i.e., a list of the aircraft and environmental parameters and the navigational waypoints programmed into the on-board computer. The instructor can review these elements but he is not able to make on-line changes to an initial conditions set before entering it.

At the bottom of the Freeflight Initial Conditions Index, in addition to the ASSIGN OTHER CRT line, are two other lines entitled COCKPIT MONITOR and MAP DISPLAYS. These lead the instructor to the indicated displays, which are additional indexes, from which he can select appropriate sub-displays.

All of the displays have similar exit lines, each set designed to provide the most logical options based on the purpose of the display being shown. If the instructor reaches a dead end, he can always select the Menu Display Switch on the panel below his CRT and go back to the beginning of the display structure.

If the instructor selects the Cockpit Monitor Display, the Main Instrument Panel Display is shown. From there he can progress to other displays entitled Left Vertical Console, Left Console, Right Vertical Console, and Right Console. These displays depict the position of switches and other controls on the indicated panels and consoles.

If the instructor selects Map Displays, he can go to a series of graphic displays entitled Cross-Country, Approaches, Departures, and GCA. The Cross-Country Display is a map depicting the radio navigational facilities in the gaming area and showing an aircraft symbol and track; the map coordinates are established by the initial conditions set entered by the instructor. The instructor can change the scale, operate Map Slew and Aircraft Slew, change the visual scene, initiate two levels of declutter, and take other actions by illuminating appropriately-identified strike areas at the bottom of the page. He can exit only to the previous display.

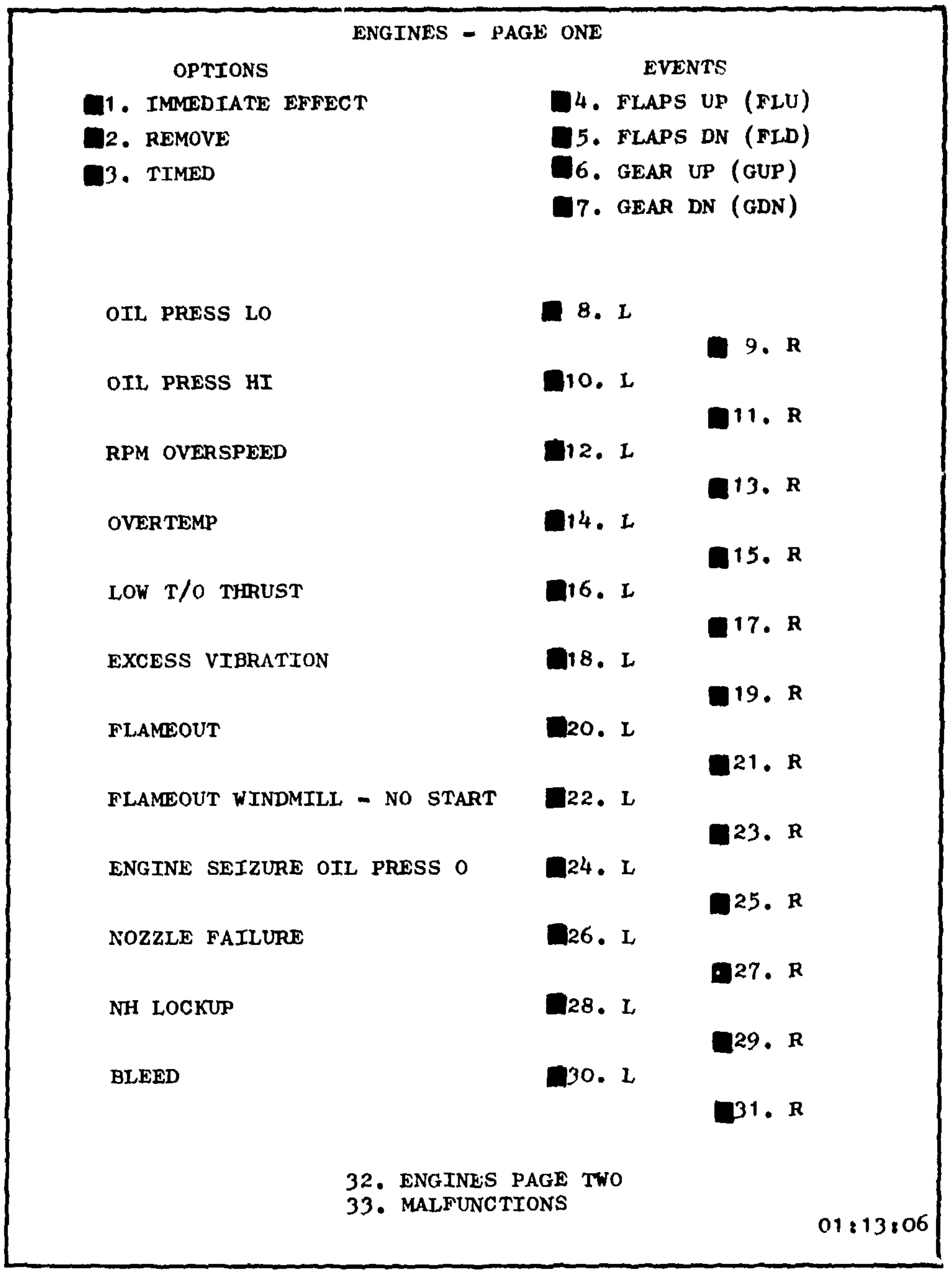
The Approaches and Departures Displays contain indexes of 42 published approaches and 22 standard instrument departures. If the instructor selects any of these, a depiction of the DOD approach or departure plate is shown.

The GCA/CCA Display shows the glide slope and course line, as is standard for this type of display. This display, as well as the display of individual approaches or departures, contains a functional control capability similar to that on the Cross-Country Display, although it is tailored to fit the individual display. For example, the GCA/CCA display does not have Map Slew, Aircraft Slew, scale-changing, and declutter.

The method of controlling malfunctions and the display of emergency (and normal) procedures is intended, again, to minimize demands on the instructor. The instructor's first step in activating one or more malfunctions is to call up the Menu Display from which he can go to the Malfunctions Display. Next he selects the sub-display for the category of malfunction that he desires; the categories are Flight Control, Engines, Fuel, Hydraulic, Electrical, Comm/Nav, Display Subsystems, Aircraft Systems, and EMI. The display that he selects contains a list of malfunctions with related strike areas, one for the left engine and one for the right when applicable (the display for the engine malfunctions is shown in Figure 7). At the top of the page are a list of three "options" and four "events". The options are labeled IMMEDIATE EFFECT, REMOVE, and TIMED, and the events are FLAPS UP, FLAPS DN, GEAR UP, and GEAR DN. By illuminating with the light pen the appropriate strike area the instructor can activate a malfunction immediately or in the future. Future malfunctions can be related to a mission clock time, which the instructor must enter with the keypad, or to one of the four events. From this display the instructor can exit to the previous or next display in the same category, if there is more than one available, or he can return to the Malfunctions Display, where he can find his way through a similar route to another list of malfunctions.

When the instructor calls up a map display after entering malfunctions, he can observe up to ten current and future malfunctions listed at the bottom of the page, in an area called the All-Modes Area. Strike areas are provided for the current malfunctions so that the instructor can clear them whenever he desires.

Emergency and normal procedures are displayed in a way that is consistent with other displays. The Procedures Display, which the instructor obtains via the Menu Display, enables access to four sub-displays containing lists of procedures: Normal, Ground Emergency, Takeoff Emergency,



```
                         ENGINES - PAGE ONE
         OPTIONS                                   EVENTS
   ■1. IMMEDIATE EFFECT                 ■4. FLAPS UP (FLU)
   ■2. REMOVE                           ■5. FLAPS DN (FLD)
   ■3. TIMED                            ■6. GEAR UP (GUP)
                                        ■7. GEAR DN (GDN)


    OIL PRESS LO                       ■ 8. L
                                                    ■ 9. R
    OIL PRESS HI                       ■10. L
                                                    ■11. R
    RPM OVERSPEED                      ■12. L
                                                    ■13. R
    OVERTEMP                           ■14. L
                                                    ■15. R
    LOW T/O THRUST                     ■16. L
                                                    ■17. R
    EXCESS VIBRATION                   ■18. L
                                                    ■19. R
    FLAMEOUT                           ■20. L
                                                    ■21. R
    FLAMEOUT WINDMILL - NO START        ■22. L
                                                    ■23. R
    ENGINE SEIZURE OIL PRESS 0         ■24. L
                                                    ■25. R
    NOZZLE FAILURE                     ■26. L
                                                    ■27. R
    NH LOCKUP                          ■28. L
                                                    ■29. R
    BLEED                              ■30. L
                                                    ■31. R

                       32. ENGINES PAGE TWO
                       33. MALFUNCTIONS
                                                          01:13:06
```

Figure 7. Engine Malfunctions Display

Inflight Emergency, and Landing Emergency. After the instructor selects (with the light pen or keypad) the procedure that he wants, it appears in a "ready" status on a divided display entitled the Procedure Monitor Display (see Figure 8). The instructor can place it in "active" status so that it indicates whether the student is accomplishing the steps in the correct sequence; advance the steps, if there are more than 16 in the procedure, so that the second half is displayed; retract from the second half to the first half; and clear the malfunction related to the procedure, if it is an emergency procedure. These actions are taken by illuminating with the light pen the strike areas in a list of instructions at the bottom of each procedure.

Emergency procedures are displayed automatically, also, when a related malfunction occurs.

Additional displays include those used to initiate and control the programs entitled Dynamic Replay, Minute Replay, and Print; an extensive series of displays for Programmed Missions; a display for controlling and monitoring Parameter Recording; an index of available demonstrations; and a family of sub-displays originating from the Environment/Aircraft Data Display and containing the parameters for varying the weather, visual system conditions, aircraft configuration, external stores and carrier conditions, and for recording and displaying landing and ejection data. Since the F/A-18 OFT has generally the same instructional programs as the EA-6B WST, its repertoire of displays is equally as large.

User Experience

The F/A-18 OFT will be used initially by VFA 125, a replacement training squadron at Lemoore, and later by a similar organization at Cecil. Follow-on trainers, if procured, will be used by operational squadrons.

The first trainer is currently in HSI (hardware/software integration), and until Government testing commences there will be no user experience to draw on for analysis purposes. Operational user experience, of course, will not be obtainable until after final acceptance, scheduled for early 1982. At present it is possible only to estimate, based on an assessment of the trainers' characteristics, what user opinions will be.

There is no reason to conclude that the users will not be satisfied with the general features of the IOS. Navy pilots in the Fleet Project Team have been closely involved in its development, commencing with the initial mock-up. In fact, the concept of emulating the F/A-18 cockpit originated with them. Sperry SECOR's initial design, presented at the Mock-Up Conference, envisioned a conventional IOS liberally equipped with push-button switches for control of functions and displays and featuring non-display dependent formats with input codes similar to those on the EA-6B WST. At the end of the conference the Government concluded that the F/A-18 pilots who were assigned to be instructors on the trainer would resist learning how to operate a sophisticated IOS. It was stated that the demands of flying the aircraft and operating its advanced systems would be so engrossing that another substantial learning task would be unduly burdensome. Sperry SECOR was then charged with developing the cockpit-oriented approach.

There are some questions to be answered when the users acquire experience with the IOS. The first is whether the intended use of the light pen will be more successful than this method has proven to be with the EA-6B WST. Sperry SECOR anticipates that the use of strike areas, plus faster processing, will correct the previous problems, which appear to have been caused primarily by attempting to illuminate individual numerals or letters, much smaller targets. Preliminary testing of the light pen has shown encouraging results, but the proof will be whether the instructors and device operators, under the stress of a fast-moving training problem, use that method or resort to the back-up method, the keypad and line numbers. Use of the keypad will not be unusual for the instructors because they will have experience with a similar device on the aircraft's Up-Front Control.

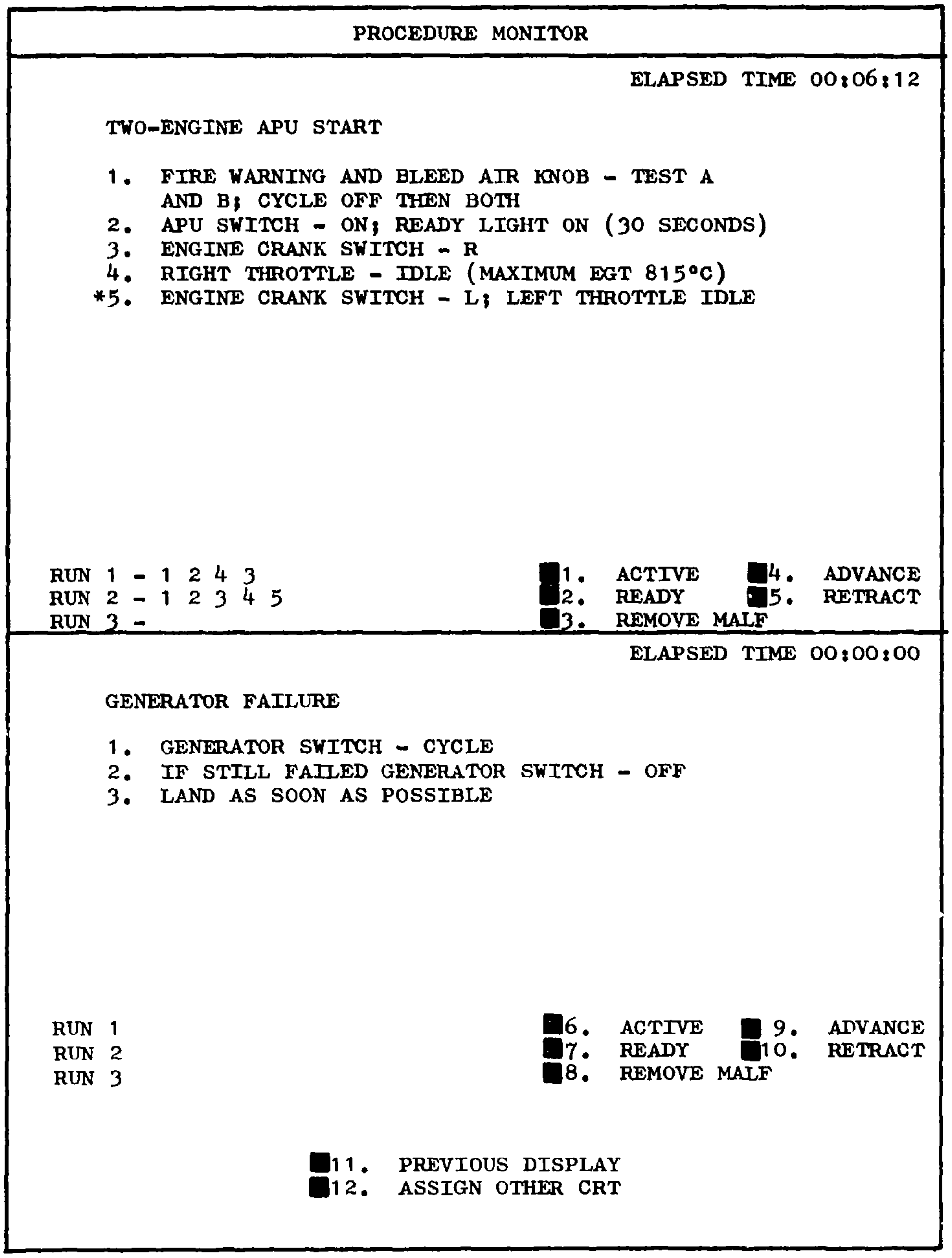
The second question is whether the elaborate "cascading" of displays will result in too much manipulation. There are many successive indexes in the display structure, and they may delay the instructor's finally obtaining the display that he desires. Also, it appears that there are very few choices available in the exit lines. A more liberal use of options would possibly enable the instructor to find short-cuts.

Finally, there is a question regarding the function of the device operator. Because of the design of the IOS, his role will be limited to those functions that can be exercised through the displays. The functions accomplished by the switches grouped around the visual monitor are reserved for the instructor--there is no redundant capability available to the device operator. This approach requires that instructors be uniformly well-trained; if one is not capable of operating his portion of the instructor station, there is no way for the device operator to compensate Fortunately, the instructor's controls are relatively simple, and this situation may not become a problem.

CONCLUSIONS

It is impossible to state conclusively that one of the three designs is the "best" or the "most efficient". The users of each trainer are generally satisfied with their own IOS, assuming that the opinion of the F/A-18 users will be as expected; there are valid reasons for having selected each of the designs used; and there certainly is no reason to conclude that one design should have been adopted for all three trainers.

The input codes and non-display dependent formats of the EA-6B WST seem to be appropriate for that trainer, in view of its many instructional features and the complexity of its IOS. Additionally, the use of function keys for calling up displays and for controlling operating functions and instructional programs serves to facilitate



```
                       PROCEDURE MONITOR
                                         ELAPSED TIME 00:06:12

   TWO-ENGINE APU START

   1.  FIRE WARNING AND BLEED AIR KNOB - TEST A
       AND B; CYCLE OFF THEN BOTH
   2.  APU SWITCH - ON; READY LIGHT ON (30 SECONDS)
   3.  ENGINE CRANK SWITCH - R
   4.  RIGHT THROTTLE - IDLE (MAXIMUM EGT 815°C)
  *5.  ENGINE CRANK SWITCH - L; LEFT THROTTLE IDLE

RUN 1 - 1 2 4 3                     ■1. ACTIVE     ■4. ADVANCE
RUN 2 - 1 2 3 4 5                   ■2. READY      ■5. RETRACT
RUN 3 -                             ■3. REMOVE MALF
                                         ELAPSED TIME 00:00:00

   GENERATOR FAILURE

   1.  GENERATOR SWITCH - CYCLE
   2.  IF STILL FAILED GENERATOR SWITCH - OFF
   3.  LAND AS SOON AS POSSIBLE

RUN 1                               ■6. ACTIVE     ■ 9. ADVANCE
RUN 2                               ■7. READY      ■10. RETRACT
RUN 3                               ■8. REMOVE MALF

                     ■11.  PREVIOUS DISPLAY
                     ■12.  ASSIGN OTHER CRT
```

Figure 8. Procedure Monitor Display

and expedite the operations involved. On the other hand, the simpler design philosophy adopted for the NCLT suits the limited mission of that trainer. Finally, the cockpit-oriented IOS of the F/A-18 OFT can be considered to be successful if it results in instructor pilots wanting to become trainer instructors. If the light pen proves not to be preferred by instructors, the back-up method is merely another version of the input method used on the NCLT--display-dependent formats.

Obviously, improvements can be made at each IOS. For the EA-6B, the greatest need appears to be to increase the capability of the device operator. This can be accomplished, at least initially, by adding the mission panels at the ECMO-1 Instructor position; further design changes, particularly in the organization of the function switches, may be helpful. In addition, the digital readouts on the Pilot's Instrument Monitor Display should be changed to a pseudo-instrument display; and, if the strike areas on the F/A-18 OFT displays solve the light pen problem, the EA-6B WST displays should be changed accordingly.

On the NCLT, apparently the only major improvement needed is the addition of a function switch to start the parameter recording procedure.

Regarding the F/A-18 OFT, it is too early to predict what improvements will be needed. The most likely candidate, however, is the organization of the displays, particularly the number of levels of indexes.

The principal single conclusion that can be drawn from the foregoing analysis of IOS designs is that it is very difficult to design an IOS that meets the operating requirements of a modern trainer with sophisticated instructional features and yet is so simple that it can be operated by an instructor pilot who, perhaps through no fault of his own, cannot keep current in the use of its controls and display. The F/A-18 OFT is an attempt to solve this dilemma by using an IOS that resembles a cockpit with which the instructor is already familiar. Another solution is to design the IOS so as to maximize the role of a device operator, who can be thoroughly trained and kept current, and to allow the instructor to concentrate on teaching and monitoring the student.

LIMITATIONS OF THE PAPER

The only investigative method used in the development of this paper has been interviews with designers and users of the trainers. These contacts have been very productive, but subjectivity is always a factor to be considered. Unfortunately, it has not been possible to try to develop objective measures of efficiency.

Some thought has been devoted to the subject. Possible approaches are to measure the time required to accomplish representative control functions and to determine the associated error rate. Typical functions common to all three trainers are activating and removing malfunctions, modifying environmental parameters such as sea state and wind speed and direction, modifying visual system parameters such as ceiling and visibility, and modifying aircraft parameters such as fuel load and external stores configuration. An additional function worth evaluating is the control of instructional programs such as demonstrations and programmed missions; however, all three trainers do not have the same instructional capabilities and any comparisons in this area would be incomplete.

An approach worth noting is that taken in a report prepared by the Boeing Aerospace Company for the Air Force Human Resources Laboratory entitled "Instructor/Operator Display Evaluation Methods" (1). The 20 subjects participating in the study observed flight indications on two types of displays--digital readouts and repeater instruments--and were required to answer questions demonstrating their short-term recall of the data displayed. The use of digital versus analog readouts is not an issue with the three trainers discussed in this paper--the digital instrument displays of the EA-6B WST have already been found wanting--but the question-and-answer approach with a large number of subjects involved would be a useful technique in any investigation.

A major difficulty in making objective evaluations of the three IOS designs with which we are concerned is that the process of obtaining data would require considerable effort and would tend to disrupt the normal training activities at the device sites. If the users participate in the data-gathering effort, the disruption would be major. Measurement of elapsed time and calculation of error rate could possibly be done with a computer program that would operate unobtrusively while training is in progress, but such an approach would be expensive.

It is anticipated, in this case, that there would be a question regarding the significance of observed differences. It can be concluded, from casual observation, that the time to make an average entry with a keyboard will not be more than two or three seconds more than with a light pen, assuming that the latter is operating optimally. Such differences are not important, particularly when the operations can be performed by the device operator while the instructor is concentrating on observing the student's performance.

In any evaluation of the efficiency of display-dependent formats, the time to call up the display should be added to the time to make the entry. If the displays are designed to use a maximum number of lines per page, there will be less need for display manipulation, and this factor will have a lessened impact on efficiency. Thus, display design would be a variable that would have to be considered in the evaluation.

In spite of the limitations of the interview method, this approach is probably the one best suited to the problem of evaluating an instructor station. Additionally, a detailed study and careful analysis of the design features involved, accomplished conscientiously by the investigator, are necessary elements of the evaluation. This has been the case in the development of this paper.

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INTERACTIVE COMPUTER GRAPHICS FOR TRAINING COMBAT VEHICLE CREWS AND COMMANDERS IN THE REQUIREMENTS AND LIMITATIONS INVOLVED IN A NUCLEAR, BIOLOGICAL, CHEMICAL (NBC) ENVIRONMENT

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ABSTRACT

The training of combat vehicle crews and commanders via Interactive Computer Graphics is a feasible and effective method to maintain readiness against the existing threat of Nuclear Biological-Chemical (NBC) warfare. Data and computer programs have been generated which provide real world chemical battlefield scenarios. The system user encounters different battlefield scenarios and can select various defensive responses (e.g. initiate overpressure). Dosages encountered and casualties (for unprotected crew members) suffered in the chemical battlefield simulation are tabulated.

BACKGROUND

Nuclear, Biological and Chemical (NBC) Threat

Little attention to Chemical/ Biological (CB) warfare threat has been exhibited in the last decade. This lack of concern was due mainly to the assumption that any Chemical/Biological action would escalate directly into a full scale nuclear war. Current information indicates that the Soviet Union is well prepared and equipped to fight a small scale tactical NBC offensive. This fact was proclaimed in an overview statement of the US military posture for FY82 by the chairman of the Joint Chiefs of Staff:

> "The Soviet Union is the best prepared nation to conduct offensive chemical warfare operations. Doctrinally chemical warfare capabilities are tied to employment in a nuclear war. However, the evidence of a Soviet use of chemical weapons in a non-nuclear scenario is not clear, but the possibility cannot be discounted. The Soviets and their surrogates may have used lethal and nonlethal chemical agents in Afghanistan, Laos, and Kampuehan." (1)

It is contended that after the chemical release decision is made, authority for use would be delegated down to the Soviet divisional commander level where chemical weapons could be used freely as a normal compliment to conventional weapons. The Soviets employ 50,000 to 80,000 chemical troops whose mission it is to support (technically and in training) each military division.

Sources estimate fifteen percent of all Soviet warheads contain chemical agents. Many Soviet combat vehicles employ collective protection and troop training in a CB environment is extensive, including exposing troops to actual toxic chemical agents. Soviet preparation for NBC warfare is indeed awesome.

Need for United States Chemical Warfare Readiness

It is clear the Soviets have the capability to fight a tactical NBC war. US preparedness to fight in a NBC environment is the best deterrent to the Soviets initiating a chemical attack. Adequate readiness requires both development/fielding of NBC protected hardware and the improvement/development of training procedures to prepare troops for operations in NBC surroundings.

INTRODUCTION

Need for Combat Vehicle Crew Training

The NBC environment is a major change from the normal battlefield. Possibly more devastating than toxic agent casualties will be the physiological and psychological effects. Impaired vision, impaired communication, restricted tactile deftness, and thermal loading, along with latent claustrophobia and fear will make extremely difficult the rational thinking required for the combat vehicle crew on a NBC battlefield. To counter this problem combat vehicle crew and commanders must be trained not only to survive a CB attack, but to react correctly to all expected situations. Since conducting practice maneuvers in a NBC environment is unrealistic due to limitations imposed by the Surgeon General, a supplemental training method is required that will properly indoctrinate these combat vehicle crews to the requirements and limitations intrinsic to NBC warfare. This paper proposes that an Interactive Computer Graphical Training Aid can provide such a system.

THE INTERACTIVE GRAPHICAL TRAINING AID

Development

The Interactive Graphical Training Aide, an extension of previous chemical battlefield computer simulation, predicts mathematically the chemical threat to armored combat vehicle crews (tanks, armored personnel carriers, etc.). This model, designated CHEMVVAM (Chemical Vehicle Vulnerability Analysis Model), was initially developed to be an aid to combat vehicle collective protection developmental engineers and as a tool to assess current chemical and biological threat readiness. (2) Use of CHEMVVAM for a graphical computer training aid was later proposed by the authors. To accomplish this last proposal software for an interactive graphical simulation of a chemical battlefield was designed.

Use of the Interactive Computer Graphical Training Aid

System users will require no knowledge of either computer programming or language. All necessary parameters are queried by the computer. The system user also has the option to request a more detailed explanation of each parameter required. The system user selects the battlefield scenarios (stipulating weather, temperature, agent, munition type, number of munitions), and the speed and operational configuration of the vehicles. The computer then initiates the simulation. The system user then chooses the output desired. Among these outputs are graphical representations of the battlefield (vehicle positions and agent concentration gradients) and listings of crew dosages and vehicle internal concentrations. Histories of the vehicle internal concentration and crew dosages can also be tabulated. From these varied outputs the system user can assess the requirements and limitations inherent in fighting on a chemical battlefield. It is anticipated that this type of training can prepare the combat vehicle crew to make appropriate response to NBC situations as they arise. Furthermore the ease of administrating this training enables one to train often and thereby reinforce proper reactions in given situations. However, to minimize physiological stress field training must supplement this training.

Mode of function

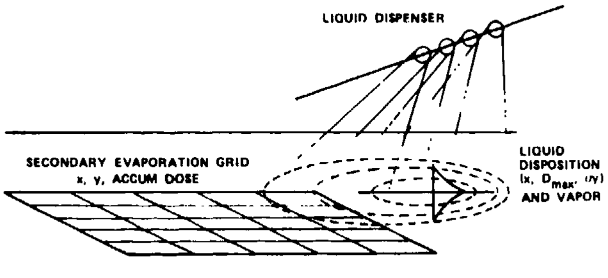
By inputing selected parameters into the mathematics model, CHEMVVAM generated battlefield conditions at various times after attack can be observed. This data can be listed numerically or represented graphically on a battlefield. CHEMVVAM, programmed in FORTRAN, is executable from the Chemical Systems Laboratory UNIVAC 1108 computer.

Mathematical Model (CHEMVVAM)

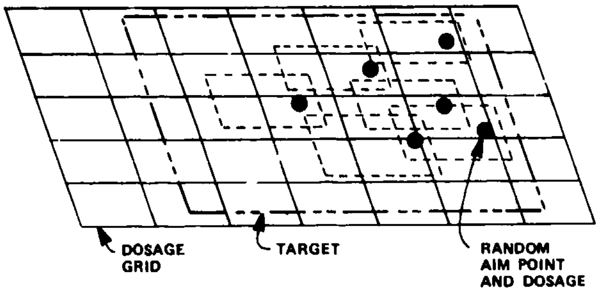
CHEMVVAM is an integration of four mathematical models: 1. NUSSE - Non Uniform Simple Surface Evaporation Model, 2. PARACOMPT - Parametric Analysis Of Respiratory Agents Considering Operations, Motivation, Protection And Time Model, 3. Data Analysis Model, and 4. Vehicle Track Model.

These four models interact to generate effects from the time the attack begins until the vapor cloud has disipated. The generated effects include: concentration levels at each point on the battlefield, vehicle movement, vehicle interior concentrations, and crew dosages. A description of each model is presented.(3)

NUSSE. The NUSSE model simulates the delivery of a chemical agent from a single munition onto a target area. Agent dissemination can be either an air burst (breakup of a liquid mass along an inclined line) or a surface burst (a point source). Given an air burst, NUSSE simulates the fall of liquid through the air and liquid evaporation during its fall to the surface disposition pattern. For the surface burst, only the disposition pattern is calculated. Then dosages are computed for each point on the target area at various times after the agent contamination. This series of dosage grids presents an accurate history of the dispersion of a chemical agent from a single munition. The NUSSE model is itself an integration of three separate models developed at Chemical Systems Laboratory in 1978. A pictorial representation of the NUSSE model is shown.



PARACOMPT. The PARACOMPT Model takes the effects of a single munition as computed by NUSSE and aggregates the effects for a multiple weapons attack. Weapon delivery errors and firing rates are included. The resulting output represents the effects of the entire multiple munition chemical attack in a time series of dosage grids analogous to those produced by NUSSE for a single munition. This is shown schematically below:

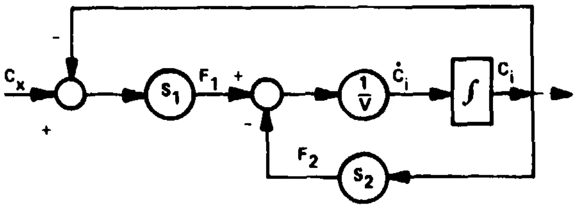


Input: Time series of secondary evaporation dosage grids are produced by the NUSSE Model.

Output: Time series of aggregate dosage grids, each such grid reflecting the total dosage resulting from the set of munitions analyzed, at each point on the grid, at the point in time with which the particular grid is associated.

The PARACOMPT Model was developed in 1963 at Chemical Systems Laboratory. Modifications were made to accept the input from NUSSE and present the output in a format acceptable to the third model in this system. It should be noted that a specific target has not been addressed in the system of models yet. Chemical agent effects have been computed and aggregated with reference to a specific grid.

Data Analysis Model. This model was developed based on test data from combat vehicle simulant challenge testing. The following concept for ingress and egress of chemical agents for combat vehicles is a mathematical representation of observed test results:



C_x	External Concentration
C_i	Internal Concentration
V	Internal Volume
S_1	Capacity of Channels for Ingress of Agent
S_2	Capacity of Channels for Egress of Agent
F_1	Flow of Agent into Vehicle
F_2	Flow of Agent out of Vehicle

Assumptions concerning the above process:

(1) Agent ingress is the product of the difference between internal and external vehicle concentration and vehicle leakage inward.

(2) Vehicle internal concentration changes as a ratio of agent net flow to internal volume of air.

(3) Agent egress is the product of internal vehicle concentration and vehicle leakage outward.

The assumption as equations are:

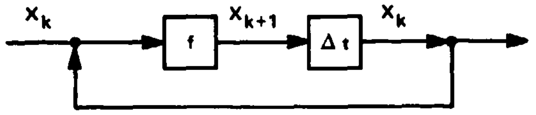
$$F_1 = S_1 (C_x - C_i)$$

$$C_1 = \frac{1}{V} (F_1 - F_2)$$

$$F_2 = S_2 C_i$$

and $$C_i = - \frac{S_1 + S_2}{V} C_i + \frac{S_1}{V} C_x$$

The equations are the basis for a simple first order model representing chemical vapor ingress/egress for a combat vehicle. Although the process of agent ingress/egress is continuous, this process uses a discrete formulation. The two levels of this model are shown below:

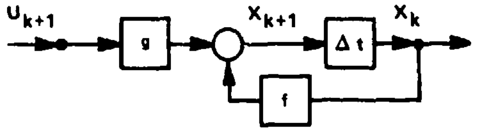


$$X_{k+1} = f \cdot X_k$$

$$f = e^{-a \Delta t}$$

where $\Delta t = t_{k+1} - t_k$

INTERNAL CHALLENGE



$$X_{k+1} = f \cdot X_k + g \cdot U_{k+1}$$

$$f = e^{-a \Delta t}$$

$$g = b/a \ (1-e^{-a \Delta t})$$

EXTERNAL CHALLENGE

X_k = Internal concentration at time k, X (t) for t=k

U_k = External concentration at time k, U (t) for t=k

f, g = Transition matrics

The regression model

$X_i = F \cdot X_{i-1} + g \cdot u_i$ becomes the algorithm for predicting agent ingress.

Vehicle Track Model

The last of the four major models of the system, this model calculates the internal vehicle dosage history as the vehicle is passing through a contaminated area. The time histories can be calculated for a group of twenty-five combat vehicles. The combat vehicles against which chemical effects are to be assessed are described in terms of location, direction of movement, speed and configuration (ventilation parameters). Vehicles that move and react as a group can be described as a group, however, individual vehicle dosage histories will still be calculated as the vehicle follows its own route across the battlefield. Vehicle operational configuration (hatches open, blowers on/off) can be varied as vehicle moves through the PARACOMPT grid.

FUTURE

Planned development of this system at Chemical Systems Laboratory will continue until the CHEMVVAM program has the capability to simulate a chemical battlefield for a battalion level force.

It is suggested that simulations employing similar techniques as CHEMVVAM be developed to better represent the actual tank environment on a total NBC battlefield. This would provide a unique stimulus-response reinforcement for the system user and further insure proper reactions to situations encountered on a NBC battlefield.

CONCLUSION

By affording combat vehicles crews and commanders the opportunity to actually see (if only graphically) the results of many possible NBC battlefield scenarios, they can determine what their decisions will have on the combat vehicles capability to effectively fight in a chemical battle. Additionally the training system is practical and inexpensive to operate, thereby making continued retraining feasible. Continued exposure to chemical battlefield scenarios will better ensure that through both field exercises and simulation training the US combat ehicle fleet will be effective on a NBC contaminated battlefield.

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The authors are all members of Respiratory and Collective Protection Branch, Physical Protection Division, Chemical Systems Laboratory. Mr. English is Chief of the Branch, Mr. Ferriter is a Senior Engineer in the Combat Vehicles Section. Mr. Kammerer, Engineer, and Ms. Smith, Chemist, are members of the Respirator Section. Their combined experience with NBC protection concepts exceeds 15 years.

TRAINING EFFECTIVENESS - A TOTAL SYSTEM PERSPECTIVE

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ABSTRACT

Training Effectiveness, both in terms of measurement and prediction, has become an issue of increasing concern to training system users, acquisition managers, and contractors. The analytic tools available to address this issue have generally come from the realm of Human Factors and have tended to focus on individual training devices rather than total training systems. This paper describes a training system effectiveness model that addresses all elements of a jet pilot training program (academics, simulators and aircraft) which was developed through the application of Operations Analysis and Instructional System Development techniques. The processes used to identify and validate characteristics which drive training effectiveness are described, as are the methods used to relate these characteristics to training objectives. The techniques used to quantify the training value associated with various design options are presented along with a discussion of how the model was actually used during the training system design process.

INTRODUCTION

Within the training community the concept of training effectiveness has emerged as a major issue influencing virtually every aspect of the training equipment procurement cycle - from the initial user definition of need; through the specification process; and into design, development, test and acceptance of the equipment. The reason is clear: The continuing proliferation of training devices in terms of numbers, complexity and cost has reached a point where "mistakes" in the form of devices and systems which are ineffective and/or inefficient simply cannot be afforded. Military training equipment procurement agencies have responded by incorporating training effectiveness clauses in recent device specifications and by including training effectiveness "tests" as part of the government acceptance process. Our experience with these new requirements began in Mid 1978 with the Navy's A6 TRAM Detection and Ranging Set maintenance trainer. Here, and for the first time in our experience, the contractor was required to deliver a plan, including test objectives and criteria, for the empirical demonstration of improved student performance following training with the device. Satisfactory completion of this demonstration was required prior to Navy acceptance of the trainer.

A similar and more extensive demonstration/ evaluation is planned as part of the Army Maintenance Training and Evaluation Simulation System (AMTESS) Program, under the cognizance of PM TRADE. The concept definition phase of this program included the specification, by the contractors, of programs of instruction to be used with the trainer during an Army evaluation program. These programs are currently under contractor development and will be delivered with the prototype trainers in early 1982. The results of the Army's assessment of the relative training effectiveness of the two competing AMTESS designs will be a major factor in determining the future of the program.

Even more extensive training effectiveness requirements have been incorporated by the Army in the trainer programs for the U. S. Roland missile system. For both the Roland Operation and Maintenance Trainers contractors are being required to implement formal training effectiveness program plans as well as supporting the Army during Training Effectiveness Potential Tests to be conducted as part of the trainer acceptance process. The planning and implementationof both activities are documented in formal plans submitted in response to specific contract data requirements.

All of the above training effectiveness efforts have one important common characteristic:

They focus on a single training device rather than a total training system. The responsibility, therefore, for effectively integrating the training device within the context of the total training system (classroom, actual equipment, etc.) remains principly with the user.

The Navy's Undergraduate Jet Flight Training System, VTXTS, marks a major departure from this approach. This program encompasses the simultaneous development of all four major elements of flight training: academics, simulators, aircraft and a training management system. The Alternative System Exploration (ASE) Study phase of the VTXTS, which was concluded in March of this year, included a requirement to include consideration of training effectiveness throughout the concept definition process for all constituent system elements. Contractors were specifically required to balance the training effectiveness of each candidate system element design concept, with their anticipated Life Cycle Cost. The training effectiveness model described in this paper was developed as a tool to assist the Grumman/Beech/ Link Team in addressing these requirements for our entry into the VTXTS competition, called System 730. The model was developed and implemented through the joint efforts of personnel from both our Operations Analysis and Instructional Systems Development groups.

Evolution of Our Approach

Based on our own training system experience we knew of no overall approach to Training System Effectiveness. Indeed, no agreement existed as to the definition of the term. In terms of the specific issue of jet pilot training we were familiar with the work of Bazzocchi on the cost effectiveness of trainer aircraft. (1) Bazzocchi assumed that the teaching effectiveness of a training aircraft can be correlated to a certain number of important characteristics related to performance and equipment. He then interrogated expert pilots to rate the importance of each characteristic vis-a-vis the mission listed. Bazzocchi concentrated only on the aircraft, not the entire training system. Moreover, his selection and definition of characteristics seemed to focus more on the performance of the airplane rather than on its role as a trainer. Nevertheless, the concept of polling experts offered a quantitative technique for evaluating effectiveness which looked attractive, especially since this type of decision theory had been used successfully by the operations analysis members of the VTXTS team. (2) (3) Thus we set out to develop an analytical tool by which we could poll and evaluate the opinions of "experts" and quantify, in a relative sense, those attributes of a training system which make it more effective. We emphasized the system, and sought to go beyond what Bazzocchi did. A system is more than a training aircraft. Hence we included in our model not only proposed aircraft designs but also the simulators and academic programs and equipment which will ultimately make up the system.

THE MODEL

The model is described by the logic diagram of Fig. 1. The essential operations involve:

- o An "importance rating" relating system characteristics to the 87 Terminal Learning Objectives (TLOs) provided by the Navy for the VTXTS
- o A "criticality factor" which weighs the significance of each of these learning objectives
- o A "system amplification factor" which compares an alternative system to a baseline.

From these three assessments a relative figure of merit (FOM), or relative effectiveness is generated.

Training System Effectiveness

Logic diagram shows flow of analysis.

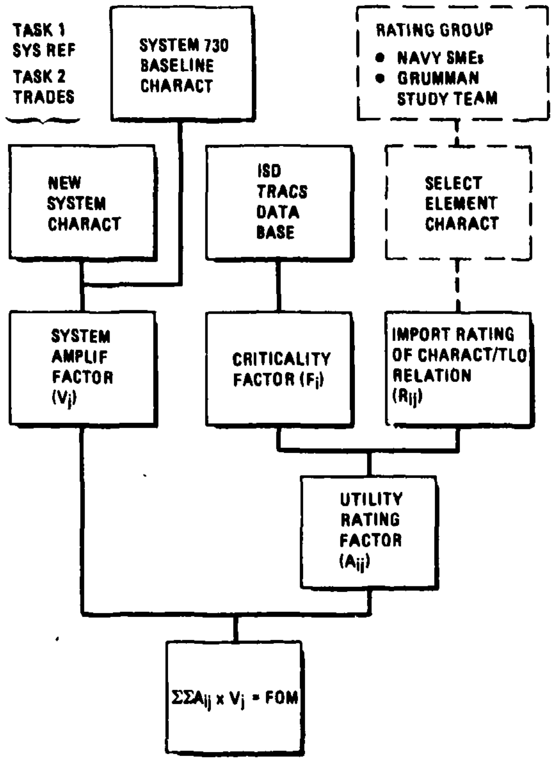

FIGURE OF MERIT = $\Sigma\Sigma A_{ij} \times V_j$

WHERE:

A_{ij}: UTILITY RATING FACTOR = $R_{ij} \times F_i$

V_j: SYSTEM AMPLIFICATION FACTOR (VALUE RATIO OF j^{th} CHARACTERISTIC)

R_{ij}: EXPERT RATING OF TLO/CHARACTERISTIC INTERFACE

F_i: CRITICALITY FACTOR

Figure 1

Selection of System Characteristics

The core of the approach is a matrix relating system characteristics to learning objectives. The purpose of the matrix is to provide a format whereby Navy SMEs could rate the importance of a selected group of aircraft, simulator and academic characteristics against the learning objectives. Those attributes of a training system which make it more effective are identified and quantified through the evaluation of polled "expert" opinion.

The chosen characteristics are not necessarily simple performance measurements but, rather, the salient features of a system for ensuring effective training. The final set of characteristics was selected through discussion with the Grumman team and with Navy SMEs. This resulted in a characteristic set which was comprehensive, but not too lengthy. An overly rigourous list would enlarge the matrix and increase the time required for the ratings. For similar reasons, the set of learning objectives used was not the 87 TLOs, but the set of 13 learning stages (for aircraft and simulators) and eight courses (for academics). The final matrices employed in the ASE are shown in Fig. 2 and 3.

Matrix Rating Procedure

The SMEs were asked to rate each of the boxes of the matrices on a scale of 0 to 3, as follows:

- o 0 = not applicable
- o 1 = desirable
- o 2 = important
- o 3 = essential

Thus, if a particular characteristic was absolutely necessary for attaining the objectives of a learning stage, a three would be inserted in that box. If it had no bearing at all, then a zero would be the appropriate entry, and so on. Many in-house

VTXTS Rating Matrix (Aircraft and Simulators)

Mean importance ratings of 82 SMEs.

System Characteristics / Learning Stages	Aircraft Characteristics									Simulator Characteristics					
	Maximum Speed	Maximum Rate of Climb	Maximum Range	Approach Speed	Stability Index	Instructor Load Factors	Student - Instructor Interface	Student - Envirnmt Interface	Maneuverability Index	Fidelity to Aircraft Perform & Stab	Visual Field of View	Visual Characteristics	Motion Cueing	Instructor-Console Interface	Emergency Capability
Familiarization; Stage 1	1.18	1.38	1.44	2.19	2.39	1.74	2.81	1.82	1.75	2.41	1.95	1.86	1.87	2.08	2.89
Familiarization; Stage 2	1.67	1.74	1.38	1.89	2.44	1.53	2.64	1.86	2.19	2.26	1.97	1.78	1.82	1.99	2.67
Basic Instrumentation	0.71	1.14	1.44	1.12	1.99	1.53	2 53	1.38	0.96	2.46	0.83	0.79	1.56	2.32	2.44
Radio Instrumentation	0.83	1.18	1.75	1.36	1.71	1.51	2.41	1.90	0.92	2.42	0.80	0.83	1.51	2.30	2.25
Airways Navigation	1.26	1.42	2.64	1.15	1.61	1.44	2.30	1.86	1.03	2.38	0.87	0.88	1.50	2.33	2.27
Formation	1.46	1.41	1.38	0.93	1.83	1.48	2.73	1.79	1.84	1.97	1.97	1.72	1.49	1.55	1.95
Gunnery	1.94	1.97	1.37	0.79	1.94	1.84	2.81	2.05	2.56	2.01	2.22	1.83	1.82	1.86	2.00
Night Familiarization	0.96	1.19	1.42	1.90	1.74	1.44	2.46	1.81	1.23	1.95	1.67	1.53	1.41	1.67	2.28
Operational Navigation	1.88	1.46	2.53	0.88	1.54	1.56	2.55	2.01	1.79	1.87	2.01	2.10	1.45	1.34	2.11
Weapons	2.24	2.29	1.67	0.81	1.90	2.10	2.78	2.32	2.64	2.28	2.36	2.34	2.12	2.30	2.13
Air Combat Maneuver	2.72	2.81	1.81	0.81	2.24	2.27	2 79	2.40	2.94	2.20	2.54	2.10	2.17	2.18	2.09
Carrier Qual I	0.65	1.49	1.75	2.44	2.21	1.73	2.37	2.26	1.56	2.51	2.22	2.37	1.93	2.18	2.47
Carrier Qual II	0.65	1.48	1.78	2.20	2.17	1.64	2.26	2.32	1.58	2.50	2.22	2.37	1.96	2.18	2.48
MEAN RATINGS	1.40	1.61	1.72	1.28	1.98	1.68	2.57	2.02	1.77	2.25	1.82	1.73	1.74	2.06	2.31

3: Essential
2: Important
1: Desirable
0: Not Applicable

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Figure 2

VTXTS Rating Matrix (Academics)

Mean importance ratings of 82 SMEs.

Academic System Characteristics / Learning Stages	Performance Based/Adaptive	Multiple Instructnl Strategies	Multi-Media Use	Student-Instructor Interaction	Media Update Capability
Flight Support	2.08	1.72	1.86	2.06	2.10
Aviation Student Info	1.23	1.30	1.43	1.78	1.86
Engineering	2.14	1.76	2.02	1.70	1.90
Aerodynamics	2.12	1.70	2.04	1.90	1.78
Meteorology	1.54	1.40	1.72	1.58	1.62
Flight Rules & Reg	1.61	1.42	1.54	1.70	2.16
IFR Nav	1.98	1.58	1.84	1.92	2.08
Oper Nav	1.98	1.64	1.88	2.10	2.02
MEAN RATINGS	1.84	1.56	1.79	1.84	1.94

3: Essential
2: Important
1: Desirable
0: Not Applicable

Figure 3

trial runs of the model showed that the scale offered a wide enough spread to allow for distinguishing between ratings. It was compact enough so that results were not haphazard considering the sample size.

Flight Instructors and academic experts were polled at four Naval Air Stations. In addition, officers at CNATRA participated in the ratings. In all, 82 SMEs filled out the matrices. The arithmetic means of their ratings are the numbers entered in each cell of Fig. 2 and 3. The numbers at the bottom of each column are the means for each characteristic. The value of each of these numbers dictates the importance of that characteristic to the entire learning process. They are the basis for the bar chart in Fig. 4 which vividly portrays the expert assessment of the Navy SMEs.

Importance Ratings - For the aircraft, there is no doubt that "student-instructor interface" was the most important characteristic. The SMEs clearly indicated that the ability of the instructor to demonstrate flight maneuvers, communicate with and observe the student, act in a safety role, and in general, to provide close supervision and control are of prime importance. Figure 2 shows that "student-instructor interface" not only has the highest overall rating, but in every learning stage its significance is dominating.

Two other characteristics which rate highly are "student-environment interface" and "stability index". The first of these deals with human factor issues within the cockpit.

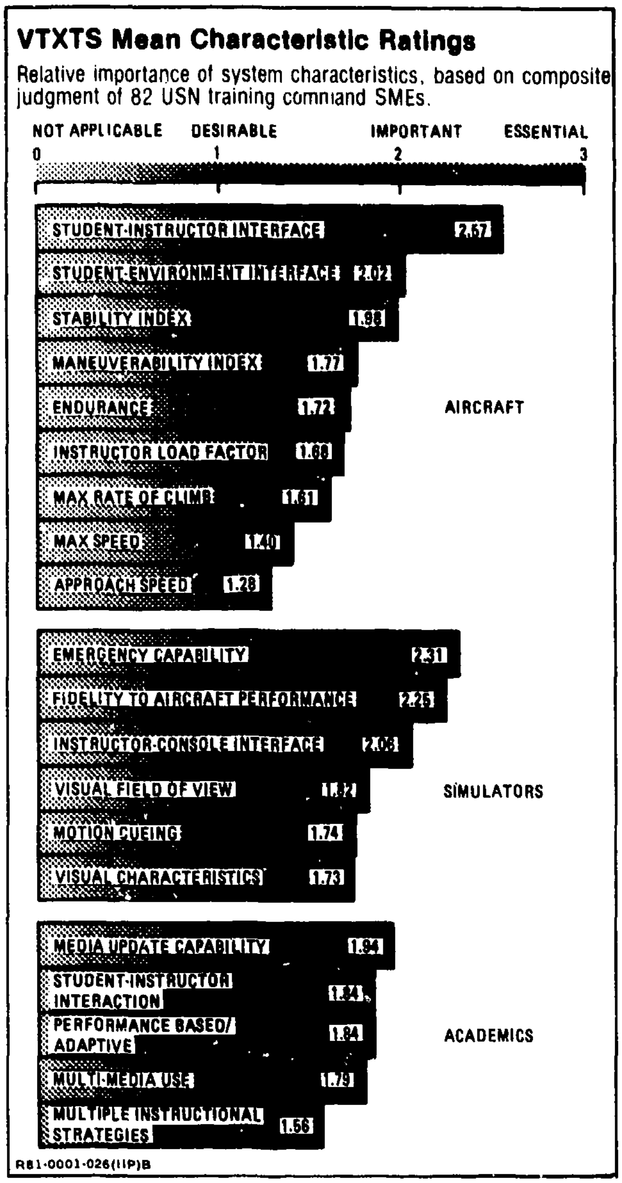

Figure 4

Stability index involves the ability of the aircraft to fly honestly and predictably, with controllability during stalls and slow flight, and positively controlled entry into and easy recovery from spins.

Following these three characteristics in importance are a set of four which are grouped closely together; important, but not nearly so as the first three. Beyond these, and trailing far behind in importance are "maximum speed" and "approach speed".

Some overall conclusions are drawn from these ratings. The SMEs feel that for the training process, an aircraft is required which stresses human interactions and overall safety over performance factors which are associated with operational fleet aircraft. These were important considerations in refining the baseline design during the VTXTS ASE Study. Emphasis was placed on improvement in cockpit design, which resulted in improved visibility, communication, supervision and control.

Aircraft performance was not overlooked. Despite the low overall ratings, there are areas where the Navy SMEs deemed performance characteristics of importance. For example, maximum speed and maximum rate of climb rank respectively, 8 and 7, in overall importance of aircraft characteristics, rather low evaluations. Yet, for the learning stage, "Air Combat Maneuvers", both of these characteristics were rated almost essential by the SMEs. This type of information served as a guide to the designers during this study. As refinements are incorporated, the dialogue between system designers and ISD/operations analysts continues to encourage the development of a more effective training system.

Ratings for Simulators - The ratings for simulators once again show the SMEs' concern for safety and communication with the student. The leading characteristic in overall rating, and high for all learning stages, is "emergency capability". This is a measure of the number of possible aircraft malfunctions and the type of malfunctions that are built into the simulator system.

The next most important characteristic is "fidelity to aircraft performance and stability". This characteristic also rates highly across all learning stages, and would seem appropriate given the basic purpose of simulator training. "Instructor console interface" follows closely behind. This, again, relates to the communication between instructor and student and the ability of the instructor to monitor, augment, observe, and control the activities within the simulator. It also rates well across most of the learning stages.

There is a drop in characteristic rating after this. "Visual field of view", "motion cueing", and "visual characteristics" have evaluations that are somewhat lower. These figures can be used as an overall indicator of relative figure of merit (FOM) for comparing systems. However, if we take a closer look at "visual field of view" and "visual characteristics", we see that they are rated extremely low with regard to learning stages involved with instrumentation and airways navigation. For the learning stages involved with weapons, gunner, ACM, and Carrier Qual they rate quite high.

There are four types of simulators employed in the system. Not all are used in every learning stage. For example, ACM is accomplished in the "dome" of TFT (Tactical Flight Trainer). Here field of view (FOV) is obviously of importance. It would be an erroneous conclusion if FOV would be treated as unimportant in the design of simulators simply because of its overall rating. It is important for the ACM stage and the ratings show it as so.

These observations in no way diminish the importance of "emergency capability" or "fidelity" to the overall training process. They rate highly across the board. It does accentuate that care must be used in applying the data.

Ratings for Academics - In reviewing the SME ratings of academic characteristics, we observe some spread between the leader, "media update capability", and the least important characteristic, "multiple instructional strategies". However, reviewing the bar chart in Fig. 4, we see that the differences are not as striking as in the aircraft and simulator areas. In any event, from an overall system effectiveness viewpoint, the ratings are valuable for reaching conclusions regarding design options.

Criticality Factors

The concept of criticality as used in the effectiveness methodology addresses the uniqueness of each learning stage. The question asked is; "How important is each learning stage or course relative to the others"? If the raw SME ratings were used in the analysis, we would be assuming that all learning stages had a criticality factor of one; that is, they were all of equal importance. However, there is a history of concern among training people about this point. Indeed, a report was published by CNATRA dealing with a related study (4). This report describes the use of a task inventory questionnaire that was utilized as a data collection vehicle. Evaluators rated training tasks as to their frequency, criticality and adequacy. The results are interesting, but not directly applicable to the new system under consideration here. We are faced with the problem of developing a weighting scheme for measuring criticality in the VTXTS program.

Time Value Ratio - The Time Value Ratio attempts to determine learning stage criticality by relating it to time consumed per learning stage. At the beginning of the study this technique was planned for use on the TLO basis. When the matrix was modified to incorporate learning stages rather than TLOs, the Time Value Ratio was modified accordingly. The relative importance of the learning stage was calculated by taking the ratio of time devoted to it divided by the total training time. For example, if a particular learning stage consumes 70 flight training hours and the total flight training consists of 170 hours, then the Time Value Ratio would be 0.41. For the initial runs of the Effectiveness Model, criticality factor was defined as Time-Value Ratio. Modifications were to be incorporated during the study, as time alone is not the only factor in determining the importance of a learning stage. This was attempted with a questionnaire that introduced such factors as task performance difficulty, task familiarity, extent to which task must be completed before progressing in the training process, and eventual mission impact. The questionnaire was not exhaustive; to include all the factors would be a prohibitive task considering the scope of the study. The pairwise comparison discussed in the following subsection provided an approach which directly evaluated learning stage criticality.

Pairwise Comparison for Criticality

The general approach is to make a comparison by pairs of all of the learning stages, and judge which is the more important (i.e., critical) of each pair. After all the possible pairs have been compared, with no ties permitted, the number of "wins" is counted for each learning stage. Using a matrix technique, the weighting factors are calculated taking into account the relative strength of the individual "wins".

The two basic parts of the weighting factor (criticality) calculation are the pairwise comparison of the learning stages, and the formulation and manipulation of a dominance matrix. Since the comparisons are made on a pairwise basis, the total number of "matches" is the combination of the number of learning stages taken two at a time. A list of all the pairings is prepared, then the rater indicates which one of each pair is the more important. The degree of importance is not asked. The relative importance is taken care of by the dominance matrix manipulations. Ideally, the rater should be able to support his choices. A consensus of several raters is desired. In this case all of the raters were our consultant pilots. Differences were resolved by round-table discussions with each rater defending his choice. Assuming the choices are properly supported, a degree of objectivity is realized.

Perhaps the easiest way to explain the philosophy of the weighting calculations is to draw a parallel to a "round robin" tournament. In the scoring system, we wish to take into account not only the number of wins a team has, but the strength of the teams beaten. In general terms, we credit a team with its own wins, and the number of wins of each beaten team. Assume that teams A and B have one win each, over C and D. The we differentiate between A and B by counting the C and D wins and adding these to the A and B wins. The exact procedure with required derivations is described in Reference 3. The resulting criticality factors are shown in Figure 5.

The product of the importance rating and the criticality factor is defined as utility rating. Utility rating for aircraft, simulators, and academics were calculated and presented in our study report in a matrice format.

The values within the matrices are a measure of the importance of characteristic in accomplishing a learning stage combined with the relative significance of the learning stage in the overall training curriculum. The larger the rating value, the greater the training utility associated with the rating.

System Amplification Factor

To evaluate how well alternative systems accomplish the training goals, some measure of their value must be introduced. For any characteristic of the system, the ratio of an alternative value to the baseline characteristic value is defined as the system amplification factor, or value ratio, for that characteristic.

Effectiveness Computations

The Training Effectiveness Model performs two separate and sequential computations: the utility ratings of the system characteristics and the training effectiveness ratios of alternative systems. For the VTXTS, the utility rating computation is performed once and the results remain fixed. However, the effectiveness computation is performed repetitively in develop-

Learning Stage Criticality Factors (Pairwise Comparison)

Weighting factors applied to learning stages.

Learning Stages	Aircraft & Simulators
Familiarization - Stage 1	0.191
Familiarization - Stage 2	0.024
Basic Instrumentation	0.113
Radio Instrumentation	0.073
Airways Navigation	0.042
Formation	0.109
Gunnery	0.025
Night Familiarization	0.029
Operational Navigation	0.044
Weapons	0.088
Air Combat Maneuver	0.086
Carrier Qual I	0.148
Carrier Qual II	0.028

Learning Stages	Academics
Flight Support	0.232
Aviation Student Info	0.014
Engineering	0.170
Aerodynamics	0.109
Meteorology	0.109
Flight Rules & Reg	0.148
IFR NAV	0.126
Operational NAV	0.092

Figure 5

ing and refining the baseline system FOM and in comparing alternative systems to the baseline. The output format of the effectiveness computations is shown in Fig. 6.

In the figure ALT VAL and BAS VAL are the characteristic values for the alternative and baseline systems respectively. BAS FOM is the training utility of each baseline characteristic as obtained from the utility rating computation

The amplification factor or value ratio, VAL RTO, is the ratio of ALT VAL to BAS VAL of each characteristic. The product of BAS FOM and VAL RTO is the corresponding training utility, ALT FOM, for each characteristic of the alternative system. The effectiveness ratio of an alternative system element is the average alternative system. The effectiveness ratio of an alternative system element is the average alternative FOM divided by the average baseline FOM.

Finally, the alternative system effectiveness ratio is computed and displayed as the sum of the average FOMs of the alternative system elements divided by the sum of the average FOMs of the baseline system elements.

System Comparisons

The Training Effectiveness Model has the capability of comparing the relative training potential of two systems, each consisting of a training aircraft, a simulator suite and an academics program. Once the characteristic utility ratings are established, it remains to evaluate the characteristics of both systems, one of which is taken to be the reference or baseline system.

Figure 6 illustrates such a comparison. The baseline system is the Grumman/Beech System 730 as envisaged at the start of the [illegible] ASE study. The alternative system is the refined Grumman/Beech/Link System 730 as it emerged at the completion of the study. An increase in training effectiveness ratio has been achieved in all three system elements. Individual element improvements amount to 18.7% in the aircraft, 28.8% in the simulators and 43.1% in academics. Overall, the refined System 730 shows a 29.9% increase in training effectiveness relative to the baseline system.

A similar comparison was made between the baseline System 730 and the Naval Integrated Flight Training System (NIFTS). NIFTS is the current undergraduate Flight Training System. Since NIFTS utilizes two aircraft, the T-2C for intermediate training and the TA-4J for advanced training, characteristic values for both aircraft were used. Therefore, the computation of training effectiveness ratio for NIFTS was based upon the proportional contribution of each aircraft to the individual learning stages in the program.

The results of this comparison are summarized in Figure 7. The results show that the baseline System 730 envisaged at the start of the ASE study provided a 31.9% improvement in training effectiveness over NIFTS and the refined System 730 offers a 71.4% improvement over NIFTS. Improvements in the individual elements are indicated also.

Sensitivity Analysis

A salient feature of the Training Effectiveness Model is its ability to compare conceptual systems. If the characteristic measurement values are not established, parametric value ratios are used to determine training effectiveness sensitivity to variations of characteristic values. Figure 8 shows the training effectiveness sensitivity of the aircraft, simulators and academics to value ratio variations. The relationships are established by varying the value ratio of one characteristic at a time and recording the percent change in the system effectiveness ratio. This type of sensitivity analysis identifies the element characteristics offering the greatest potential for improvement in effectiveness ratio.

The Training System Effectiveness Model, is being used as a management tool to evaluate the relative merit of competing systems. The major comparison considered the growth in effectiveness of the Grumman/Beech/Link System 730 as it progressed from the baseline to the refined design. The characteristic changes accounted for a growth of 29.9% in effectiveness by the conclusion of the ASE study. The refined System 730 is shown to be 71.4% more effective than NIFTS.

VTXTS Training Effectiveness Output Format

Measures an alternate system's potential to implement the training curriculum relative to that of an established baseline system.

```
                         AIRCRAFT EFFECTIVENESS RATIO
                         ******** ************* *****
              HR        STABL      INST      STU-INS   STU-ENV     MAN
            ENHOUR      INDEX   LOAD FACT    IFACE     IFACE      INDEX
            ------      -----   ---------    -----     -----      -----
ALT VAL     2.920      14.000    12.000     30.000    32.750     31.662
BAS VAL     2.920      11.000     8.000     22.800    28.900     38.279

VAL RTO     1.000       1.273     1.500      1.316     1.133      0.827

ALT FOM     1.658       2.604     2.568      3.432     2.288      1.443
BAS FOM     1.658       2.046     1.712      2.608     2.019      1.744

AVG. ALTERNATE FOM= 2.332
AVG. BASELINE FOM = 1.965

ALTERNATE AIRCRAFT EFFECTIVENESS RATIO= 1.187


                         SIMULATOR EFFECTIVENESS RATIO
                         ********* ************* *****
             FIDEL       VIS        VIS       MOTION    INS-CON     EMERG
            TO ACFT      FOV      CHARACT      CUE       IFACE      CAPAB
            -------      ---      -------      ---       -----      -----
ALT VAL     51.000     51.333     5.379     68.000     9.200     33.000
BAS VAL     46.000     29.333     2.789     49.500     8.300     30.000

VAL RTO     1.109       1.750     1.420      1.374     1.108      1.100

ALT FOM     2.554       3.206     2.496      2.441     2.318      2.613
BAS FOM     2.304       1.832     1.758      1.777     2.091      2.375

AVG. ALTERNATE FOM= 2.605
AVG. BASELINE FOM = 2.023

ALTERNATE SIMULATOR EFFECTIVENESS RATIO= 1.288


                         ACADEMICS EFFECTIVENESS RATIO
                         ********* ************* *****
             PERFM    MULT-INST    MULTI     STU-INS     MEDIA
             BASED      STRAT      MEDIA      IACTN      UPDAT
             -----      -----      -----      -----      -----
ALT VAL     32.000     29.000     27.000     32.000     32.000
BAS VAL     12.000     24.000     22.000     32.000     32.000

VAL RTO     2.667       1.208      1.227      1.000      1.000

ALT FOM     5.152       1.950      2.254      1.858      1.974
BAS FOM     1.932       1.614      1.937      1.858      1.974

AVG. ALTERNATE FOM= 2.638
AVG. BASELINE FOM = 1.843

ALTERNATE ACADEMICS EFFECTIVENESS RATIO= 1.431


          ***********************************************
          ALTERNATE SYSTEM EFFECTIVENESS RATIO = 1.299
          ***********************************************
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Figure 6

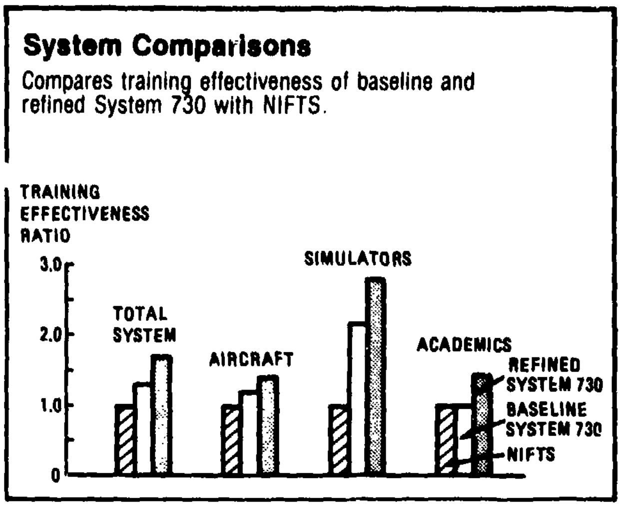

Figure 7

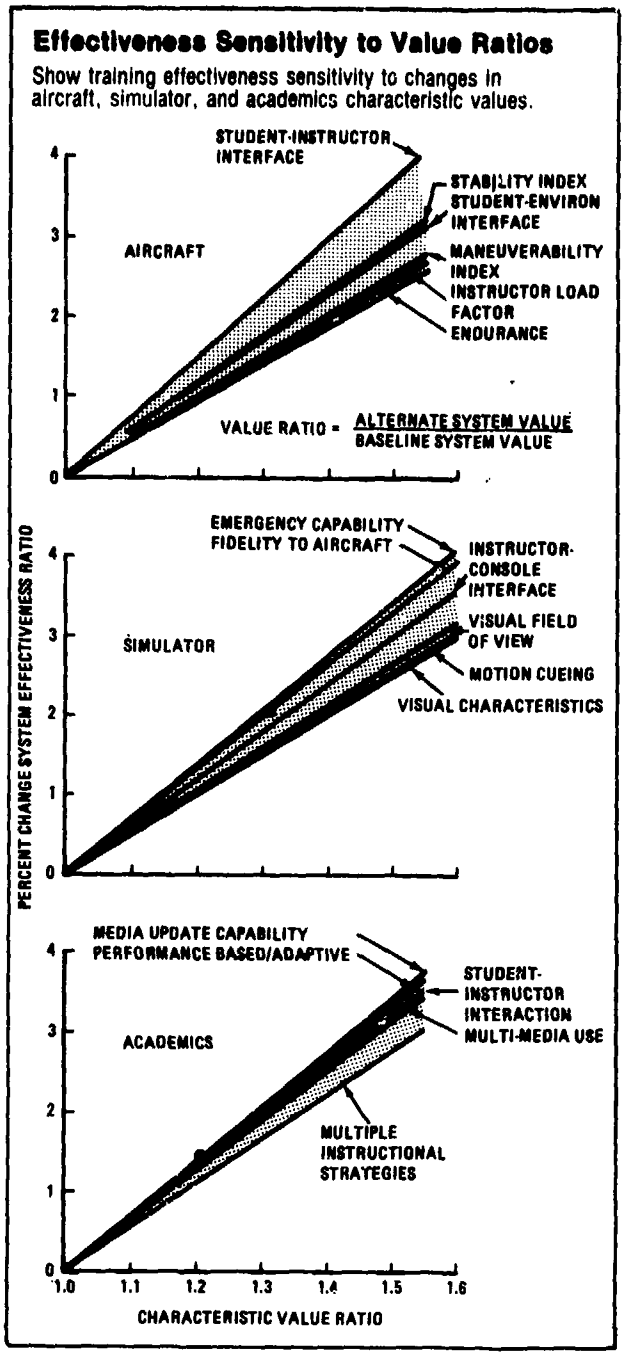

Figure 8

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WRITING AN ISD TRAINING PROGRAM CONCURRENTLY WITH FULL SCALE DEVELOPMENT

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ABSTRACT

Developing a training program concurrently with full-scale development of a new system has been looked upon by several educational professionals as being impossible. The US Air Force desire to shorten the time from drawing board to full operational capability for a weapon system requires combining normal system life phases whenever possible. Therefore, the 4235th Strategic Training Squadron was tasked to develop a training program for the Offensive Avionics System (OAS) and Air Launch Cruise Missile (ALCM) Modifications to the B-52 G and H fleets concurrently with full-scale development of hardware and software for the aircraft. Having written the training program using the ISD approach, the squadron provides insight into the problems of such an effort and the solutions it developed to overcome those problems. Areas addressed in this paper include:

(1) Developing a core of knowledge about a new system without an established working model.
(2) Selecting an organizational method for presenting the training program.
(3) Developing training devices.
(4) Developing technical orders.
(5) Handling of changes to system operation and implementing them into the training program.
(6) Selecting instructional media.
(7) Selecting instructors.

INTRODUCTION

Since 1977 the U.S. Air Force has prepared to integrate the Offensive Avionics System (OAS) and Air Launched Cruise Missile (ALCM) into the B-52 G and H model aircraft. With the date for delivery of the first operational aircraft set for August 1981, preparation for its arrival had to be expedited drastically. To do so several phases of normal system development had to be accomplished simultaneously.

Along with full-scale development and flight testing the prototype system, a training program had to be written for the aircrew member. Despite the fact that many educators believe such a simultaneous effort is impossible it had to be done. The 4235th Strategic Training Squadron (STS) actually began working on the training program using the ISD approach in April 1978. The training program developers have experienced numerous problems throughout their three years of work. However, they have overcome them and are ready to implement their program to the crewmembers for the conversion to the new equipment. The squadron can now provide insight into the problems they encountered, the solutions they used, and additional suggestions to help in similar circumstances.

DEVELOPING A CORE OF KNOWLEDGE

One of the most obvious problems that arises when trying to create a training program simultaneously with full-scale development of the equipment is building a core of knowledge about the system. Early in 1980, almost 8 months before the first OAS/ALCM equipped B-52 flight, seven instructor radar navigators were assigned to the 4235th Strategic Training Squadron at Carswell AFB, Texas to begin preparing the training program.

First, all the training program developers completed an Instructional Systems Development course given by the squadron. This course provided the basic understanding necessary for all the writers to work toward the same goals using the same methods. This proved to be an extremely essential ingredient in developing continuity and uniformity in the various training blocks.

Next, the training program developers began reading the numerous engineering documents published by the contractors. These documents provided in-depth explanations of all the OAS/ALCM operations. However, it must be made clear that it was not necessary to have an engineering degree to understand these documents.

The ISD course proved valuable during this phase also because each training developer was now able to evaluate each bit of knowledge as to its later usefulness to the student. After six weeks of studying documents the next phase began.

A task analysis of each activity the navigators of a B-52 would perform was compiled. This included both the tasks associated with the new equipment and those in which the new equipment did not come into play. This phase of preparation served two purposes. First, it identified the items that had to be taught to the navigators so they could convert to the new equipment. Second, it translated the operation of the OAS from engineering vernacular to understandable English. This phase took approximately four months to complete.

The final source of information prior to the first simulator or aircraft having OAS equipment was the familiarization course and operator's course conducted by Boeing (Type I Training). Although the course that was taught encountered the same problems of not having a simulator or aircraft to verify the system's actual operation, it did provide some additional information. It also allowed the training personnel to meet the engineers who wrote the software. This was important because when questions arose later the training developers knew who to call for a possible answer.

When the aircraft finally made its maiden flight training personnel had already begun the actual development of their program. As the aircraft continued its test program, daily phone conversations with the flight personnel provided constant updates to the training program. Ironically, the information flow was also reversed at times. The training developers having spent so much time preparing to build their program were able to provide flight test personnel with information how the engineering documents said the OAS should operate. This allowed flight test to identify numerous actual system operation errors which needed correction.

Combining their early efforts in learning the engineering documents and the updates from flight test, the training program progressed on schedule. Having almost completed the training program several recommendations can be drawn from the 4235th STS experience:

(1) All training program developers should use the same basic instructional approach within a program.

(2) The training program should start as early as possible so personnel can develop a sound knowledge of the system to be taught.

(3) Training program developers should attend all available contractor training but only after they know a good deal about the system operation. This provides a framework for understanding the system rather than mere acceptance of the contractor's claims.

(4) In the case of simultaneous accomplishment of several phases of system development it is essential that the test personnel for the system be highly qualified and knowledgeable in the expected system operation prior to the actual test phase. Since the engineering documents are the only basis for training programs development, test personnel must be intimately familiar with them. Then they can not only identify system errors and shortcomings but also provide timely information to training personnel about discrepancies from the documents. Early identification of such discrepancies can be handled by changes to the training program or by placing the demand on the contractors to correct the problem. If a strict deadline is set for bringing the system on line, it becomes more difficult to make such changes to the equipment. Therefore the equipment is delivered with less than the original capabilities and/or the operator must use workaround procedures to achieve his objective.

(5) When descrepancies are identified by the test or training personnel the system manager must support the effort to rewuire the correction of the deficiency. If it is not required that all deficiencies be corrected, a weekly report of such deficiencies must be published. This provides all other agencies with data to modify their efforts.

SELECTING AN ORGANIZATIONAL METHOD

After developing a core of knowledge about how the OAS and ALCM operated the training program developers had to choose an organizational pattern for the training program. The decision came down to two alternatives - the systems approach and the phase-of-flight approach. Traditionally, the Air Force has used the systems approach for most aircrew training programs. Using this approach the training program breaks the large system into subsystems (radar, doppler, heading, etc) and then teaches the student all he needs to know about the subsystem.

After all the subsystems are explained the student is expected to have an understanding of the overall system operation. However, more often than not this approach leaves the student with fragmented system knowledge and requires a lengthy period of time for complete knowledge of the system to be obtained. The other alternatives phase-of-flight provided a much more task-oriented approach for the training program. Beginning with mission-planning the student would proceed through preflight, enroute procedures, descent, landing, and post-flight. This approach allowed the program developers to concentrate on developing procedures and checklists as well as transmitting knowledge to the student. Therefore, the student left each segment of training knowing both the knowledge he needed and how to use it. Because the conversion of each crew member to the OAS/ALCM was to be done in only three to four flights, the task-oriented phase-of-flight approach was selected for the training program organizational pattern.

As was stated earlier the initial step in actually writing the training program was completing a task analysis for each activity

EXAMPLE TASK ANALYSIS

T	N	ENRUTE	AA	XXPPXX		F	I	4		PERFORM ENRUTE PROCEDURES
T	N	ENRUTE	AA	XXPPXX		O	I	4A		Perform General Navigation
T	N	ENRUTE	AA	XXPPXX	MFD IKB RN MGT RADTILT RADPRES	R	I	4AA		Perform radar position fix
	N	ENRUTE	AA	XXPXXX	MFD	R	I	4AA	1	The AP will automatically position the crosshairs on that point which is: 1. Closest to the aircraft, and 2. Within the field of view
T	N	ENRUTE	AA	XXPXXX	IKB	R	I	4AAA		Select the MFD supporting radar
T	N	ENRUTE	AA	XXPXXX	RN MGT MFD IKB RADTILT	R	I	4AAB		Perform altitude calibration
T=Task Blank=Knowledge item	N=Non critical C=Critical	Phase of Flight M PLAN PRETAK T/ODEP ENRUTE PDLAND POSTFL ALERT	E=EWO C=Contingency T=Training A=All Trng Reqred;B=Conversion only A=All	Plt Coplt RN Nav EWO Gun Crew member role P=Primary I=Interaction B=Backup X=NA	Panel used	Media C=CPT R=Text O=OSMT W=WST L=Lecture T=Tape/ Slide V=Videotape S=Seminar F=Flight	I=Introduction R=Reinforcement T=Test	Task ID	Knowledge Code	Task

FIGURE 1

accomplished by the crew members. Formatted and entered in a word-processor this document formed the skeleton for the body of the training program. Figure 1 shows a task analysis for one of the tasks during preflight. The key explains how this document was used for the conversion training and how it will be used for the Combat Crew Training School curriculum which must be developed. The phase-of-flight approach was especially well-suited for organizing this task analysis which now could be used as an outline of the training program.

Regardless of which pattern was chosen the simultaneous accomplishment of full-scale development and writing a training program would have caused problems. The systems approach would naturally be more suited to handling the constant changes of the OAS software. A training program developer could simply find the training block devoted to the changed equipment and make the required changes. The phase-of-flight approach on the other hand required locating all the tasks involved with a particular change and making the corrections. Although the task analysis format used in this program aided in the change process, corrections did take more time to insure all tasks were correct. However, once made, the change helped stimulate reexamination of checklists and procedures. These crosschecks aided in delivery of a training package that agreed with checklists and the operator manuals.

The problems of handling the constant changes to OAS software required flexibility in curriculum development. As each change notice arrived the appropriate task analysis and training lesson was updated. However, it surfaced that just teaching the basic tasks to the crew members failed to give him the "big picture" of managing the navigational computers. To provide this insight required a departure from the task-oriented format. After the functional descriptions of the switches and equipment used during preflight and before takeoff, the student needed an understanding of what he was trying to achieve in programming the navigational computers and the best way to go about doing so. Therefore, a lesson was written which explained the techniques and theory of inertial navigational equipment. However, this theory was extremely limited in scope and operator oriented. Collecting the data for such a block proved difficult because empirical data did not exist due to the limited experience of flight test. Instead, the procedures for basic management of the system had to be derived from software documents and telephone conversations with Boeing programmers and engineers. The important aspect of this effort was not the magnitude of the work involved but the realization that training personnel must be flexible. The objective should be to make the student as capable of performing the desired task as possible. With limited time to achieve this objective willingness to depart from standard procedures must be present. If a systems approach is more suitable for a training block then it must be used. If theory must be taught in a task oriented program - do it. The student performing the task is the ultimate. To argue over educational concepts or delay completion of a training program to spend excessive time to maintain purity of the training approach is inexcusable. In the OAS/ALCM training program this flexibility saved invaluable time in meeting the deadline set for aircrew training. It also provided a period of time to review the program and publish last minute errata.

DEVELOPING TRAINING DEVICES

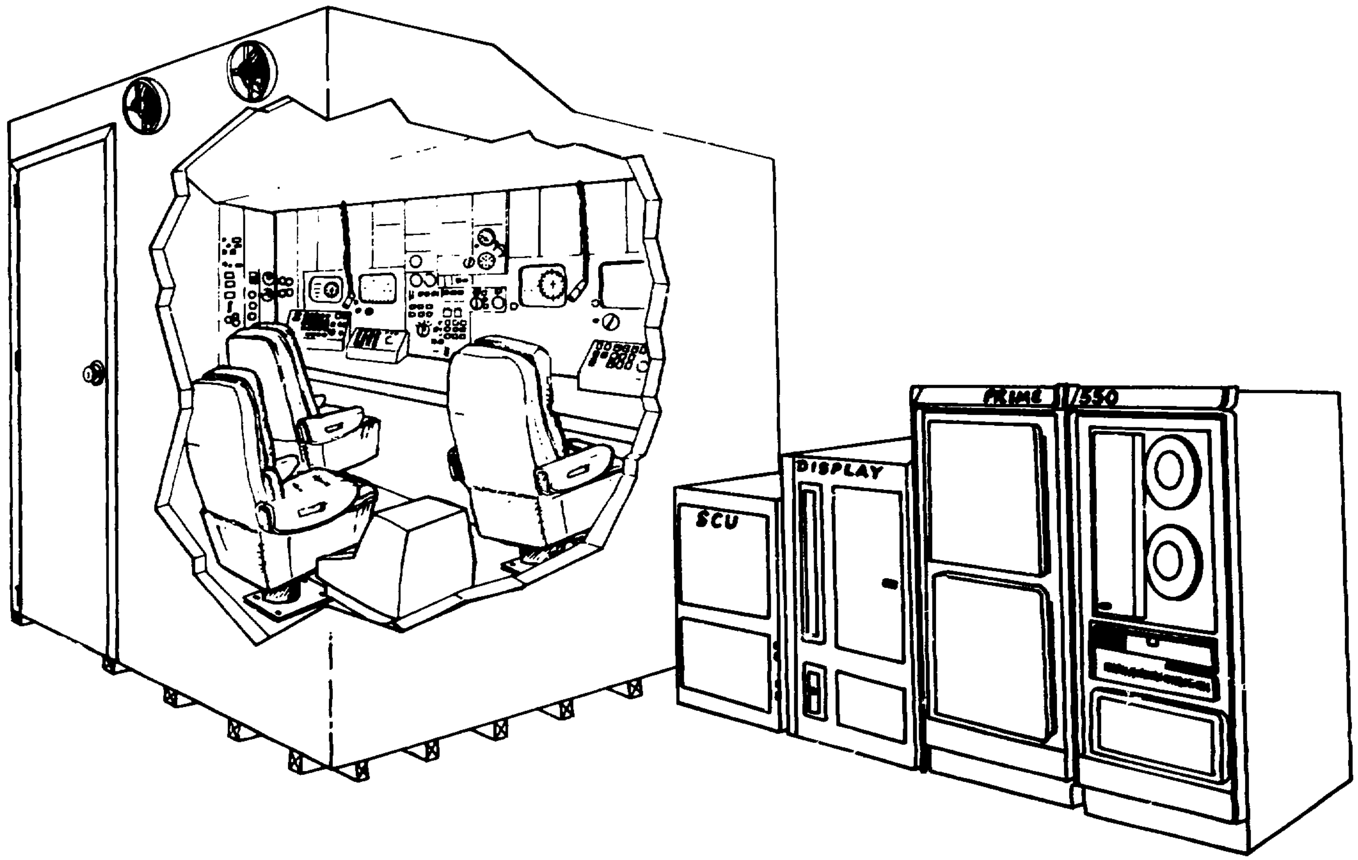
As the training requirements for the OAS and ALCM were developed, it became apparent that lower level tasks and systems functions would have to be trained in a ground simulator. The first question that arose pertained to what simulator could be used. The WST designed for the B-52 would not be ready for the OAS conversion and the present T-10 could not be modified due to current training requirements. Using the ISD approach, the 4235th STS developed a list of tasks which required training in this ground simulator. These tasks and trainer requirements were determined with both the OAS conversion program and the Combat Crew Training School program in mind. The tasks were prioritized from simple to hard. A simple task consisted of anything from knowledge of switch locations to a 3 - 5 step system operation proceudre. The hearder tasks consisted of weapons supervision and OAS system management. Investigation of these tasks determined that a series of training devices could be developed. For the OAS/ALCM program two devices were necessary. The first device would be used to train simple tasks or lower level objectives. The second device would be used to train simple tasks or lower level objectives. The second device would be quite sophisticated and would train higher level objectives. The two devices would compliment each other and the weapon system.

The OAS training managers decided to use a Cockpit Familiarization Trainer (CFT) for lower level objectives and a Part Task Trainer (PTT) for the higher level objectives. As the requirements and designs of the devices began to take shape, it became readily apparent, that these devices would be the backbone of the OAS Conversion Training Package.

The CFT was designed as a wooden mock-up of the B-52 OAS/ALCM modified Radar Navigator and Navigator stations. All the panels in the CFT are inoperative with visible pushbutton switch legends. Two of the four multifunctional displays are also inoperative; however, two are replaced with Singer Caramate II Tape/Slide Projectors. As stated before, this device will be used to teach switch locations and minor procedures.

The student will select a tape/slide program and view it on the projector in the CFT. As the program directs him to a certain switch or series of switches, he is able to locate them in a more real environment. The student can run checklists and even take step by step actions necessary to perform minor OAS procedures.

The design of this device is simple but the training impact is great. Another important



B-52G/H OAS/CMC PART TASK TRAINER

Figure 2

design feature in the CFT is mobility. This device must be capable of being moved to the various sites where the OAS/ALCM training program will be conducted.

The B-52 OAS/ALCM Part Task Trainer is a sophisticated device that addresses some of tasks, procedures and conditions the crew members must handle with the actual weapon system (see FIGURE 2). Because the aircrews receiving training will be highly experienced with B-52 navigational functions, the focus of the PTT will be on procedures training; specifically, those procedures unique to the new OAS. As an example, the PTT must respond exactly as the OAS would to all commands (button pushes, switch activations, etc.), but only those features used directly in navigational and weapon procedures need be displayed in radar video.

The physical layout of the, the PTT provides stations for the two crewmembers required to operate the OAS, as well as for an instructor. The PTT is a physical mockup identical to the OAS layout. The mockup is comprised of 16 operational panels, two of which include a keyboard and trackball (one for each crewmember). Four monochromatic display monitors provide up to 33 different display formats, three of which include synthetic radar imagery. The instructor's position is equipped with a CRT console for setup and monitoring of the training sessions.

The only problems in training device development occurred when changes were made to the OAS hardware (panels/aircraft configuration) and software (program and system operation). Since the CFT was being constructed locally, any changes that were received were incorporated directly to the design. The panels being static could be changed or rebuilt with relative ease. Any change in cockpit configuration could be done easily. Software changes did not effect the CFT.

The PTT with its full-working mockup was effected greatly by both software and hardware changes. A system to handle these changes was established between the 4235th STS and the other agencies involved in the project. As in the CFT, the PTT crewstation was constructed locally so changes could be implemented with minor coordination efforts. The software changes had a much greater impact on the PTT design. A change in the OAS operational system put the PTT software one step behind the aircraft.

To handle this problem the simulator manager set up coordinated communication between all agencies to determine how the changes impacted the software design. The 4235th STS received changes from Boeing and determined what impact they had on the PTT and the training program. If the change was significant, a written change request was forwarded to the other agencies involved. The software specialist would act on the request and forward a yes/no proposal for implimentation. For the prototype software a freeze date finally had to be established. All software changes were accepted until this date. After this date, all changes were held at the 4235th STS for further evaluation. After completion of the prototype software effort, any remaining changes would be implemented in the baseline software effort for the first production device. By developing a prototype and a baseline software a minimum number of crews would be effected by differences between the PTT and the aircraft.

The software design of the PTT was based on the modular design concept which made software changes easy. This gave the PTT the flexibility necessary to incorporate changes.

DEVELOPING TECHNICAL ORDERS

One of the associated items involved with bringing any system into operation is the development of manuals (tech orders) for the operator. Recognizing that manuals written for other aircraft systems often became bogged down in engineering jargon and a conglomeration of useless facts, Air Force personnel involved in the early stages of the OAS/ALCM integration insured training personnel would play an important role in the new manuals. Even before a working model of the OAS was available or the ALCM had flown, meetings were held to organize the development of the aircrew manuals.

These meetings were essential for several reasons. They established that the books were to be written for the OAS/ALCM operator not the staff planners or weapons officers. Therefore, extraneous material was deleted or placed in other manuals used by those individuals. Readability and functionality of the manuals was also stressed to Boeing writers. This ensured the engineering language would not be present since most crewmembers lacked such backgrounds. Also important was the fact that the books would be used by the fully-qualified crewmembers. Therefore, the books did not have to take a tone of training documents. This eliminated the need for repeated explanations of basic operations such as keyboard entries. Through the meetings these cosmetic changes became easier to make as Boeing writers learned the desires of the Air Force. Each published change underwent editorial and technical reviews by Air Force and Boeing personnel. As each change was published these reviews required less time due to the parties understanding each others problems and desires.

However, the largest pay off from these meetings came from the communications established between the Boeing writers, flight test personnel, and the 4235th STS. Sometimes bordering on harassement, the interplay caused several hundred questions to arise about the system's operation. Procedures and checklists were developed which would have otherwise taken months to evolve without the collective knowledge of the groups. However, despite the success brought by early efforts there is no denying that simultaneous accomplishment of several phases of system development created problems.

Software implementation of the OAS/ALCM did not proceed as easily as anticipated. Daily changes to the software programs became commonplace. This caused changes to the engineering documents. The lag between actual change of operation of the OAS and changes to the engineering documents required tech order development to be extremely flexible. To keep up with these changes not only in the training program but also in the manuals required almost daily telephone communication between the three groups. Without this constant conversing, an OAS would have been delivered that bore little resemblance to the engineering document, the training program, or the tech orders.

In addition to the meetings to establish the early groundwork for communications, several other actions could ease the task of developing operator tech orders. First, tech order writers, test/test flight, and training personnel should all become extremely knowledgeable concerning the information in the engineering documents. Then they all should attend contractor training for the new system (Type I Training in Air Force terminology). This allows them the opportunity to ask questions concerning unclear areas and to be questioning students rather than naive listeners during the training. Once having completed the contractor training all individuals involved in testing, training, and publication writing are on equal ground and can be valuable inputs at subsequent meetings.

Finally, tech order witers, training program developers, test/test flight personnel, and a system engineer should meet as often as possible to discuss how the system is actually working. In the case of an aircraft, this should be required after each flight. This provides the forum for discussion of system operation of the engineering documents. It also provides feedback to all parties from the system engineer concerning any changes made or to be made to those documents, on a more timely basis than normal printed distribution which normally takes weeks.

HANDLING SYSTEM CHANGES

Ideally training programs written after a system is developed do not encounter serious problems with changes in system hardware or software. This luxury does not exist in a training program developed simultaneously with the full-scale development of the system. The daily changes in the Offensive Avionics System had numerous effects on the training program.

Anticipating a system resembling the engineering documents, personnel of the 4235th STS had written a task analysis, lesson outlines, and simulator mission profiles based on those documents. Each change called for adjustments to all these efforts. The changes initially caused consternation and frustration in the training program developers. However, when it became apparent that changes would be part of the daily routine, the developers learned to adapt more quickly.

A few suggestions to minimize the problems associated with the handling of changes to the system follow:

(1) Prepare <u>all</u> individuals involved with the training program for the changes that will more than likely evolve. This means not only the actual writers for the training program but also the instructors who will teach it; the graphics people who must prepare new slides for what seems to be a miniscule change; the individuals who are building trainers, etc. This preparation lets everyone know that the changes are not generated by the training developers' errors but by actual changes in the system. This understanding not only leads to increased credibility for the training developers but also unites everyone into the challenge of preparing a quality program within the time constraint imposed.

(2) Establish communication lines between all parties involved in the program. The system manager, system test personnel, training personnel. system enginers, manual writers and any other groups concerned with system operation must meet often to resolve how the system is operating and how it will operate once in the field. Communications lines must also be established to allow more rapid reaction to problems if it is required between such meetings. In its program the OAS training developers conducted numerous telephone conferences with any agency that could provide up-to-date information concerning OAS/ALCM.

(3) The use of a word processor was essential in keeping the training lessons up-to-date. When a writer changed a lesson it was immediately put into the word processor. This provided a current printout of any lesson when an instructor asked for it.

(4) Realizing that it is often easier and cheaper to change an engineering document rather than hardware and/or software, curriculum developers must develop the flexibility to change any lesson. However, at some point a "freeze" must be implemented on courseware changes. At this point coursebooks or multi-media programs should be completed and all changes should take a form of errata. This prevents "the last minute" publication of courseware. If such last minute efforts are allowed editorial and reproduction errors will create the appearance of lack of professionalism. As was said earlier - changes due to system development can be explained. Sloppiness in controllable areas can not be excused.

SELECTING INSTRUCTIONAL MEDIA

Using the ISD concept, the curriculum development manager usually has a number of instructional media choices to deliver his training course. In selecting the proper instructional media, the curriculum manager must select the media that is the best to convey his subject matter to the student.

In developing the OAS/ALCM Conversion Training Program, the selection of instructional media was limited by certain constraints. Many media options were not available, became to complex, or were not flexible enough to handle program changes. Because the curriculum was being written and produced during system full-scale development, the instructional media had to be simple and easy to update. The training manager had to anticipate system changes and be able to update the courseware quickly. If the media chosen for a lesson was to complex, it became costly in both time and dollars to change. The curriculum development managers of the OAS/ALCM program used simple but effective instructional media. The three forms of media that proved flexible enough to use were tape/slides, coursebooks, and trainers (CFT or PTT). All three of these proved effective and withstood the constant change of a developing system.

SELECTING INSTRUCTORS

As the OAS specifications and system requirements were completed the 4235th STS established an initial cadre of instructors. These seven instructors were to function as both Subject Matter Experts (SME) and Curriculum Development Managers (CDM). Once assigned, the instructors began to establish a core of knowledge by studying the OAS/ALCM specification and Boeing documentation. Using the ISD approach, the seven instructors were tasked to develop the entire OAS/ALCM Conversion Training Program. In the program plan, additional people were to be added to the OAS program and with the original seven instructors these individuals would form a "road show" instructor team. The teams would travel to each SAC base and conduct the conversion training. They would provide both the ground and inflight instruction.

Due to assignment priorities for fliers and shortages of qualified instructors, the above concept did not develop. The 4235th STS and SAC were faced with the problem of conducting extensive training with minimum instructor resources. A new concept of training was developed which created a less then optimum situation. The responsibility of the curriculum development remained with the 4235th STS but the responsibility of the "road show" was given to the 4017th Combat Crew Training Squadron (CCTS), Castle AFB, CA. The problem arose that a training program was being produced in one organization but the instructors to conduct that training would come from another.

A three step solution was formulated to eliminate this problem. First, a channel of communication was established between the OAS project officers at the 4017th CCTS and the 4235th STS. Boeing documentation, task analysis, and system specifications were sent to the 4017th CCTS to establish a core of information for the initial instructor team. This improved the communications between the two organizations since the 4017th CCTS now knew something about the OAS/ALCM.

The second step to solve the problem fell on the 4235th STS. A training program for the initial "road show" instructors was established. In this class, the 4017th CCTS instructors would take the entire conversion course. Doing this, the 4235th STS was able to perform validation on the curriculum and the 4017th CCTS instructors were able to learn the system plus see how the course was produced and delivered. 4017th CCTS instructors also completed a course in ISD so the philosophy of the coursaware was more meaningful to them. Both organizations became confident that the other was doing its job.

In the third step, the 4235th STS established a procedure to have at least one CDM present at each base for the entire length of the conversion. This individual would be there to oversee the training program and to make note of valid changes. He will not be an instructor but an evaluator of the curriculum presentation. The 4235th STS three step program has thus far been successful. These efforts have averted a potentially serious situation. However, future programs requiring simultaneous curriculum development and full-scale development should make every effort possible to use the curriculum developers as the initial cadre of instructors. They have the most current knowledge of system operation and courseware. Serving as instructors they could also discover changes between system operation and courseware more readily due to the longer amount of time they have been involved in the system.

CONCLUSION

The 4235th STS has produced a training program simultaneously with full-scale development of the system requiring the training. Is has certainly not been as easy as conventional training program development; however, it is possible. Evaluations of the OAS/ALCM training program by Strategic Air Command's 1st Combat Evaluation Group and the Griffiss Air Force Bass staff have been highly complimentary. With the long lead times required to bring todays'sophisticated systems into operation, the combining of full-scale development and training program development might become a common occurrance. Hopefully the suggestions made in this paper to solve the typical problems of such an effort will help in the devleopment of future training programs.

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THE SIMULATOR TRAINING MATRIX

Michael P. Scher
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ABSTRACT

There are five basic questions that should be answered by various DOD personnel prior to selection and procurement of a training device. The sequence of these questions and who does the answering is a critical determinate of whether or not the ultimate user actually gets what he wants or needs to fulfill the training requirement. An example of a simplified sequence of events or matrix is included, which can be applied universally to all new simulator procurements, modification to existing devices (CILOP - Conversion In Lieu Of Procurement), or new concepts incorporating "non training" requirements.

The rapidly changing threat environment has created a technology race that has finally reached a point in which the human factor must be removed from mundane operations. New weapon systems being delivered have attempted to accomplish this by increasing system capability and complexity, but the results have been an increase in the operators task loading. Although the manual manipulation of knobs and processing of information may have been decreased under routine conditions, the assimilation of data from several sources and abnormal situations which occur only in combat scenarios have actually increased the operator's task. To properly evaluate the equipment within the limited time frame of combat requires thorough knowledge and working experience with the individual black boxes and the whole weapon system. This, then, sets the requirement for a training program capable of realistically reproducing as much of the actual combat scenario and equipment capabilities/deficiencies and abnormalities (malfunctions) as possible.

We have now reached the point where the training system is necessarily more complex than the actual prime equipment it simulates. At some point in the not so distant past, this phenomenon would have resulted in instant turn-off and the training would have been scaled to a point less than necessary. Fortunately, the increased training system complexity commanded more budget attention, which opened the doors to more professional educators. These professionals then proved that the advantages of the super training system far off-set the heavy initial investment.

Many people have asked why systems are not made simpler, requiring less training, and thereby causing less budget strain. This paper will not dispute the virtues of either side, but only state that U.S. defense policy is to compete against "numerical superiority" with "qualitative superiority". It is a plain and simple numbers game where they have the manpower numbers in abundance - we don't.

The problem is to supply the needed training device with the sophistication required within the available budget. Since funding for specific programs of significant size is either funded within the prime budget or assigned a separate line number, timing of the requirement can be significant. If the program is new, such as a new aircraft buy or modification, the funding level asked takes trainers (new or modifications) into consideration. In cases where modification is no longer applicable or the trainer is procured after the prime is operational, a new line number is assigned and funding must be justified based on the merits of the trainer itself.

Maximizing the use of each budget dollar is easy to say, but difficult to accomplish. Alignment of priorities within the DOD budget starts after the known personnel costs are deducted. What is left is hardware and R&D. Training is relegated to the bottom rung of the ladder. This is where training dollar utilization is scrutinized. This is also where I believe the injustice is done. A system that uses checks and balances enhances the probability of fair and impartial decisions, but in this case provides for waste by contractor and military alike. No one can effectively argue that good training does not add to the effectiveness of any combat system. Regardless of the weapon system's age or complexity, training of some degree (whether operator, maintenance, or both) will add to its utility and efficiency. The waste comes from the different directions each agency takes. In each service we can account for at least four inputs; the Washington community that has to justify the budget figure; the using Command that inputs its priority list; the procuring Command (NTEC, PM-TRADE, AFSC), which may be further subdivided, and the user who has to actually utilize the device.

The breakdown and subsequent confusion results from the importance each agency attaches to the issues relevant to the requirement. I can think of five basic questions which are pertinent to any requirement:

1) What type device is best to satisfy the requirement.

2) Sophistication/fidelity required?

3) Number of devices needed for best return?

4) Value of the trade-offs (savings possible)?

5) New concepts availability/adviseability?

Each of these questions is asked and partially answered by at least one of the directing agencies. In some cases, the answers will cause program delays, late RFPs, or even total redirection of the program. The priority given each factor is the key issue. Who should control the priority assigned is the key problem, and just as significant, where should the compromise be made?

The first question of what type device is best to accomplish the objectives appears easy to answer for the uninitiated. The user almost always will opt for the most elaborate innovative new contraption "available". Available is an important word because he wants it now. The budgeteer attempts to use the existing device with a minor modification effort. This is the CILOP (Conversion In Lieu Of Procurement) principle and is a very effective method of getting a needed training capability at a relatively inexpensive price - sometimes. A third approach comes from the engineering faculty that tends to push technology that favors an innovative approach, and a full scale development. Neither of the three methods should be eliminated but they should be harnessed into a useable matrix where they are treated fairly in accordance with operational priorities.

Agreement can be reached on the correct type of device for most situations when no present device exists and funds are either limited or capable of sustaining the latest technology. Throwing a hitch in at this early stage is the non-training requirement. This elusive non-training related capability can come in several flavors. Another important aspect affecting relatively large programs is politics. Politics play an obvious part in the budget cycle, but often forgotten are the issues of foreign buys, State favoritism, and reelection commitments/promises. Images and morale are also aspects to be considered.

A good example of a program caught in the clutches of both the non-training requirements and the conflict between agencies is the Air Force's Companion Trainer Aircraft (CTA) program.

Originally heralded by Strategic Air Command as the answer to several near and far term problems, the CTA has yet (as of 1 July 1981) to be clearly defined and into a contractors hands.

Senator Barry Goldwater spoke at the 1st Interservice/Industry Training Equipment Conference in 1979 calling the CTA program " .... an innovative way to have real flying training with significant fuel and dollar savings." The original concept did that. It would save in fuel by providing B-52 crews training in an aircraft at less than one-tenth the fuel of a B-52, and unlike a ground trainer it provided actual flight training that could be judged as a positive for pilot morale as well as proficiency.

The CTA program utilizes an off-the-shelf business jet with both real and simulated equipment in the passenger compartment to train a B-52 crew. The electronic warfare portion was to be closed-loop simulation whereas the offensive system would use simulated bombing controls, but real-time radar.

The cockpit would receive only minor instrumentation changes to reflect the B-52 environment. Analyzing the CTA program, it becomes very easy to see how it was sidetracked so often. The problems started with Congress were aggravated by the contractors, and finally ran into internal Air Force problems related to solving the first two conflicts. Problems from Congress came in funding profiles, foreign politics, and basic civilian trust of the military objectives. Normally non-defense contractors jumped in early to exercise their political muscle to see this new avenue of potential sales start up. In this innovative new approach to training, civilian products would find a relatively large market not previously open. Finally, the user (SAC) and the buyer (ASD) fought over the requirements and procurement method.

Back to the type of device to be utilized. Assuming no non-training aspects are apparent, the real requirements should be decided by the user, then negotiated with the buyer. Only after this procedure is complete and fully agreed to by both parties should contractors be allowed entry. Now the draft RFP and industry comments. Unfortunately it never seems to happen this way. In most cases the user states the requirement in general terms and the buying engineers attempt to design the product within budget constraints. The user does not object strongly to the procurement approach or the specific requirements the buyer described in the RFP.

With this scenario, the emphasis is placed on budgetary constraints and how the service estimates the program profile. Whereas this may be a totally realistic approach, it is not in the best interest of the service.

Quite often the cost estimating by the service is off considerably in either direction. This can serve to slow down or kill a particular project before it has a chance to begin. If the project is assumed to cost more than the budget will allow, the requirements may be cut to a minimum. This leads to a mediocre training device that won't do the required job, but the user has no choice - take this item or none at all. When the RFP is issued with the reduced requirement, industry will bid the budget less the winning price strategy. If the original requirement had been pursued, perhaps the competitive nature of our system would have produced the project within budget by innovation. In effect, the Government is robbing itself and stifling innovative competition.

Back to the five basic questions, question two is asking for a qualification of the sophistication or fidelity to do the job. Again the problem rests with who should answer the question. Engineering can certainly investigate or evaluate the competitiveness of analog versus digital, but they should not have the final say in training fidelity. This should be answered by the direct user. The direct user is not the using Command, it is the simulator supervisor or simulator instructor. These are the individuals who can answer the question of device requirements better than anyone. Let the Instructional Systems Development (ISD) personnel determine the training goal for the device and the simulator supervisor determine what "he" needs to achieve that goal.

The third question is for those staffers that have finally seen the "big picture". The number of devices needed is related to manning and the particular operation. This question must be coordinated between the user and buyer. The user can state the number of places the devices will be required and the time required on each per day. The buyer can utilize this requirement, combine it with the engineering assessment of life-cycle cost and MTBF (Mean Time Between Failure) rates, and a fairly accurate number can be arrived at. Although the questions of number is usually answered by a pseudo-reliable method, problems arise in funding profiles and force structure changes. Since multi-year funding is probably a dream in simulator procurement and changing administrations bring new modernizing ideas for the military, stability in numbers will probably be no more accurate in the future than they are now.

Evaluating the trade-offs for training (question 4) can be hazardous to one's career in government service. Although the weapon systems training expert may evaluate procurement timing as the important factor overriding a cost penalty, the final result may not even consider the device availability. Again, as in the other questions, the value assigned to specific features or requirements are generally stipulated too late in the game (causing them to be slanted due to cost, politics, or other known inputs) and by the people least affected by the outcome. Up-front assignment of values to different aspects should be completed and agreed upon at the same time the requirements are laid out. The value points should be assigned by requirement priority, rather than realistic expectations. Too often cost becomes predominate. The question of how much will be allotted to spend on this system should not be utilized as a criteria for establishing requirements or priorities. The training needs are first. Potential savings should be evaluated after realistic cost and performance data is evaluated in response to the requirement. Looking for the cheap way out or the paper savings that everyone claims have jeopardized some training programs and on occasion have produced a product of little actual training value because the program structure was decided before the facts were in or the requirements were defined.

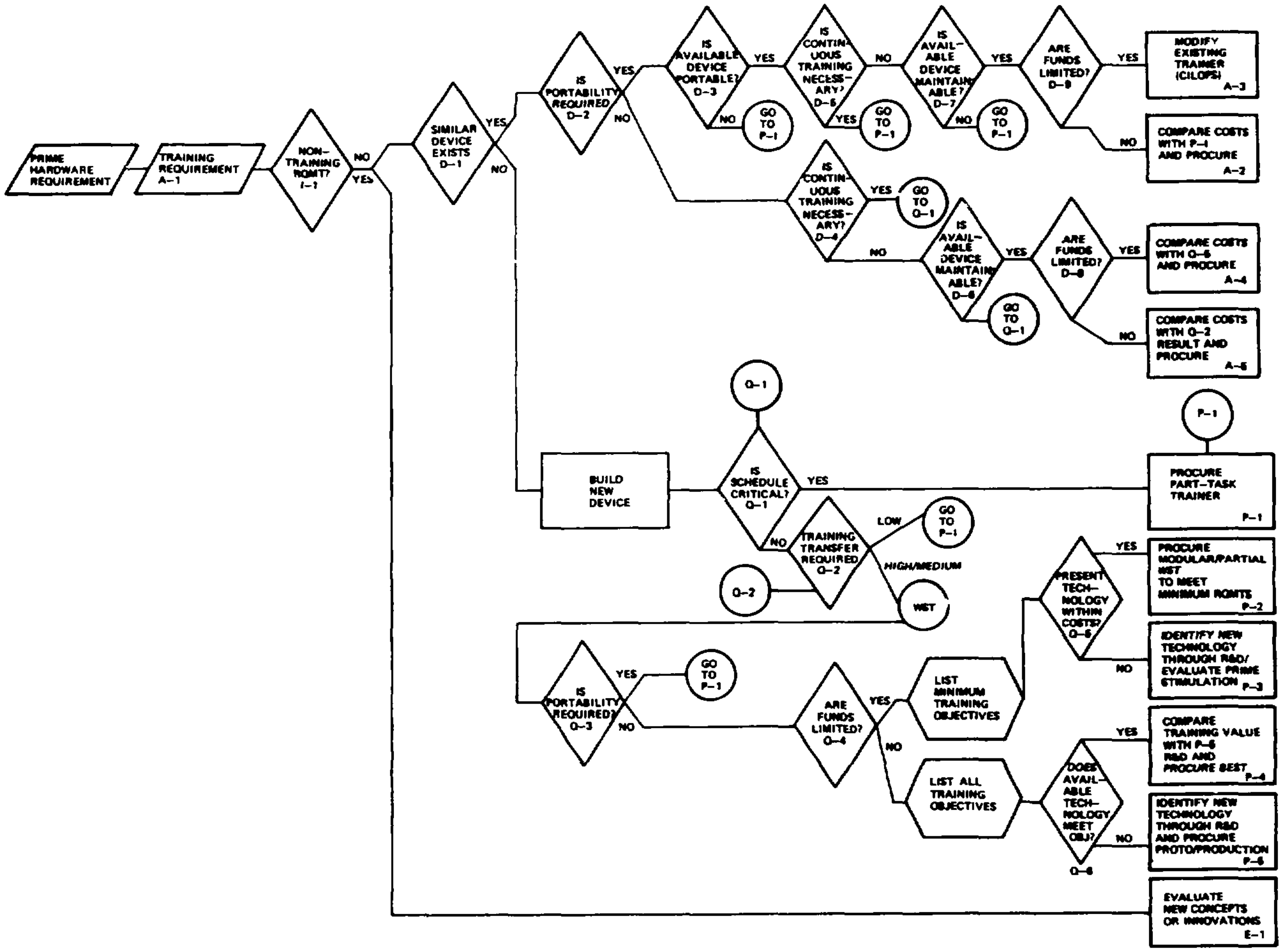
Many times the contractors will bid to the budget rather than to the requirements, or even worse, bid for the "buy-in" with the expectation of ECP's (Engineering Change Proposals) to pull them out of the "red". When this occurs, the usual result is the end user gets an inferior product with idle hopes of recovery far down stream. Perhaps the answer is a complete reversal of DOD buying strategy. Don't set a budget for individual items, but rather a total figure for each service with further breakdowns for such categories as strategic or tactical. Issue the RFP's for projects deemed worthwhile on a priority basis each year and assign budgets to the programs when the proposals are evaluated. Perhaps a tougher way to do business, maybe impossible to convince Congress (for major sums of such projects as MX, CX, Trident, LRCA), but it might eliminate buy-ins and products of lesser value than originally requested. This concept will seem totally irresponsible if not closely thought over. Isn't the DOD budget already decided this way? Real growth is projected against the inflation and when added to the previous years figure, a new budget is born. For those of us not involved in the budget process, isn't it odd that the yearly budgets always increase by a small, but semi-predictable growth factor. Can anyone remember when the DOD budget showed radical movement, either up or down, in response to real weapon system costs (except possibly during actual war periods)? Don't major weapon system costs get spread over a period of years to alleviate major deviations in the upward straight-line graph? Now, without changing this method, let's lump all minor cost (relatively speaking) items such as training devices into a pot, large enough to compare favorably with the overall budget increase, and draw our individual allocation by program priority after the costs are in. Costs are now real and the user gets the required capabilities on his "top priority" devices.

Back once-more to the question of trade-offs or savings, the question today is loaded with problems. Who decides the trade-off at any point during the program acquisition cycle? The difference between a full visual system or motion base can be significant in cost, but the training obtained or lost by elimination may be of a much higher value. Negotiation should not have to occur once the requirements are written. If the front-end analysis was done correctly in the beginning, the training requirement is a true requirement and should not be reduced or eliminated to achieve cost trade-offs.

The question of whether to proceed or not with a new concept should be answered within the engineering faculty of the procuring agency. They are best suited to decide the merits and risks in a new approach to solving the requirements. This question must not be asked until all requirements are defined, costs are evaluated, and the procurement timing is agreed upon. The tendency for engineering to explore new areas and concepts is natural, but must be avoided if it will destroy the integrity of the program structure such as operational viability or cost.

These brief discussions of the five basic questions are incomplete at best. A full answer to each question would take an entire paper in itself. By utilizing a matrix of decision flow and assigning the responsibility for the decision points, the questions are put in perspective, thereby eliminating some of the current problems and reducing others to manageable levels. The crude matrix I have drawn here is elementary, but is should serve as an adequate example. It assumes the dimensions enclosed by the five questions, and the relative sequence in which the decisions should be made.

Rather than following the matrix point-by-point to the conclusion, I will point out only specific areas and relationships. Note first that funding is considered last. The entire basis of my paper is that we have short-changed


PRIME HARDWARE REQUIREMENT
TRAINING REQUIREMENT A-1
NON-TRAINING RQMT? I-1
NO
YES
SIMILAR DEVICE EXISTS D-1
YES
NO
IS PORTABILITY REQUIRED D-2
YES
NO
IS AVAILABLE DEVICE PORTABLE? D-3
YES
NO
GO TO P-1
IS CONTIN-UOUS TRAINING NECESS-ARY? D-5
NO
YES
GO TO P-1
IS AVAIL-ABLE DEVICE MAINTAIN-ABLE? D-7
YES
NO
GO TO P-1
ARE FUNDS LIMITED? D-9
YES
NO
MODIFY EXISTING TRAINER (CILOPS) A-3
COMPARE COSTS WITH P-1 AND PROCURE A-2
IS CONTIN-UOUS TRAINING NECESS-ARY? D-4
YES
GO TO O-1
NO
IS AVAIL-ABLE DEVICE MAINTAIN-ABLE? D-6
YES
GO TO O-1
ARE FUNDS LIMITED? D-8
YES
NO
COMPARE COSTS WITH O-5 AND PROCURE A-4
COMPARE COSTS WITH O-2 RESULT AND PROCURE A-5
O-1
P-1
BUILD NEW DEVICE
IS SCHEDULE CRITICAL? O-1
YES
NO
PROCURE PART-TASK TRAINER P-1
TRAINING TRANSFER REQUIRED O-2
LOW
GO TO P-1
HIGH/MEDIUM
WST
O-2
IS PORTABILITY REQUIRED? O-3
YES
GO TO P-1
NO
ARE FUNDS LIMITED? O-4
YES
NO
LIST MINIMUM TRAINING OBJECTIVES
LIST ALL TRAINING OBJECTIVES
PRESENT TECH-NOLOGY WITHIN COSTS? O-5
YES
NO
PROCURE MODULAR/PARTIAL WST TO MEET MINIMUM RQMTS P-2
IDENTIFY NEW TECHNOLOGY THROUGH R&D/ EVALUATE PRIME STIMULATION P-3
DOES AVAIL-ABLE TECH-NOLOGY MEET OBJ? O-6
YES
NO
COMPARE TRAINING VALUE WITH P-5 R&D AND PROCURE BEST P-4
IDENTIFY NEW TECHNOLOGY THROUGH R&D AND PROCURE PROTO/PRODUCTION P-5
EVALUATE NEW CONCEPTS OR INNOVATIONS E-1

ourselves by purchasing the wrong item because it "fit the budget profile." Define the product first, then budget to accomplish the task.

The inclusion of a non-training requirement is a significant factor normally left out. Obviously more detail could be placed between the decision of a non-training requirement to be fulfilled and the resultant buy of a new concept. CILOP also has a place up front. This block is where the initial "training" requirement should be detailed by the user. Allow the user command or the buyer engineers to determine the applicability of the CLIOP principle.

The rest of the matrix involves a simplistic decision tree that need not be detailed in this paper. The necessary factors to be considered in any acquisition cycle are listed; the order or priority and the decision maker are the important concepts. It is the obligation of both industry and DOD agencies to assure the public that each dollar spent is based on a real need. Purchasing a device because it fits the budget does not guarantee that the dollar was spent wisely. Only when the total training requirement is satisfied and an industry's competitive nature is exercised is the public being assured of getting its money's worth.

ABOUT THE AUTHOR

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CURRICULUM VIEWED AS A BINARY SYSTEM:
AN APPROACH TO THE DETERMINATION OF SEQUENCE - A PROJECT REPORT

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ABSTRACT

Determining alternative curriculum sequences is a tedious task involving many individuals and analysis of large amounts of curriculum-related information. Because these tasks are not readily reduceable to mathematical operations, and because educators and curriculum designers are generally not so inclined, computer intervention into this design process has been meager. Nevertheless, the power of the computer to handle vast amounts of information coupled with its high speed manipulation ability makes it an ideal instrument to use in the instructional design process. The project reported herein describes the development and application of a model by which a curriculum may be analyzed to determine alternative instructional sequences based upon curriculum objectives and limiting constraints. The project's primary goal is to ultimately apply the model to the analysis and design of instructional sequences for 16 closely related courses currently under development by the U.S. Navy Recruiting Command.

THE PROJECT

The U.S. Navy Recruiting Command has undertaken the task of developing training programs for 16 individual, yet closely related jobs (or billets) within the duty called recruiting. Although development of training programs is not new to the military, the approach to this particular curriculum design problem is. Due to the close interrelationship between and among each of the 16 courses under development, there is heavy reliance upon instructional sequence. For example, several competencies have been identified which overlap in many of the 16 courses. Because such overlaps parallel real-life recruiting practices, they were not avoided. It is educationally sound practice to structure student learning experiences so as to simulate reality as much as possible. Some educational psychologists believe this produces maximum learning transfer.

However, the payback comes in the form of an increased demand on curriculum sequencing. A non-sequitor or ill-sequenced curriculum can damage the realism of learning experience. It can also reduce the student's ability to internalize the concepts presented. The student may appear to perform satisfactorily in the school environment but become disoriented in trying to perform a similar task in the real-world environment. Thus the need for well-sequenced instruction.

The *classical* approach to determining acceptable instructional sequences has characteristically been human intuition. Such an approach is time-consuming in that it seldom produces an adequate sequence on the first attempt. Additionally, considerable work is involved with each iteration. In this current project, intuition is simply not sufficient for the task of aligning 16 courses into a unified sequence.

In any curriculum design problem, there are a myriad of variables which may dramatically affect the ultimate instructional sequence. However, a model exists in the literature which is capable of dealing with complex systems of interacting variables.(1) This model, known as Interpretive Structural Modeling (ISM), has been successfully applied to the sequencing of process elements in a number of design projects in the fields of engineering, agriculture as well as a host of other complex scientific and social problems. (2) Unfortunately, ISM has seen limited use in the field of education as a tool for planning and design. In fact, this writer has found only one such use. And this has been accomplished primarily by Sato and his colleages in Japan. (3,4) It is the intent of this project to adapt ISM to the instructional sequencing problem and build upon the work that has already been done in this area with the hope that successful development here may spawn more educational uses of ISM in this country.

As the initial project report, this paper will present some basic theory underlying the ISM concept as well as a method which shows great promise in assisting the curriculum designer in determining appropriate alternative instructional sequences.

COMPLEXITY IN THE DESIGN PROCESS

The instructional systems approach, or any systematic approach to instructional design for that matter, is anchored in mathematical modeling. It has long been recognized that a systems approach to instructional development is patterned after the scientific method(5) which is in itself a modeling approach. (6) The question then arises as to why the design of instruction is not treated by a mathematical approach to approximating the shape and scope of a curriculum! In their text, Programmed Learning in Perspective, the authors allude to the mathematical character of curriculum. They describe a quasi-mathematical technique (termed the matrix technique) which is useful in determining optimum unit sequencing within programmed instructional material. (7) Davies further generalized this procedure, demonstrating its utility in optimizing presentation sequences for objectives of an entire course of instruction. (8) The logical extension of this work leads one to believe there may be a method by which a complex curriculum composed of disjointed competencies might be alternatively sequenced.

Successful instructional design models call for some sort of determination of sequence at some time during the design process. Often this is achieved through construction of objective trees (or hierarchies). In fact, instruction in the building of such hierarchies is often in great detail (9) -- testimony to its importance in the instructional design process. To anyone familiar with such a task, it is immediately obvious that instructional hierarchies are complex structures not only to build, but also to interpret. The casual observer is often unable to visualize the many possible sequencing strategies from the maze of lines displayed. Such insight requires a knowledge of the course content and at least some grounding in basic learning psychology. Yet, even if this prior knowledge is assumed, the task of choosing an appropriate sequence from all the possible sequences displayed on the hierarchy is still not easy. Mathematical modeling and operations research provide some interesting algorithms, however, which demonstrate the potential to assist in solving complex instructional sequencing problems.

In their paper Unified Program Planning, Hill and Warfield describe a method for reducing complex systems of elements (in our case, objectives) into a matrix which describes their mutual relationships. (10) They call this a *self-interaction matrix* because it contains information relating to the interaction of each element with itself and the others in the system. The authors define such a matrix as containing enough information to construct an objectives tree.

For this project, their matrix method is used in developing an objectives hierarchy from an initial set of course objectives. The worth of this matrix method is in its ability to produce a hierarchy which actually contains more information than hierarchies developed by other means. As an example of the kinds of information stored, and generally gleaned from typical objectives trees, consider the hierarchy of a hypothetical curriculum containing 15 interrelated objectives as shown in Figure 1 below.

Several *bits* of information are implicitly stored in this hierarchy. For example, OBJECTIVE 1 appears to be the terminal objective for the curriculum. That is, all other objectives either directly or indirectly terminate at OBJECTIVE 1. Also, OBJECTIVEs 3,8,10,11,12,13,14, and 15 are at base levels with no supporting objectives. Thus, these are ideal starting points for sections or modules of instruction. Yet another *bit* of information available from the hierarchy is implied by the arrows connecting the various objectives. Their pattern indicates the existence of partitions between objective clusters (though such partitions are purely arbitrary). For example, one such partition could be OBJECTIVEs 11, 6, 2, and 1; another, OBJECTIVEs 13, 12, 7, 2, and 1; another, OBJECTIVEs 8, 4, and 1; still another, OBJECTIVEs 15, 14, 9, 5, and 1; etc. Although such partitions are arbitrary, these groupings give some indication of the amount of information potentially stored in an objective hierarchy. All these *bits* of information taken together represent a detailed picture of how each objective interacts with all the rest in this particular hypothetical curriculum.

Yet, a completely different class of interactions exists which also come to bear on a curriculum. This class contains such instruction-related items as resource constraints (money, manpower, and time), student needs, types of learning activities available to students to meet course objectives, types and timing of measurement tests, etc. Each of these has a effect on whether or not a given instructional sequence will work effectively. However, these interactions cannot be stored or displayed on a typical objectives hierarchy, such as that in Figure 1. Even by looking at the hierarchy, it is impossible to discern if such interactions were taken into consideration in the hierarchy's development. Of course, this information could be superimposed onto the hierarchy, however, this could very easily complicate the diagram to the point that interpretation becomes impossible. The reason for this is that there seems to be an upper limit on the amount of

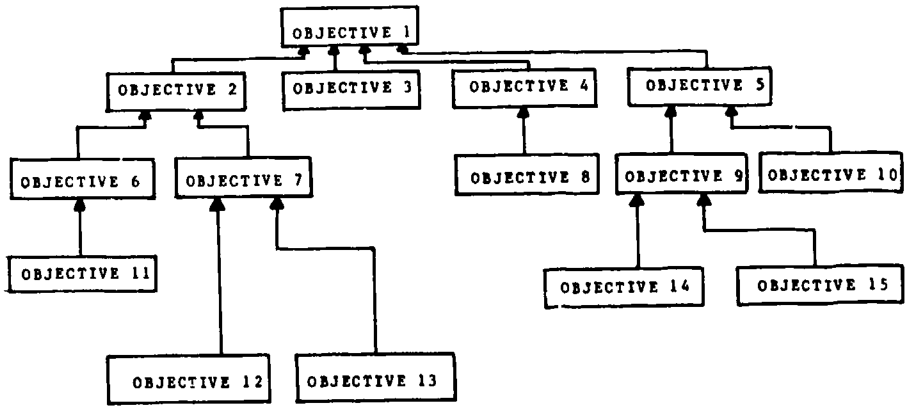


Figure 1. An objectives hierarchy containing 15 interrelated objectives

information that one human can process and operate on at any given time. "Research tentatively shows that the amount of information man is capable of processing is limited, and more data...do not necessarily increase the quality of decisions in the same proportion." (12) It must be made clear at this juncture that the self-interaction matrix is not intended to replace the objectives tree, but only to enhance it. "The self-interaction matrix ...is not as clear as the objectives tree for viewing the relationships among objectives, but it incorporates significant advantages in relating objectives to constraints, alterables and needs" inherent in the instructional system. (13) Thus, in this project, both the matrix and the objectives tree are utilized to their maximum advantages.

In actuality, the curriculum designer, the teaching staff, and the management personnel each recognize a different set of such interactions as mentioned above which impact on the curriculum. Thus, the designer must spend considerable time with teachers to develop an instructional hierarchy which takes into account as many of the ancillary interactions as possible. And when they finally come to an agreement on a reasonable teaching sequence, they may find (to their dismay) that the administration rejects the plan because of some constraining factor neither the designer nor the teachers knew about. Such situations are common and illustrate the need for a model which can contain and process much more curriculum-relevant information than is currently possible. The major requisites of such a model would have to be: convenience, simplicity and utility.

Convenience can be described as the ease of applying the model to the design problem. Simplicity refers to the quantity of information that must be provided by the user for the model's operation. And utility can be expressed as the model's adaptability to a general class of curriculum design problems - from the relatively simple task of sequencing information within a programmed text to the highly complex task of determining the sequence for effective learning in a *spiraled* "K through 12" educational network. ISM, the model used in this project, posesses these primary requisites in varying degrees and is thus a likely candidate for the curriculum design problem.

CHARACTERISTICS OF A BINARY MATRIX

Before detailing the results and current status of the project, we should first clarify the terms used. The literature on the subject is primarily mathematical. For this discussion, the mathematics have been simplified in some places, and eliminated altogether in others. In its place, intuitive arguments have been used. Readers interested in the actual mathematical derivations are referred to the work of Warfield. (14)

A binary matrix is a square array of elements whose values are either 1 or 0. If all the main diagonal elements (from upper left to lower right in the array) are 1s, the matrix is said to be reflexive. Thus, an irreflexive matrix has some 0s on its main diagonal. An irreflexive matrix must be made reflexive in order to be analyzed by the matrix method. Fortunately, this is easily accomplished by adding to the irreflexive matrix an identity matrix. This is also a binary matrix with 1s along the main diagonal and 0s everywhere else.

The rows of a matrix are usually referred to by the letter i, while the columns are usually referred to by the letter j. Every matrix element occupies a position which is at the intersection of a row and column. Thus, any arbitrary element of a matrix can be referred to as the (i,j) element. If a matrix element (i,j) and its "mirrir-image" element (j,i) are the same value (either 1 or 0), then the matrix is said to be symmetric. The degree of symmetry depends upon how many elements (i,j) are matched to their "mirror-images". To illustrate this more clearly, note the mirror-image quality in the binary matrix in Figure 2 on both sides of the main diagonal. For clarity, the zeros have been removed

$$\begin{array}{c|ccccc|}
 & 1 & 2 & 3 & 4 & 5 \\
\hline
1 & 1 & & & 1 & 1 \\
2 & & 1 & 1 & & 1 \\
3 & & 1 & 1 & & \\
4 & 1 & & & 1 & 1 \\
5 & 1 & 1 & & 1 & 1 \\
\hline
\end{array}$$

Figure 2. Mirror-Image Symmetry Above and Below the Main Diagonal (dashed)

A binary matrix may have a few assymetric points and still be considered symmetric for purposes of this method if the number of assymetric points are kept to a minimum. In reality, an assymetric matrix yields the best instructional hierarchy. Thus, the degree of assymetry in the matrix determines the richness of the resulting hierarchy. However, this depends upon the nature of the objectives under consideration and the nature of the interactions among objectives - both of which are dependent on the type of curriculum being designed.

TRANSITIVE RELATIONS AND DIRECTED GRAPHS

In determining an appropriate curriculum sequence, considerable thought must be given to how each instructional objective relates to all other objectives in the curriculum. During the so-called "front-end analysis" phase of a design project, relationships between what the student needs and what the curriculum will offer to meet those needs are more likely to be philosophical intuitions than rigorous proofs. The mathematical character of ISM, however, requires a more detailed analysis of such relationships. These relationships are logical rather than mathematical.

Consider the logical relationship among three objectives (a, b, and c) as illustrated in Figure 3. Figure 3A shows that objective a relates to objective b, and that b relates to c. However, objectives a and c are not directly related to one another. Clearly, if objective b were removed from the curriculum, objectives a and c would exist as isolated entities. Such a relation among objectives is called intransitive because there is no direct relation or, or connection, between objectives a and c.

Figure 3B, on the other hand, indicates that

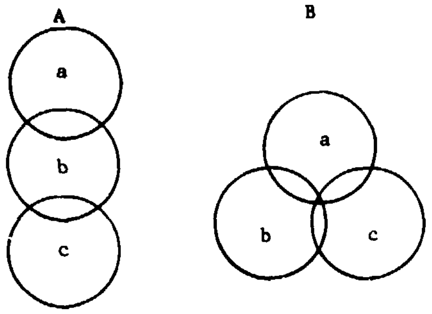


Figure 3. Two Types of Relationships
Among Objectives a, b and c

all objectives are directly related to each other. If any one of them is removed, the remaining two are still linked together through a binding relationship. A transitive relation is one in which each objective relates, or is somehow linked to the others in the group.

Though we have used the term "relation" numerous times, we have not yet clearly defined it. A relation is a phrase or term that shows how two or more elements (or objectives) interconnect, or link, to one another. Whether or not a relation is transitive depends not so much on what relation is used, as on the situation in which it is used.

For example, consider the relation "is contained within". If a "is contained within" b, and if b "is contained within" c, then it follows that a "is contained within" c. We can visualize this relation in Figure 4. Any objectives a, b and c for which this relation holds true is considered a transitive set of objectives. It must be borne in mind, however, that even though the *relation* is transitive, not all *objectives* will suit it. If one particular relation is not transitive across an entire set of objectives under consideration, a relation that does apply must be found. Each new relation chosen, of course, must be similarly tested to insure transitivity within the entire objective set.

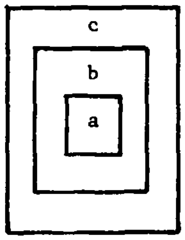


Figure 4. Visualization of the relation
is contained within

Some relations are intransitive in all but the most specific of situations. For example, Warfield has reported that the relation "obeys" fails the transitivity test (15): if a "obeys" b, and if b "obeys" c, a may not necessarily "obey" c. In fact, most relations are situation specific. They must be carefully considered in the context of the entire objective set.

Once a transitive relation has been identified, it remains to be discovered how the relation specifically affects each pair of objectives. Does, for example, the relation link objective a to objective b, or vice versa? A simple example should serve to illustrate this point. Consider the transitive relation *depends upon prior accomplishment of*. If objective a *depends upon prior accomplishment of* objective b, then clearly, b cannot possibly *depend upon prior accomplishment of* objective a. In addition to illustrating assymetry, this example also illustrates the concept of directability. In the above example, an arrow could be drawn between objectives a and b with the arrowhead pointing toward objective a to show that a *depends upon prior accomplishment of* b.

If all such directed relations between objectives are considered, a picture of the interactions can be obtained. Such a picture is known as a directed graph. Warfield has shown that any directed graph or *digraph* possesses an associated binary matrix (16). A given binary matrix, however, may produce a number of alternative digraphs. Any one of them could be used as an objectives hierarchy to describe the interrelationships among instructional objectives. The binary matrix needed to produce the digraph is called the reachability matrix. If transitive and assymetric, this matrix can be manipulated to produce a digraph (otherwise known as an objectives hierarchy). The procedure, described by Warfield, requires the formation of tables consisting of various arrangements of objectives (17). The actual procedure followed for this project will be described in greater detail in the next section. This cursory overview of the underlying theory supporting the matrix method will suffice for our purposes here.

THE PROJECT'S METHOD

The process of generating a digraph from a set of curriculum objectives is a straightforward approach composed of the following steps:

1. Identify the objectives of the curriculum.
2. Determine a transitive relation which applies to the objectives in the context of the instructional situation.
3. Place objective relations into a matrix format - termed a self-interaction matrix.
4. Manipulate the matrix into a suitable form - termed a reachability matrix.
5. Re-order the rows and columns of the reachability matrix and partition it to reflect hierarchical levels - termed a modified reachability matrix.
6. Compute a hierarchy (or digraph) from the modified reachability matrix

The curriculum design project described in this paper follows this six step process for generating hierarchies and determining instructional sequences. Since the approach is both complex and time consuming, computer algorithms have been designed to perform most of this work. The remainder of this paper details the process followed in the Navy curriculum project.

Step 1

After the front-end analysis had been completed for the 16 courses under development, a listing of tasks required for training were identified. And from these, a series of learning objectives were developed for each course. One course was used for the pilot study in this project.

Step 2

The transitive relation *is necessary to accomplish* was agreed upon by the subject matter specialists, the curriculum design staff and the approving board for curriculum development. This relation was used in the analysis of the relationships between every possible pair of objectives. Since 18 objectives were originally identified for training in the pilot course, 18 x 18 (=324) distinct objective pairs were analyzed via the agreed upon relation.

Step 3

For each of the 324 objective pairs, a 1 was placed into the corresponding cell of a matrix, if the relation was true. If, however, the relation was false for a particular pair, a 0 was placed in the appropriate matrix cell. The resulting matrix required approximately four manhours to accomplish. The self-interaction matrix which resulted is shown in Figure 5.

Objective Number

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	1	1	0	0	0	0	1	1	0	0	0	1	0	0	1	1	0	1	0
O	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
b	3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
j	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
e	5	0	0	1	1	1	0	0	0	0	1	0	0	1	0	0	0	0	0
c	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
t	7	0	0	0	0	1	0	1	1	0	0	1	0	0	1	1	0	1	1
i	8	0	0	0	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0
v	9	0	0	1	0	1	0	1	1	1	0	0	0	0	1	0	0	0	0
e	10	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0
	11	0	0	0	0	1	0	1	0	0	0	1	1	0	1	0	0	1	0
N	12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
u	13	0	0	1	1	1	0	0	0	1	1	0	0	1	0	0	0	0	0
m	14	0	0	0	0	1	0	1	0	0	0	0	0	1	1	0	0	1	1
b	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
e	16	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
r	17	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
	18	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1

Figure 5. A Self-Interaction Matrix for the pilot Course

Warfield describes an algorithm with which a computer can be programmed to accomplish this data entry step with reduced effort on the part of the user.(18) Currently, the algorithm is being modified for use in this project, but was not used for the pilot project. After creation of the self-interaction matrix of Figure 5, it was loaded into a BASIC language microprocessor via a prompting routine developed by Orwig. The flowchart of this routine is shown in Figure 6.

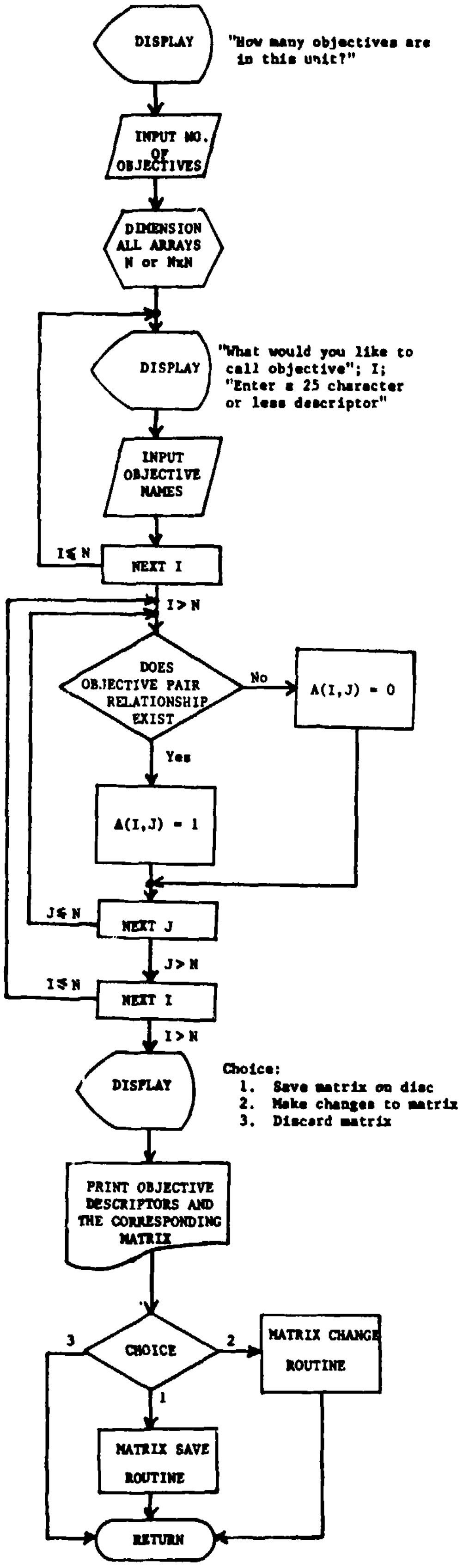


Figure 6. A Prompting Routine for Matrix Data Entry

Step 4

The self-interaction matrix of Figure 5 must be manipulated into a reachability matrix before further analysis can be performed. This manipulation involves raising the self-interaction matrix (M) to successive powers (squared, cubed, etc. by Boolean multiplication) until the following equality is met: $M^n = M^{n+1}$. An algorithm used to accomplish this multiplication process is presented in flowchart form in Figure 7. (A flowchart of the entire computer program developed by the authors appears in the Appendix.) According to theory, if there are *N* objectives in the matrix, the reachability matrix will be derived in *N-1* or less iterations. (19) The self-interaction matrix for the pilot course (Figure 8) was converted to reachability form in four iterations. In other words, the matrix of Figure 8 multiplies out in four iterations to form the reachability matrix in Figure 9, which satisfies the equality: $M^3 = M^4$.

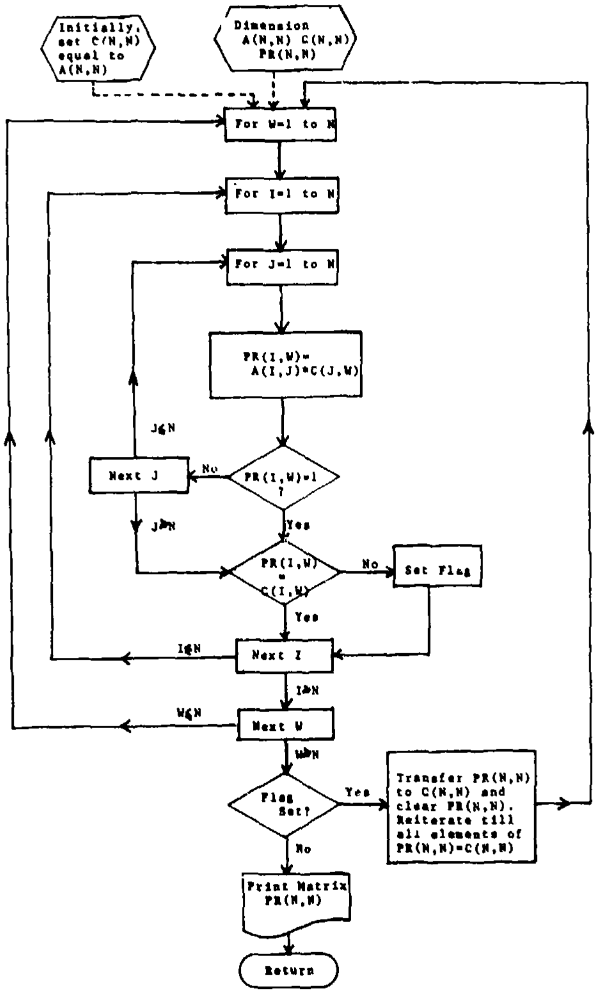


Figure 7. An Algorithm To Convert A Self-Interaction Matrix A(N,N) Into A Reachability Matrix PR(N,N)

Objective Number

Objective Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	0	0	0	0	1	1	0	0	0	1	0	0	1	1	0	1	0
2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
5	0	0	1	1	1	0	0	0	0	1	0	0	1	0	0	0	0	0
6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	0	1	1	0	0	1	0	0	1	1	0	1	1
8	0	0	0	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0
9	0	0	1	0	1	0	1	1	1	0	0	0	0	1	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0
11	0	0	0	0	1	0	1	0	0	0	1	1	0	1	0	0	1	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
13	0	0	1	1	1	0	0	0	1	1	0	0	1	0	0	0	0	0
14	0	0	0	0	1	0	1	0	0	0	0	0	1	1	0	0	1	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
17	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
18	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1

Figure 8. The Self-Interaction Matrix of Figure 5

Objective Number

Objective Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
5	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
8	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
9	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
10	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
11	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
13	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
14	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
17	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
18	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1

Figure 9. The Reachability Matrix Derived From the Matrix of Figure 8

Step 5

The purpose of this step is to partition the reachability matrix into submatrices which reflect the levels within the instructional hierarchy. The resulting partitioned matrix will be the reachability matrix modified by row and column interchanges. To determine the eventual order of this interchange, a table is created which contains a reachability set, an antecedent set and the product (or intersection) of both sets.

The reachability set for element 1 is found by inspecting row 1 of the reachability matrix (Figure 9). Every 1 in row 1 corresponds to a column index, and every such column index will be in the reachability set of element 1. To find the antecedent set of element 1, inspect column 1. To every entry of 1 in column 1, there is a corresponding row index; and the set of such row indices is the antecedent set of column 1. Each row and column is similarly considered in turn thus producing a table of reachability and antecedent sets for each row of the matrix.

In Figure 9, the row and column indices (1-18) are used to identify the respective elements of the reachability and antecedent sets. Table 1 is constructed from Figure 9 by inspection.

Table 1. A Reachability Table

ROW INDEX(S)	REACHABILITY SET R(S)	ANTECEDENT SET A(S)	SET PRODUCT $R(S) \cap A(S)$
1	1 3 4 5 6 7 8 9 10 11 12 13 14 15 17 18	1	1
2	2 4 15	2	2
3	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
4	4 15	1 2 3 4 5 7 8 9 10 11 13 14	4
5	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
6	6	1 6	6
7	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
8	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
9	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
10	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
11	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
12	12 15	1 3 5 7 8 9 10 11 12 13 14 16 17 18	12
13	3 4 5 7 8 9 10 11 12 . 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
14	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
15	15	1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 17 18	15
16	12 15 16	16	16
17	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
18	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18

From Table 1, it is immediately apparent that the only rows for which the set product equals the reachability set are rows 6 and 15. These two rows are therefore removed from the table along with all references to numbers 6 and 15 everywhere else in the table. Thus, rows 6 and 15 from the reachability matrix (Figure 9) become the first two rows of the modified reachability matrix. These two rows will be considered the top level in the instructional hierarchy (or digraph).

Ordinarily, the references to rows 6 and 15 can simply be erased from the table, and the next iteration begun. For the purpose of illustration in this paper, however, each new (reduced) table will be enumerated.

Removal of all 6s and 15s results in the reduced form of Table 2. This time, the reachability set R(s) and set product columns match for rows 4 and 12. As before, these rows are removed from the table and the reachability matrix to become the second level in the modified matrix. Again, removing all references to 4 and 12 from the above table results in the formation of Table 3.

Table 2. Reduced Table - Level 1 Removed

ROW INDEX(S)	REACHABILITY SET R(S)	ANTECEDENT SET A(S)	SET PRODUCT $R(S) \cap A(S)$
1	1 3 4 5 7 8 9 10 11 12 13 14 17 18	1	1
2	2 4	2	2
3	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
4	4	1 2 3 4 5 7 8 9 10 11 13 14	4
5	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
7	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
8	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
9	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
10	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
11	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
12	12	1 3 5 7 8 9 10 11 12 13 14 16 17 18	12
13	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
14	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
16	12 16	16	16
17	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
18	3 4 5 7 8 9 10 11 12 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18

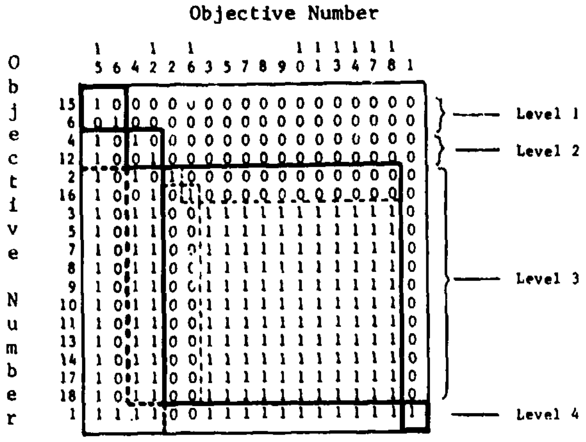
Table 3. Reduced Table - Level 2 Removed

ROW INDEX(S)	REACHABILITY SET R(S)	ANTECEDENT SET A(S)	SET PRODUCT $R(S) \cap A(S)$
1	1 3 5 7 8 9 10 11 13 14 17 18	1	1
2	2	2	2
3	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
5	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
7	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
8	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
9	3 4 5 7 8 9 10 11 12 13 14 15 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
10	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
11	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
13	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
14	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
16	16	16	16
17	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18
18	3 5 7 8 9 10 11 13 14 17 18	1 3 5 7 8 9 10 11 13 14 17 18	3 5 7 8 9 10 11 13 14 17 18

From Table 3, the third level of the modified matrix is shown to be composed of rows 2, 16, 3, 5, 7, 8, 9, 10, 11, 13, 14, 17, and 18. Deleting all these references from Table 3 results in the formation of Table 4. Note that only row 1 remains to make up the fourth and final level of the modified matrix. The resulting modified matrix is shown in Figure 10. The heavy black squares clarify various submatrices which denote the four levels identified from the tables. Note that both row and column designations in the modified matrix have been identically interchanged. This is automatically accomplished by the computer algorithm.

Table 4. Reduced Table - Level 3 Removed

ROW INDEX(S)	REACHABILITY SET R(S)	ANTECEDENT SET A(S)	SET PRODUCT R(S) ∩ A(S)
1	1	1	1



	15	6	4	12	2	16	3	5	7	8	9	10	11	13	14	17	18	1
15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
5	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
7	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
8	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
9	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
10	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
11	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
13	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
14	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
17	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
18	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1

Figure 10. The Modified Reachability Matrix Containing Four Hierarchical Levels

The dashed lines within the level 3 submatrix identify constituents, or interior links, within that level. The largest of the three constituents is called a universal submatrix because it contains all 1s indicating that each of the associated objectives in that submatrix are mutually reachable to each other. In the literature, this is more commonly known as a *maximal cycle*. The dashed lines to the left of each of the four heavy-lined submatrices outline what we in the project have termed *communication submatrices* which essentially describe how one level communicates with the level above it. These submatrices become useful in determining paths in the eventual digraph.

Step 6

At this step, all required information exists in the modified reachability matrix to compute the digraph. Warfield has noted that a given reachability matrix does not produce a unique digraph. (20) This implies that more than one digraph can be constructed from the reachability matrix of Figure 10. All the digraphs constructed in this project are generalized digraphs which are actually composites of all the possible digraphs contained in the reachability matrix.

The construction method is illustrated using Figure 10 for reference. The following illustration represents the process used to manually construct the digraph from the modified matrix. The computer algorithm accomplishes this entire process in a manner which is *transparent* to the user. The process is presented here for those who wish to develop their own algorithms.

Begin by laying out each of the four levels identified by the heavy-lined submatrices (levels) and starting at the bottom of the matrix. Level 4 contains only row 1. Level 3, the largest level, contains rows 2, 16, 3, 5, 7, 8, 9, 10, 11, 13, 14, 17, and 18. Level 2 contains rows 4 and 12. And level 1, the highest level, contains rows 15 and 6. By referring to the dashed submatrices (communication submatrices) to the left of each level submatrix, connecting paths between the objectives of one level and the objectives of each higher level on the hierarchy can be determined.

For example, the level 4 communication submatrix (bottom row in Figure 10) has the following pattern: (0 0 1 1 1 1 1 1 1 1 1 1 1). This pattern matches the patterns of rows 3, 5, 7, 8, 9, 10, 11, 13, 14, 17, and 18 in the third level. Thus, a connecting path from objective 1 to each of those mentioned above can be drawn on the digraph. Note here that no connecting path exists between objectives 1 and 16 or 1 and 2 because their communication patterns do not match.

On level 3, there are three separate parts (or *constituents*) within the level. One constituent is composed of objective 2; another is composed of objective 16; and the third is composed of objectives 3, 5, 7, 8, 9, 10, 11, 13, 14, 17, and 18. As stated earlier, this third constituent is called a maximal cycle. Thus, interconnection paths can be drawn on the digraph between objectives 3, 5, 7, 8, 9, 10, 11, 13, 14, 17, and 18.

To get from level 3 to level 2, the level 3 communication submatrix (the dashed matrix to the right of the level 3 submatrix) is analyzed gainst the level 2 submatrix. Since level 3, as was shown, possesses three separate and unique constituents, there are three unique communication patterns to consider. For instance, the maximal cycle constituent (the largest within level 3) has a communication pattern of (1 1). This pattern matches the 1s in both row 12 and row 4 of level 2. Thus, connection paths can be drawn on the digraph from any member of the level 3 constituent to each of objective 12 and 4 in level 2. It is suggested here that only one member from level 3 be connected to level 2 since each member of the maximal cycle is already connected to all others in that constituent (by virtue of it being a maximal cycle set). In addition, a single connecting path allows the resulting digraph to appear considerably more simple. However, the choice to do or not to do this is completely arbitrary. Also in level 3, the row 16 communication pattern (0 1) matches only row 12 in level 2, while row 2's communication pattern matches only row 4. Thus, two more connecting paths can be drawn. Continuing in this manner, a complete digraph can be drawn to represent the reachability matrix. The finished digraph is shown in Figure 11.

We should digress here for a moment to make an important point. Tatsuoka contends that a digraph can be constructed merely by analyzing the self-interaction matrix (he terms it the *adjacency matrix*). This writer, however, believes that although Tatsuoka's contention is valid and logically consistent, the adjacency matrix contains only enough information for one unique digraph, whereas, the reachability matrix yields a more generalized digraph. In a manner of speaking, the reachability

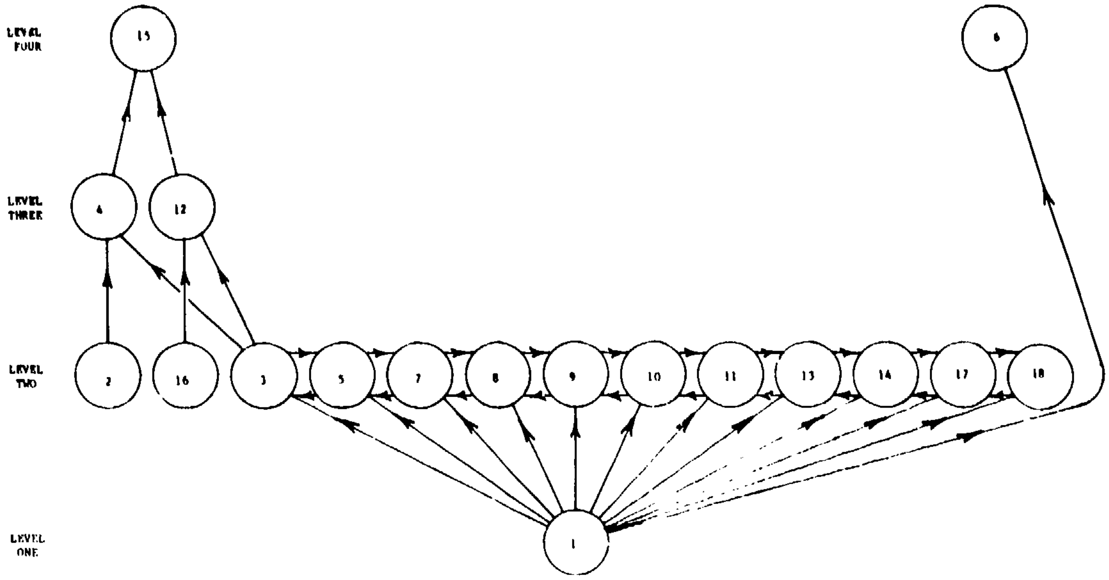


Figure 11. A Digraph for the Pilot Curriculum

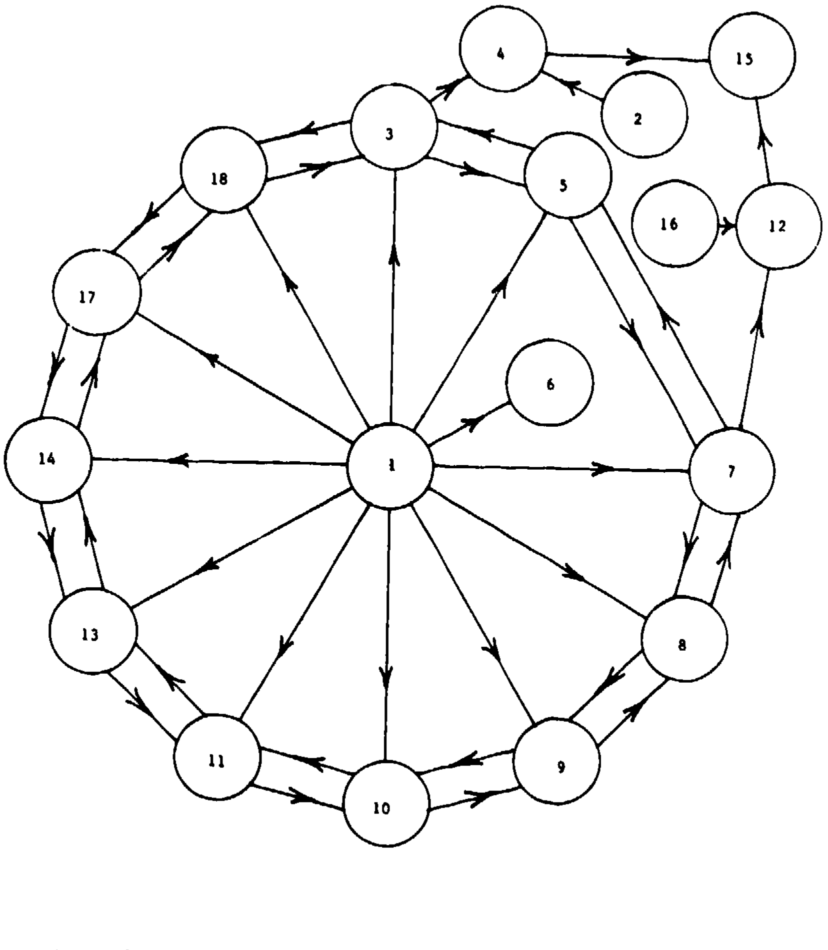


Figure 12. An Alternative Form for the Digraph of Figure 11

matrix is a composite of a family of adjacency matrices. This is intuitively true since the reachability matrix is computed by raising the adjacency matrix to consecutive powers.

This can also be shown mathematically. Take, for example, the number 16. There are two numbers whose consecutive products will equal 16 - they are, of course 2 (2x2x2x2) and 4 (4x4). Both consecutive products result in the same number - 16. However the original numbers 2 and 4 are obviously not the same. This same analogy transfers to the problem of whether to use the adjacency or reachability matrix in determining a suitable instructional digraph.

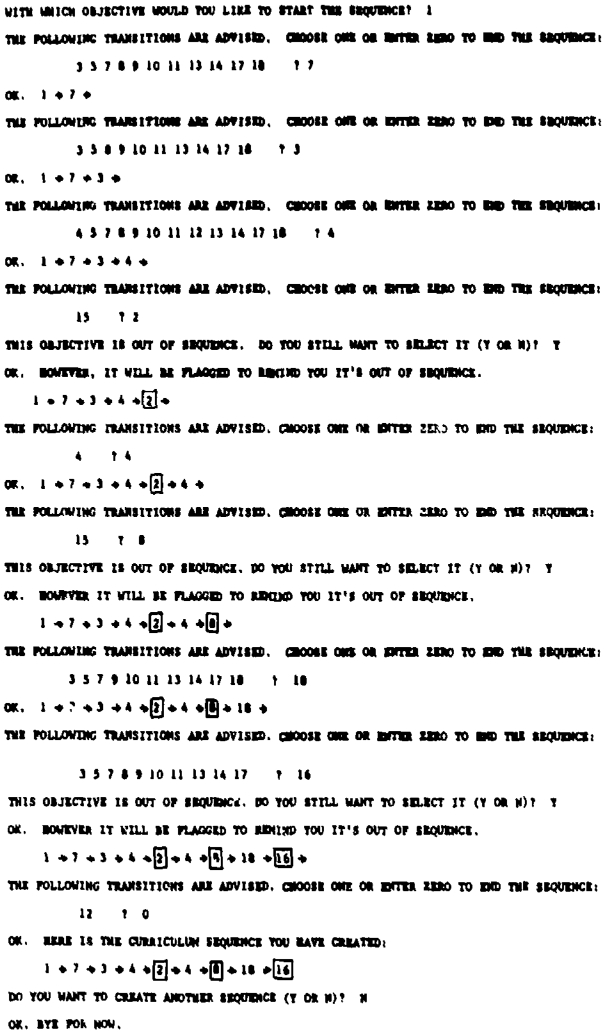
A digraph computed from the adjacency matrix will undoubtedly be more simplified than one derived from the reachability matrix, although the level of complexity does not begin to become a hinderance until very large numbers of objectives (40 or more) are to be manipulated. In other words, the digraph derived from the reachability matrix will usually contain <u>more</u> paths than that computed from the adjacency matrix.

Each path on the digraph can be thought of as a legitimate transition from one objective to another within the curriculum. Looking at the digraph in this way, one can begin to see that by developing such a transition-laden digraph yields a more fertile data base from which alternative instructional sequences may be derived.

In the pilot project, it was recognized that the digraph of Figure 11 could be redrawn to yield more meaningful information to the curriculum designer. This alternate digraph is shown in Figure 12. This type of digraph is called a *minimum edge representation* of the hierarchy (22).

Note in this figure that the maximal cycle constituent of level 3 is represented by a bi-directional circle interlocked via objective 1. From the viewpoint of the actual course curriculum there is, in fact, a great deal of coherence among objectives 1, 3, 5, 7, 8, 9, 10, 11, 13, 14, 17 and 18. Thus, it is not coincidental that such a pattern has emerged. Note also that objective 6 can only be reached by objective 1. Therefore, any instruction concerning objective 6 must rely on information presented during instruction on objective 1 - if, that is, the students are to see a logical transition from one lesson to the next. Since objectives 1 and 6 appear isolated from the rest, instruction relating to these two objectives could very easily form a module of instruction. Indeed, other modules begin to emerge from the digraph upon closer inspection. It will be left to the reader who gains pleasure from such activity to discover these other modules.

This in and of itself is a remarkable tool for the curriculum designer - to be able to identify "natural" groupings of objectives via mathematical analysis. However, this is merely a fringe benefit of the matrix analysis technique. As the computer analyzes the reachability matrix and its communication patterns, a data base is formed which contains all possible legitimate transitions from any given objective to any other. Once computed, this data base is used for comparison with a user's transition selections. A user can, in fact, experiment with various instructional sequences - transitioning from one objective to another until an entire course is created. By comparing user-selected transitions with the permissible transitions stored in memory, the computer will inform the user if a particular instructional sequence is, or is not, advisable. It will even printout the sequence created by the user in hard copy, if a printer is attached. Figure 13 is an actual, though partial, computer printout of the interactive instructional sequence creation routine.



```
WITH WHICH OBJECTIVE WOULD YOU LIKE TO START THE SEQUENCE?  1

THE FOLLOWING TRANSITIONS ARE ADVISED.  CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

        3 5 7 8 9 10 11 13 14 17 18    ? 7

OK.  1 → 7 →

THE FOLLOWING TRANSITIONS ARE ADVISED.  CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

        3 5 8 9 10 11 13 14 17 18    ? 3

OK.  1 → 7 → 3 →

THE FOLLOWING TRANSITIONS ARE ADVISED.  CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

        4 5 7 8 9 10 11 12 13 14 17 18    ? 4

OK.  1 → 7 → 3 → 4 →

THE FOLLOWING TRANSITIONS ARE ADVISED.  CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

        15    ? 2

THIS OBJECTIVE IS OUT OF SEQUENCE.  DO YOU STILL WANT TO SELECT IT (Y OR N)?  Y

OK.  HOWEVER, IT WILL BE FLAGGED TO REMIND YOU IT'S OUT OF SEQUENCE.

   1 → 7 → 3 → 4 →[2]→

THE FOLLOWING TRANSITIONS ARE ADVISED. CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

        4    ? 4

OK.  1 → 7 → 3 → 4 →[2]→ 4 →

THE FOLLOWING TRANSITIONS ARE ADVISED. CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

        15    ? 8

THIS OBJECTIVE IS OUT OF SEQUENCE. DO YOU STILL WANT TO SELECT IT (Y OR N)?  Y

OK.  HOWEVER IT WILL BE FLAGGED TO REMIND YOU IT'S OUT OF SEQUENCE.

    1 → 7 → 3 → 4 →[2]→ 4 →[8]→

THE FOLLOWING TRANSITIONS ARE ADVISED.  CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

       3 5 7 9 10 11 13 14 17 18    ?  18

OK.  1 → 7 → 3 → 4 →[2]→ 4 →[8]→ 18 →

THE FOLLOWING TRANSITIONS ARE ADVISED. CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

         3 5 7 8 9 10 11 13 14 17    ?  16

THIS OBJECTIVE IS OUT OF SEQUENCE. DO YOU STILL WANT TO SELECT IT (Y OR N)?  Y

OK.  HOWEVER IT WILL BE FLAGGED TO REMIND YOU IT'S OUT OF SEQUENCE.

    1 → 7 → 3 → 4 →[2]→ 4 →[8]→ 18 →[16]→

THE FOLLOWING TRANSITIONS ARE ADVISED. CHOOSE ONE OR ENTER ZERO TO END THE SEQUENCE:

         12    ? 0

OK.  HERE IS THE CURRICULUM SEQUENCE YOU HAVE CREATED:

    1 → 7 → 3 → 4 →[2]→ 4 →[8]→ 18 →[16]

DO YOU WANT TO CREATE ANOTHER SEQUENCE (Y OR N)?  N

OK. BYE FOR NOW.
```

Figure 13. An Interactive Instructional Sequence Dialog Between User and Computer

LIMITATIONS WITHIN A CURRICULAR SYSTEM

Naturally, the ultimate decision as to how a curriculum is to be arranged rests with the managers or administrators of the curriculum. It has been this writer's experience that a major deficiency of front-end analysis is the inadequate attention paid to the interplay among the numerous internal and external constraints and limitations placed upon a given curriculum. Limitations such as facilities, personnel, time, money, social factors, etc., if not anticipated in advance of establishing a curriculum sequence, could result in the ultimate alteration of an otherwise logical instructional sequence.

It is admittedly a complex task to consider the effects of all possible limitations affecting a curriculum without some means to organize and manipulate very large amounts of data. The project described in this paper has illustrated a method with the power to expand and accomodate the analysis of such limitations - and thus produce an ultimate curriculum sequence which is sensitive to those limitations. The work on this expansion forms the basis for Phase II of this project planned to be completed later next year.

The ultimate goal of this project is to develop an integrated curriculum for 16 closely related courses. Each course possesses certain characteristic limitations which are either reinforced or overcome by the remaining courses. It is desired that this project will produce a curriculum which will reconcile the majority of those limitations. Such a goal is common to curriculum designs both in the military and civilian sectors of education. In that respect, at least, those of us associated with this project feel a bond with educators in every sector of society.

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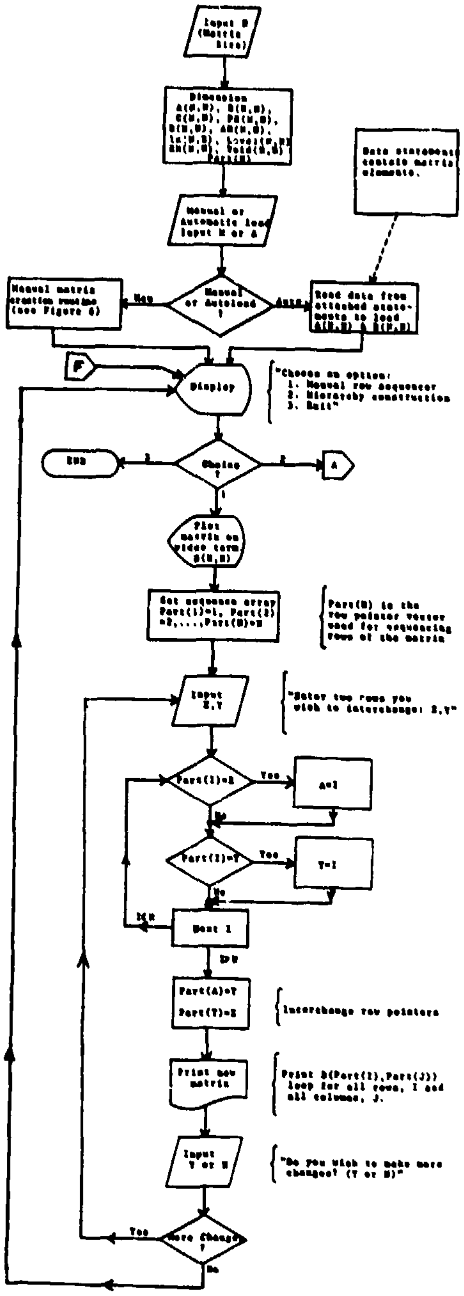
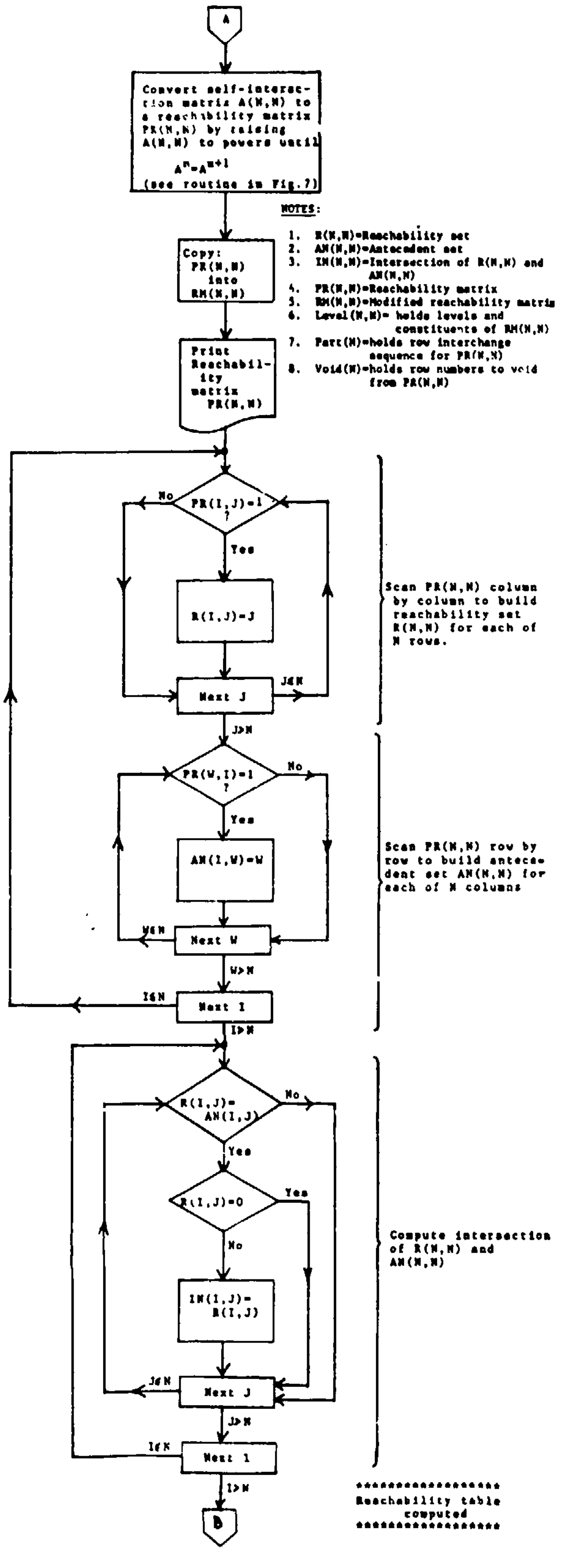
APPENDIX

A Detailed Computer Flowchart for Developing A Sequence Digraph From a Set of Curriculum Objectives (continued next 2 pages)





NOTES:

1. R(N,N)=Reachability set
2. AN(N,N)=Antecedent set
3. IN(N,N)=Intersection of R(N,N) and AN(N,N)
4. PR(N,N)=Reachability matrix
5. RM(N,N)=Modified reachability matrix
6. Level(N,N)= holds levels and constituents of RM(N,N)
7. Part(N)=holds row interchange sequence for PR(N,N)
8. Void(N)=holds row numbers to void from PR(N,N)

Scan PR(N,N) column by column to build reachability set R(N,N) for each of N rows.

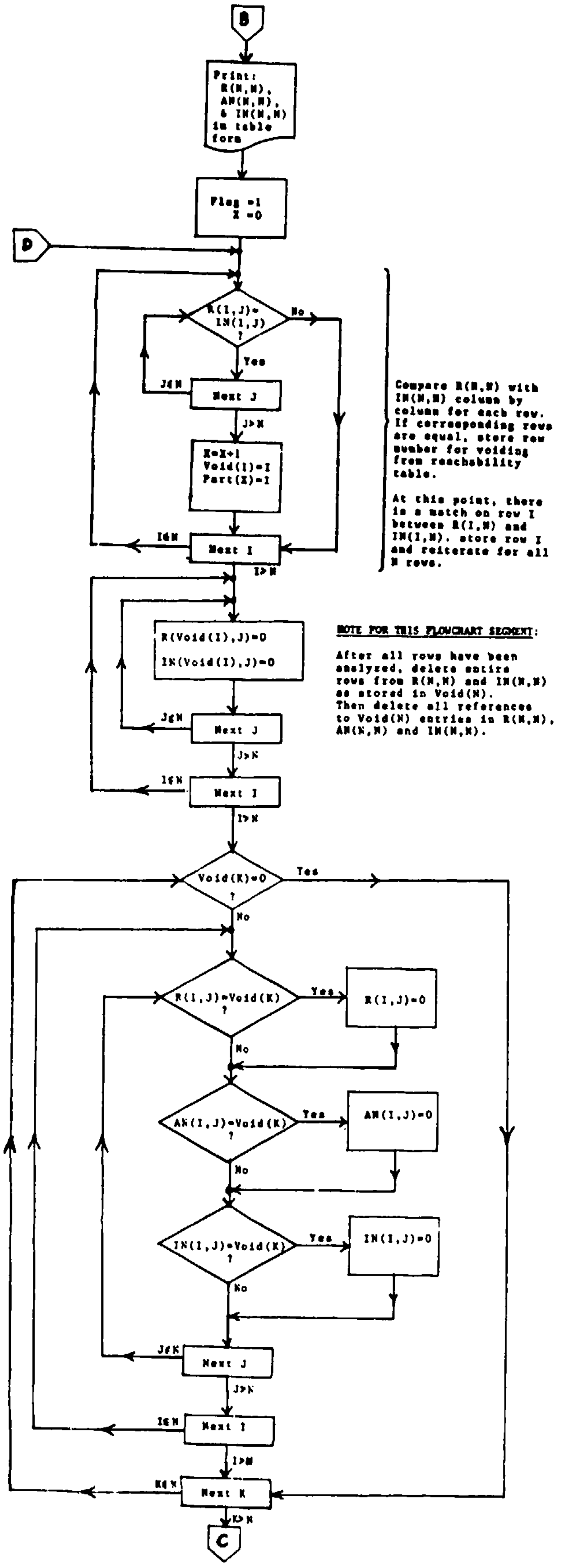
Scan PR(N,N) row by row to build antecedent set AN(N,N) for each of N columns

Compute intersection of R(N,N) and AN(N,N)

****

Reachability table computed

****

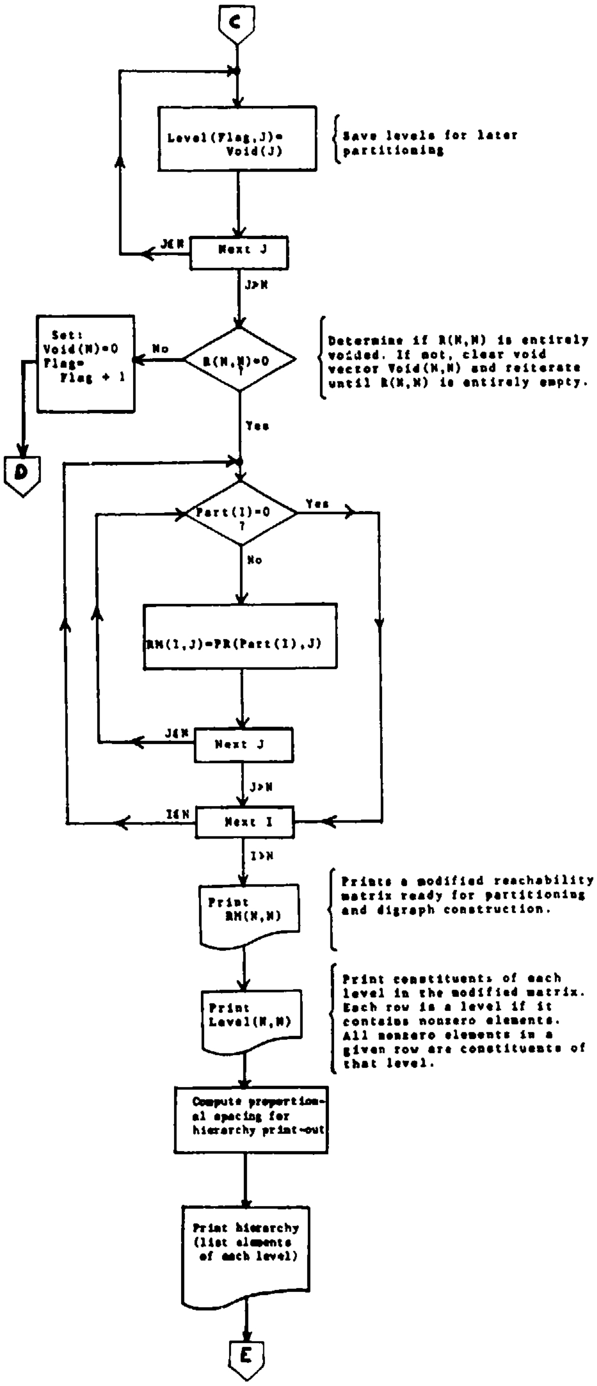


Compare R(N,N) with IN(N,N) column by column for each row. If corresponding rows are equal, store row number for voiding from reachability table.

At this point, there is a match on row I between R(I,N) and IN(I,N). store row I and reiterate for all N rows.

NOTE FOR THIS FLOWCHART SEGMENT:

After all rows have been analyzed, delete entire rows from R(N,N) and IN(N,N) as stored in Void(N). Then delete all references to Void(N) entries in R(N,N), AN(N,N) and IN(N,N).

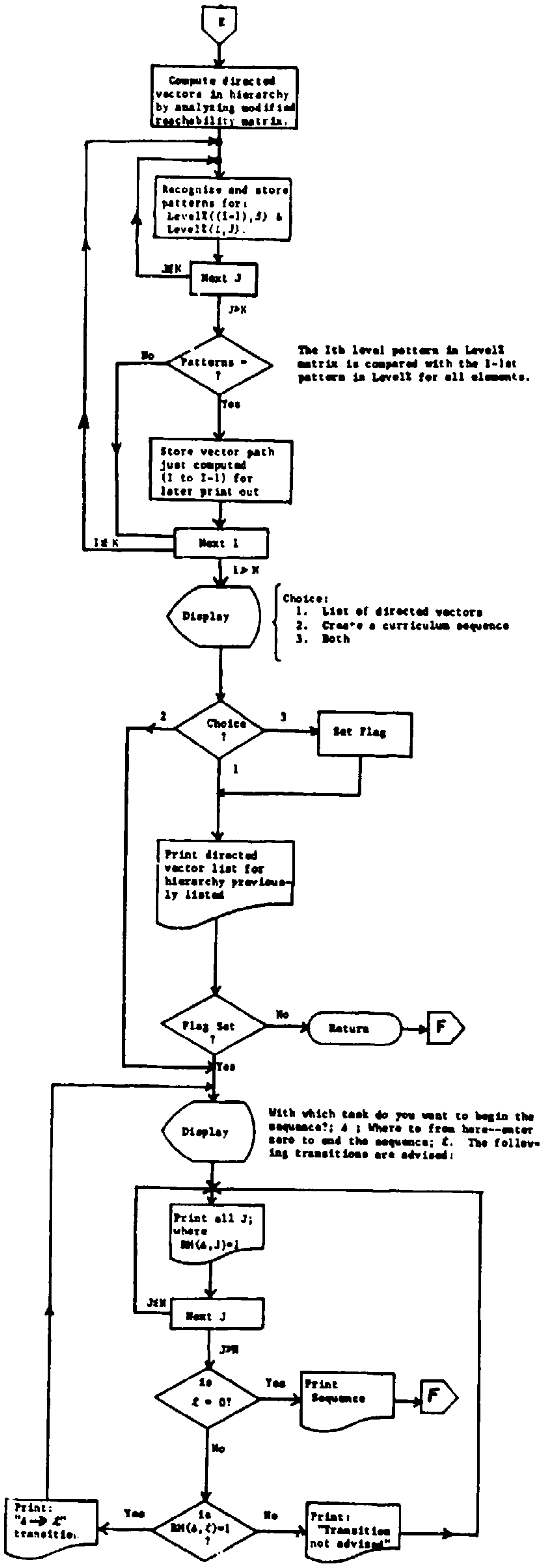


Save levels for later partitioning

Determine if R(N,N) is entirely voided. If not, clear void vector Void(N,N) and reiterate until R(N,N) is entirely empty.

Prints a modified reachability matrix ready for partitioning and digraph construction.

Print constituents of each level in the modified matrix. Each row is a level if it contains nonzero elements. All nonzero elements in a given row are constituents of that level.



The Ith level pattern in LevelX matrix is compared with the I-1st pattern in LevelX for all elements.

Choice:
1. List of directed vectors
2. Create a curriculum sequence
3. Both

With which task do you want to begin the sequence?; s ; Where to from here--enter zero to end the sequence; ℓ. The following transitions are advised:

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DIFFERENCES BETWEEN TRANSFER EFFECTIVENESS AND STUDENT PERFORMANCE EVALUATIONS ON SIMULATORS: THEORY AND PRACTICE OF EVALUATIONS

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ABSTRACT

A key concept in evaluating the training effectiveness of any training device is the difference between its use to achieve positive transfer of training and its use to evaluate student performance. As simulators are becoming more realistic, there is a trend towards using them not only to reduce training on the operational equipment (e.g., aircraft), but to eliminate entirely all training and evaluation on the operational equipment, for selected tasks. In order to eliminate all operational equipment training, we must be certain that evaluations of student performance in the simulator provide a valid assessment of actual student capabilities on the operational equipment. The assessment of the validity of student evaluations on the simulator does not have the same data requirements as a transfer of training study, although they are similar. Unfortunately, the differences between the two types of studies have been virtually unrecognized by the training device evaluation community. This paper will discuss the theoretical and practical differences between the two types of studies, differences in data requirements, and an example of the differences which were observed in a study involving the KC-135 Boom Operator Part Task Trainer located at Castle AFB, CA.

INTRODUCTION

As the fidelity of training simulators has increased, the use of simulators for evaluating trainee proficiency has also increased. Previously, simulators lacked sufficient face validity for training system managers to allow final trainee performance evaluations to be conducted in them. The simulators did not look or feel enough like the actual equipment for most tasks. The only major exceptions to this were evaluations of emergency procedures which could not be performed on the actual equipment for safety or other reasons. Recent advances in simulation technology have led to significant fidelity improvements. Now, many simulators look and feel enough like the real thing to allow training system managers to consider conducting trainee evaluations (e.g., checkrides) on the simulators. The airlines are now doing this on a routine basis.

In many training environments, however, there is doubt as to the validity of an evaluation of a trainee conducted in a simulator, regardless of the fidelity. "I won't believe he can do it until he does it in the real thing," will undoubtedly be heard more than once, even though these evaluations can usually be conducted much more efficiently and inexpensively in the simulators. While the skepticism is healthy, the rest of the sentiment is not. Face validity, in terms of looks and feel, is not the appropriate assessment technique to determine the evaluative capability of the simulator.

The alternative to a training system manager's intuition is empirical data. In fact, it is becoming increasingly common to collect empirical data for many aspects of training effectiveness (e.g., Hagin, Osburne, Hockenberger and Smith, 1980; Ditzian and Laughery, 1979). However, most of the literature pertaining to the ways and means of conducting training effectiveness studies primarily address the measurement of transfer of simulator training to the operational equipment. The issue of verifying a simulator's adequacy for conducting performance evaluations has rarely been addressed. If the data collection and analysis techniques of a simulator transfer of training study automatically verified the validity of conducting trainee performance evaluations, there would be no problem. Unfortunately, this is not the case. While there is commonality between the transfer study and validation study, there are also differences. If the transfer study is not specifically designed to assess the validity of the simulator for performance measurement, it may not be possible to accurately assess simulator validity. Therefore, to respond to the concerns of training system managers, the theoretical and practical issues of simulator measurement validity ought to be addressed.

The remainder of this paper will focus on these issues. The next section will discuss some of the theoretical issues of evaluating simulator performance measurement validity. A central focus of this section will be to highlight the differences between evaluating simulator transfer of training and validating performance measurement. The third section will focus upon the practical issues. These are issues which must be considered by a test manager during the simulator training effectiveness evaluation. Finally, the fourth section will present a study conducted on the Boom Operator Part Task Trainer, where high positive transfer of training was observed, but valid simulator performance measurement capabilities were not. This example demonstrates that the concepts of simulator transfer and validity are not equivalent, and that assumptions to the contrary may be dangerous.

THEORETICAL ISSUES

If a simulator is to be used as a predictor of future behavior in actual equipment, then it must be a valid predictor. This means that we must be able to obtain a performance score from the simulator and use it to predict what that person's score will be on the actual equipment. The simulator may not be able to teach the subjects a thing (although this would be unlikely), but if different student simulator scores correctly predict different student equipment scores, then the simulator is valid as a performance measurement device.

If the simulator is to be used as a training device, however, validity is not necessary. What must be demonstrated, in this case, is that the simulator produces transfer of behavior or transfer of training (Caro, 1975). Transfer of behavior simply means that the simulator and equipment tasks are identical, therefore, the student does not change a single thing when he goes from simulator to aircraft. Transfer of training implies that the simulator will permit a student who is unskilled at the actual tasks to obtain these skills with practice in the simulator. Practice in the simulator improves performance on the equipment, but the actual behaviors practiced need not be the same. Transfer of training is analogous to doing calisthenics and windsprints to improve one's football playing skills.

No matter what the measurement validity of the device, and no matter what the training simulator tasks, if the student group using the simulator emerges from it better able to perform actual equipment tasks, transfer of training occurred. If the relationship (i.e., correlation) between simulator performance and actual performance is zero, then the simulator is not a valid predictor, but it still may be an excellent device when viewed from the transfer of training vantage point. To recapitulate, validity refers to the device's utility in performance prediction, and transfer of training refers to the device's utility towards facilitating learning. In operational terms, a simulator's ability to make valid performance predictions relates to its utility in assessing terminal performance (e.g., checkrides), and its transfer of training utility relates to the simulator's ability to substitute for operational equipment training in the training curriculum.

These concepts can also be perceived graphically. In evaluating a simulator's validity, we are only interested in correlating performance in the simulator with performance on the actual equipment, not with respect to learning acquisition rate. The graph in Figure 1 describes a simulator which could serve as a valid predictor. Transfer of training, on the other hand, need not imply a relationship between observed simulator performance and expected equipment performance. Figure 2 identifies a situation where transfer occurs without the simulator being a valid performance predictor. The top graph describes the number of equipment training trials required to obtain proficiency without prior simulator training. The second graph describes the number of equipment training trials required subsequent to training in a simulator. The third graph demonstrates that there happens to be a lack of predictive validity from simulator aircraft.

In this case, determining transfer of training requires careful observation. Clearly, there is transfer of simulator training to the actual equipment, in that far fewer equipment training trials were required to achieve standard level performance. However, if only the first observed equipment performance subsequent to simulator training were examined, we would conclude that the simulator was ineffective. It is necessary to look for transfer on more than the first equipment trial. The rate of learning was affected, probably due to the learning of basic skills which required significant refinement to be useful in the equipment, but did not require complete relearning.

Despite the difference between validity and transfer of training, the concepts derived for measuring the former are often applied to the latter. A number of approaches to assessing transfer of training are presented by Caro (1975). In the next section, we will outline the basic concepts of validity assessment, and identify issues which need not be addressed for a transfer of training assessment.

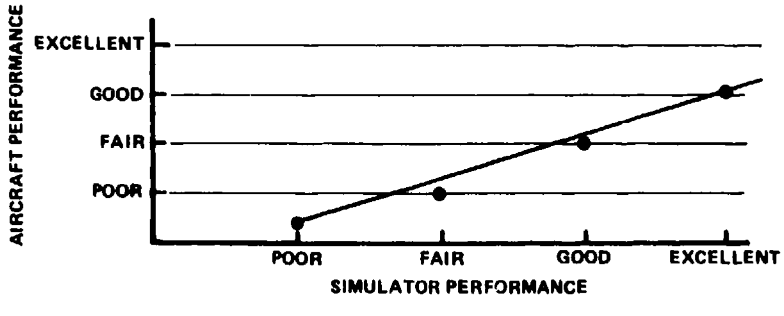

Figure 1 EXAMPLE OF A SIMULATOR WHICH HAS PREDICTIVE VALIDITY

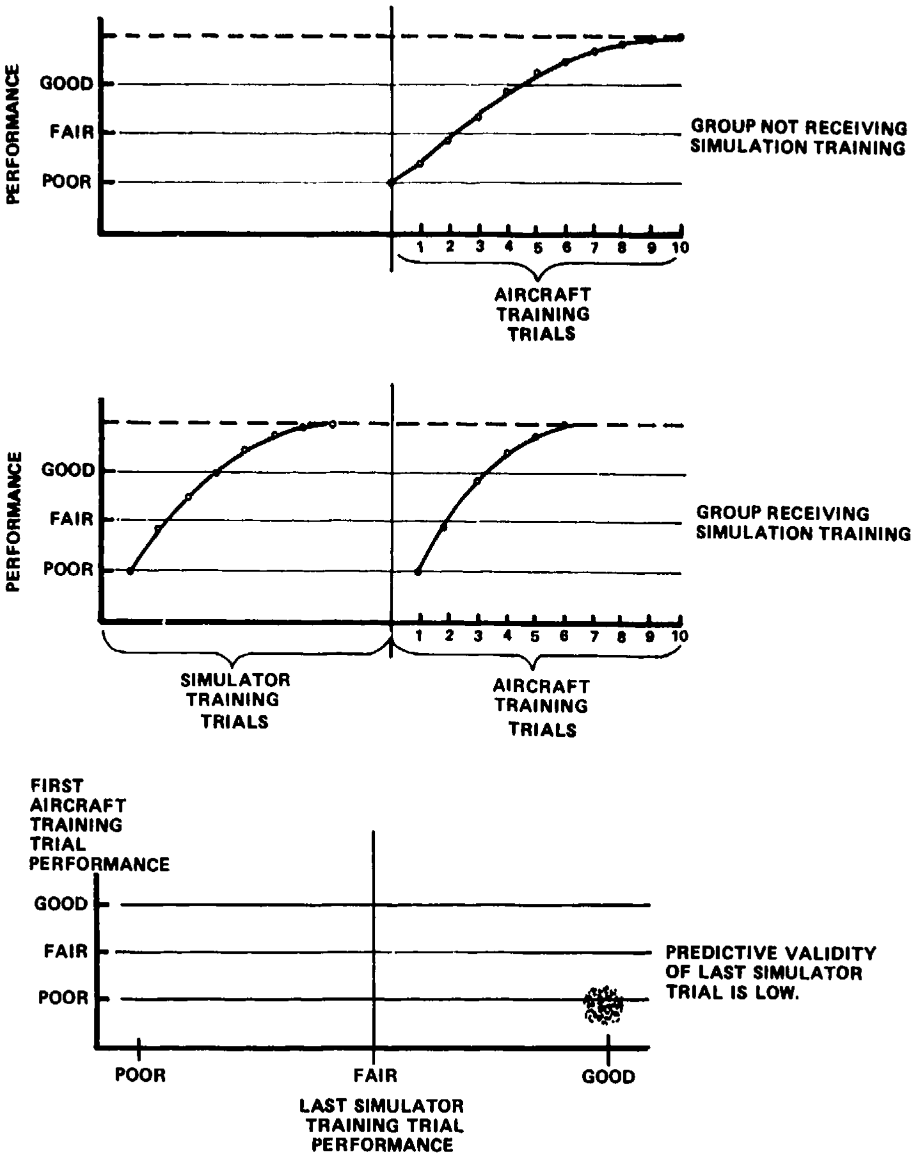

Figure 2

PRACTICAL ISSUES

Considerations During Data Collection

There are two considerations to address during data collection, both of which relate to the measurement of student performance in the simulator. First, trainee performance measurements collected in the simulator should be the same as those collected on the operational equipment, in order to test whether observed simulator performance is highly correlated with observed performance on the operational equipment. If there is no common measure, this relationship will be difficult to identify. Theoretically, we can correlate two variables which measure different dimensions, like age and height. In order to create intuitive acceptance, however, it is best to show that an observed level of trainee performance on the simulator implies that the student can perform at the same level on the operational equipment. If we do not use the same measures of trainee performance on the simulator and operational equipment, it will be impossible to prove that simulator and operational equipment performance are equal.

The second consideration is when to measure trainee performance. In a transfer study, simulator performance is sometimes ignored; only performance in the operational equipment is measured. However, the only way to obtain an estimate of the degree of correspondence between observed trainee simulator performance and expected trainee operational equipment performance, is to compare transfer of skills trained in the simulator to first trial performance in the actual equipment. The two dimensions to be correlated are the observed performance of the trainee the last time he performed the task in the simulator, and the performance of the trainee the first time he performs the task on the operational equipment. If a high correlation is observed between these two performances, we can assume that the simulator is a good predictor of concurrent performance in the actual equipment. Note that this need not be his final performance in the simulator, only his last performance prior to his first operational equipment training on the task. In fact, there may be a number of times where a trainee switches from the simulator to the aircraft and then back. If a portion of the training program involved a mix of simulator and operational equipment training, every time the student switches from simulator training to operational equipment training there will be a useful data point. We measure last simulator performance prior to the next set of actual equipment training trials, and first performance on the actual equipment after simulator training. However, for the sake of brevity, we will use the terms "last simulator" and "first operational equipment" performance.

Another related issue is the amount of time between the last simulator and first actual equipment training and what occurs during this time period. Basically, the shorter the time period, the better. This will avoid the confounding factor of forgetting, or losing the skill. Ideally, we would measure trainee simulator performance and then immediately measure trainee performance on the actual equipment. This will usually be impossible. This time period should be minimized, although the body of literature on complex skill retention indicates that periods of less than one week are tolerable.

During the period between last simulator trial and first actual equipment trial, the task should not be practiced or reinforced on other training devices. Learning or skill refinement could occur between the two trials during which performance was measured. That being the case, we would then be correlating simulator performance to actual equipment performance plus the extra learning. This extra learning is an undesirable confounding factor. However, when the trainee is measured on his last simulator trial, he may learn from this trial itself. This is likely, particularly in the early phases of skill acquisition, where the rate of learning per practice trial is much higher. This type of learning cannot be avoided. It may be possible to account for this learning statistically if we examine the learning curve for the trainee at this point in the program. His simulator performance score could be increased by the amount of improvement which would be expected from that trial. If the measurements discriminate among levels of performances, this may be possible. However, if the learning rate at this point in training is reasonably low (e.g., less than 5% expected improvement per trial), or our measures are not sufficiently discriminating, we may ignore this effect.

Considerations During Data Analysis

The correlation to be computed during analysis is that between last trainee simulator performance and first trainee actual equipment performance. However, a simple correlation analysis is not enough. A high correlation indicates that we can predict trainee performance on the actual equipment by observing simulator performance. The data presented on the graph in Figure 3 indicate a high correlation (above .85). However, a regression analysis would indicate that the best predictor of the actual equipment performance grade is determined as follows:

$$\begin{array}{l}\text{predicted actual}\\ \text{equipment trainee}\\ \text{grade}\end{array} = 2.5 + 0.5 \times \begin{array}{l}\text{observed simulator}\\ \text{trainee grade}\end{array}$$

In this example, a trainee virtually always performs better in the actual equipment than on the simulator. This could be because of simulator control difficulties which are not present on the actual equipment. Therefore, the actual equipment is easier to operate than the simulator. The opposite case is also possible, and perhaps more likely (i.e., actual equipment trainee performance is always something less than his simulator performance). This is depicted in Figure 4.

If the regression equations are known, and a high correlation exists, this approach to predicting actual equipment trainee performance is indeed valid and useful. However, convincing management of this may be another story. Someone without a background in statistical analysis may have a difficult time believing that the simulator <u>is</u> a good predictor of performance only if we take the score, divide it by two, and add 2.5 to that value. One might ask, "If the simulator is such a good indicator of capabilities, why aren't skill levels displayed in the simulator perfectly representative of skill levels on the actual equipment? Why do they require an indirect functional relationship?" The training system manager may be incredulous, or, at worst, disbelieving and suspicious of the study.

There is no simple answer to the problem of knowing an answer but being unable to convince someone else of it. Of course, if the means and standard deviations of the actual equipment performance and the simulator performance are indeed equal, then using the raw simulator scores to predict actual equipment scores presents only the problem of regression. To the extent that correlation is less than +1, this technique fails to optimize the least squares predictor equation. Studies of multiple regression using unit weights suggest that this may be less of a practical problem than it appears to be theoretically.

To test equality of means and standard deviations, we find ourselves in the unenviable position of trying to accept the null hypothesis. One way to deal with this is to set up confidence intervals around the mean and standard deviation of the simulator scores (Hays, 1963) and compare the actual equipment performance means and standard deviation to these intervals. If the means and standard deviations were identical, and the correlation were <u>r</u>=+1, then prediction would be perfect and scores would be equal. If the means or standard deviations were overly different, then the experimenter should take caution before recommending the use of raw simulator scores to predict raw actual equipment scores, regardless of the value of the correlation coefficient. The statistical analyses required for these decisions go beyond our present scope. In fact, it may be possible to derive statistics designed to evaluate these problems and aid in decision making.

Now let us present an example of a training effectiveness study which included an examination of the utility of the simulator for trainee performance assessment.

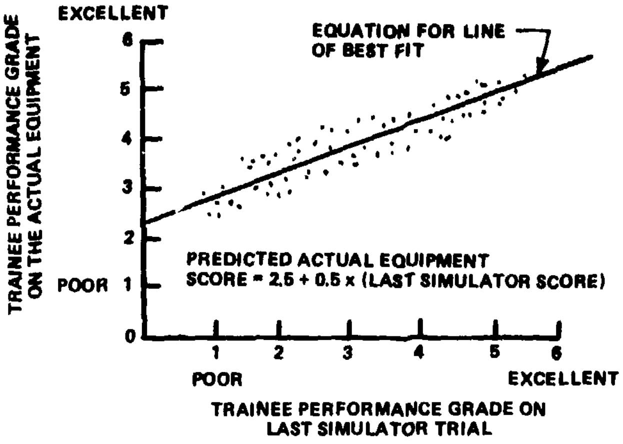

Figure 3

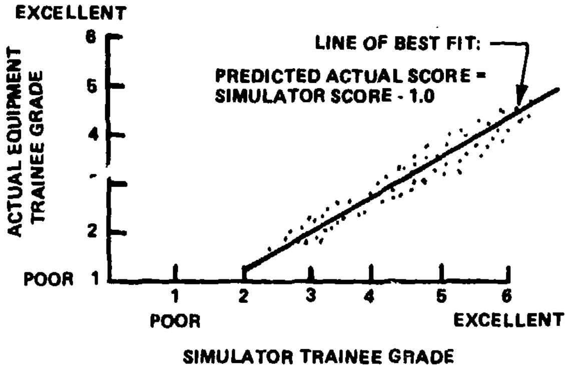

Figure 4

AN EXAMPLE: THE BOOM OPERATOR PART TASK TRAINER CATEGORY QUALIFICATION STUDY

Boom Operator Part Task Trainer (BOPTT) System Description and Background

The KC-135A BOPTT is a fixed-base ground trainer designed to duplicate essential air refueling cues used by the boom operator. Major components of the BOPTT are: a student station complete with boom operator pallet, window operator controls and indicators; a 1/100 scale model of the B-52 aircraft; and a 20 inch model of an aerial refueling boom. The instruments and controls operate as they would in actual flight. The boom operator's window is actually an optical system which makes the boom and receiver aircraft appear as they do in the real world.

The B-52 model is mounted on a three-axis gimbal that simulates aircraft pitch, roll, and yaw. A video image of the model is captured by a closed circuit TV camera and displayed on a CRT screen placed about 20 inches outside the boom operator's window. Other fighter and cargo aircraft models are also available.

The model boom is located between that screen and the window, and is designed so that the trainee operator can position and extend the boom and can simulate connecting it to the B-52. Clouds and ground terrain are displayed on the screen as they would be seen from the rear of a KC-135A. Engine noise and boom noise are produced electronically and played through speakers into the boom operator's station.

The BOPTT portrays the B-52 or other aircraft as it approaches the tanker from 1.25 miles through hook-up for refueling; the boom reacts to control inputs and aerodynamic forces. The simulation equations permit variations in refueling speed and altitude, amount of air turbulence, and the approach trajectory of the receiver aircraft. It is also possible to simulate five levels of piloting skill, which range from novice to expert.

In early 1980, Strategic Air Command (SAC) Headquarters conceived that the BOPTT might prove to be an effective environment in which category qualification training and evaluation could be conducted. The BOPTT had been in use at Castle AFB, CA for B-52 refueling training since 1978. Several studies (Gray, 1980; Walker and Rutzebeck, 1981) indicated that the BOPTT provided a highly effective environment for initial training of boom operator air refueling skills for several receiver aircraft. However, in the initial training program at Castle AFB, most training and all checkrides were performed with a B-52 aircraft receiver. There are significant differences in skills and techniques required of the boom operator to refuel different aircraft, particularly small fighters (e.g., F-4, F-16, A-10) as contrasted with large tanker/cargo aircraft (e.g., C-5). After a student completed initial training at Castle AFB, he could only refuel B-52 aircraft. Subsequent to further aircraft training and evaluation, the student would become category qualified (i.e., qualified to refuel aircraft from other categories). The other major categories most frequently encountered were the fighter category and C-5 category. Only after a student was evaluated and considered qualified in a particular category could he then refuel the associated aircraft without an instructor present in the KC-135. It was proposed that the BOPTT be used for both training and evaluation for C-5 and fighter category qualification. Therefore, both transfer of training and the ability of the BOPTT as a student performance assessment device were of interest. A test program was commenced by the 4200 TES and the 93 BMW/DO5, both located at Castle AFB, to evaluate this concept. The following subsections discuss this study.

Study Design

Two phases of studies were conducted, using boom operator students as subjects, which related to evaluation of training effectiveness. The first phase was conducted at Castle AFB and the second at the subjects' home stations. The first phase involved the training on the BOPTT for C-5 and fighter refueling. After the subjects had been trained on the BOPTT, they were given one evaluation flight each for refueling fighters and C-5s. The second phase involved an evaluation of the number of actual flights required for qualification, comparing control (no BOPTT training) and experimental (BOPTT trained) groups.

Subjects

The subjects were 30 initially qualified boom operators from the Castle training program. These subjects were derived (5 each) from six classes, during the period July through December 1980. It was originally planned to use 6 subjects in a control group and 24 in an experimental group. These subjects were selected from the first six students of each class assigned to the flightline phase of training and randomly assigned to one group or the other for the study. Upon completion of the first half of scheduled testing, the decision was made to increase the number of the control group, in order to gain a more accurate assessment of transfer, particularly in fighter air refuelings. The final sample consisted of 10 subjects in the control group and 20 in the experimental group.

Procedure

All of the subjects in the test followed the normal training syllabus through graduation and solo flight. The control subjects received only a categorization qualification briefing prior to each flight, in accordance with SACM 51-135, Vol I. The experimental group received the same categorization briefing plus simulator time, which served as a practice medium prior to each flight. The experimental group received two one-hour C-5 and three one-hour fighter simulator periods in the BOPTT. Table 1 illustrates the study design.

For the experimental group, the existing BOPTT mission scenario was used for the appropriate category aircraft to be refueled. The 93 BMW/DOTDK provided the necessary BOPTT missions as well as the instructor personnel. A 90 minute block was used for each training period, a one-hour refueling mission profile and thirty minutes for pre- and post-mission briefings. As a result of some difficulties encountered during the first half of the test (with the fighter refueling portion), changes in the BOPTT instructional technique were implemented in an effort to overcome problems associated with fighter refuelings. The areas of boom control, nozzle cocking, communications, lack of confidence and aggressiveness were specific areas of concern. The BOPTT instruction was modified to include a demonstration of fighter refueling techniques, the use of multiple receivers, and creation of a sense of urgency closer to that found in the real world. The task difficulty was increased to parallel actual

Table 1. Study Design: Categorization Research

GROUPS	C-5 CATEGORIZATION TRAINING	EVALUATION	F-4 CATEGORIZATION TRAINING	EVALUATION
Control (10 Subjects)	Categorization Briefing	Actual C-5 Air Refueling	Categorization Briefing	Actual F-4 Air Refueling
Experimental (20 Subjects)	Two 1-Hour BOPTT Missions Categorization Briefing	Actual C-5 Air Refueling	Three 1-Hour BOPTT Missions Categorization Briefing	Actual F-4 Air Refueling

or worse conditions as would be encountered in the areas of rendezvous, receiver closure, communications, and receiver stability prior to and during contact. Two specially constructed objective performance tests were used to evaluate the tasks, one for the C-5 and the other for fighter refueling. These tests, collectively named the Boom Operator Category Qualification Performance Measurement Form, were used as the criterion of subject ability in tasks relating to category qualification. The items on these scales were taken from the three skill areas (procedures, communications, and boom control and operation) critical to qualification. The item measures were either quantitative measures or qualitative ratings, depending on the item (task) evaluated.

Evaluation Points

Measures of training effectiveness for the Experimental Group were taken at each simulator period and flight. The Control Group was measured on the actual flight only. The Instructor/Evaluator graded each item attempted. These evaluations were then used to arrive at an overall performance rating.

Subsequent to their departure from the Castle AFB training environment, test data from the subject's eventual home base were obtained for the entire student population of the six classes involved in the test. The data were gathered by a questionnaire mailed to each subject's home unit. This questionnaire provided baseline data for making a more accurate assessment of number of flights required to qualify, using a larger control group for comparison. The home unit instructors were also given the opportunity to express their thoughts on the categorization program as it affected their personnel. Although data of this nature are highly subjective, they provide insight that is otherwise difficult to obtain. The opinions of those who chose to answer this item were very positive. These instructors generally believed that the students who participated in the program performed better than the students who did not participate in the categorization training.

Data Analysis

All of the items on the performance measurement form were evaluated. To summarize, BOPTT trained individuals did significantly better than those not trained in the BOPTT. Of great interest was the question of whether all the students who were graded as qualified in the BOPTT were graded as qualified in the aircraft, and vice versa. This would allow the BOPTT to be used to measure category performance. Since all of the experimental group students had been graded as qualified in the BOPTT, what remained was to determine what proportion was qualified in the aircraft.

For fighter category qualification, the following data are presented for in-flight performance:

Group	Considered Qualified In Aircraft	Considered Unqualified In Aircraft
Control	2 (20%)	8 (80%)
Experimental	10 (53%)	9 (47%)

Therefore, even though all 19 experimental group students were considered qualified in the BOPTT, only 53% were subsequently considered qualified in the aircraft. Clearly, this was not sufficient to consider using the BOPTT to evaluate a student's ability to refuel fighters. Almost half of those considered qualified in the BOPTT would then be unable to perform the task in the air.

The data for the C-5 are as follows:

Group	Considered Qualified	Considered Unqualified
Control	8	0
Experimental	13	0

Obviously, since all students were considered qualified in the actual C-5 refueling, discrimination was impossible. Any B-52 qualified boom operator is apparently capable of performing air refueling on a C-5.

It seems, therefore, that the BOPTT was not a good means of measuring boom operator performance during category qualification for fighters. The issue remains unresolved for C-5 qualification. However, the data did indicate that the BOPTT affected transfer of training. Phase two of the study clarified this issue.

Performance of Subjects at Their Home Units

The second phase of the test program dealt with the performance of the test subjects at their home units. Questionnaires were sent to the home units to obtain information regarding the categorical status of the subjects.

Table 2 illustrates the number of flights to qualification and the percentage of each group for fighters:

Table 2. Flights Required to Qualify

Groups	One	Two	Three	Four	Five
Control	3 (37.5%)	1 (12.5%)	2 (25.0%)	1 (12.5%)	1 (12.5%)
Experimental	6 (42.85%)	6 (42.85%)	2 (14.3%)		
Other (See Note)	5 (17.9%)	11 (39.3%)	8 (28.6%)	2 (7.1%)	2 (7.1%)

Note: These individuals did not participate in the test program but were classmates of the participating members.

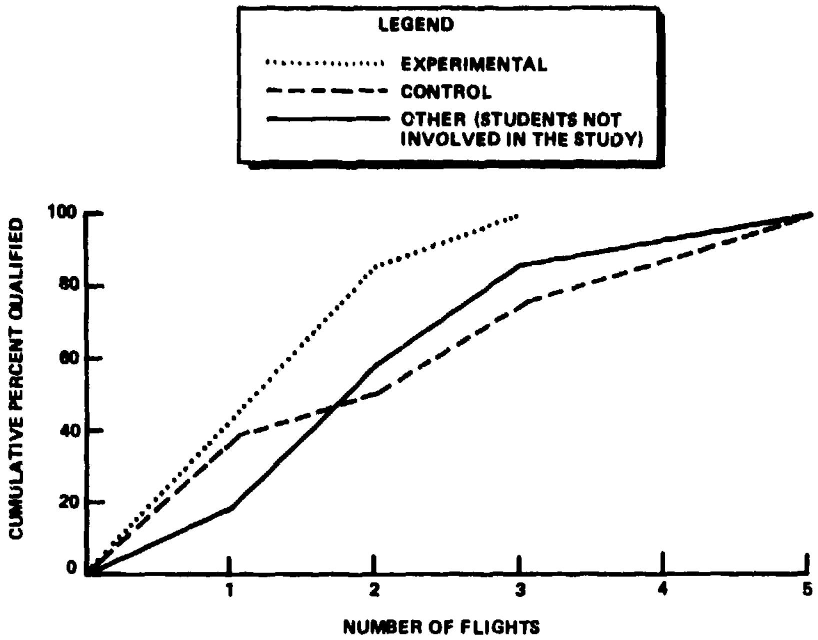

Figure 5 NUMBER OF FLIGHTS TO QUALIFY VS. CUMULATIVE PERCENT QUALIFIED

Figure 5 implies that the experimental group attained proficiency more rapidly than the control and other (nonparticipant) groups. All of the experimental participants were qualified by the third flight. It is interesting to note that approximately 86% of the experimental group were qualified by the second flight, as opposed to 57.2% of the other group and 50% of the control group. As indicated, the number of flights to qualification was cut by approximately one-third. A one-way ANOVA on the flights required to qualify indicated a significant difference among the three treatments; $F(1,52)=3.95$ $p<.05$. Post hoc tests indicated that differences existed between the experimental group and both the control and other groups. The control and other groups were not found to differ. Therefore, a substantial savings in airframe utilization, time, and money can be realized if the BOPTT is adopted formally for categorization training. These data strongly support the contention that the BOPTT provides training which does transfer in a positive fashion to the aircraft.

Discussion

The BOPTT provided positive transfer-of-training but did not provide a good environment for student performance evaluation with respect to category qualification. This example illustrates that these are two different concepts of simulator use. While a study designed to evaluate transfer may be modified to evaluate validity, one does not infer the other. We must be cautious and keep these two concepts separate to ensure the safe, effective use of simulators in the future.

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TEAM PERFORMANCE MEASURES FOR COMPUTERIZED SYSTEMS

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ABSTRACT

A theory of system performance measures that permits evaluation of the effects on mission performance of the performance of each constituent mission task was extended to tactical data processing systems. This system performance measure permits the evaluation of both teams and individual team members on either a mission or any portion of a mission, including specific tasks or task types.

INTRODUCTION

Organizations both civilian and military often rely on teams to identify, examine, and solve complex problems. Some teams are formed to solve short-term problems such as an ad hoc committee, and other teams are formed for long term continuous problems, such as departments of research and development or military campaigns.

For any particular problem, the members of a team bring certain skills, viewpoints, and limitations that are wholly individual, yet it will generally be from the interaction of the members that the team's effectiveness and worth will finally result. With this idea in mind, it is significant that previously no rigorous method existed for evaluating a team's performance at any given point during its mission. It is not possible to effectively structure teams, train teams, or to specify team performance levels without a team performance measure and a systematic means for applying such a measure. In an evaluation of Navy team training, Rizzo (1975)(1) states that basic problems exist in knowing how teams function, that teaming skills themselves have been left undefined, and that current training methods often involve throwing individuals together with the hope that "the needed team skills will naturally emerge." Also, he suggests that team performance, as it is envisioned by many training personnel, is related more often to how well individuals know each other than to what they do together. Further, he stresses the evident lack of objective measures of either individual or team performance during training.

A review of the state of the art of team training and evaluation strategies (Wagner, 1976)(2) confirms the lack of definition of teaming skills and affirms the need for a team performance measure. The review furthermore concludes from a search of the literature that performance feedback (knowledge of results via performance measurement) is critical to the learning of team skills, as well as to the learning of individual skills. The reviewers strongly warn that team performance measures must be developed before "substantial improvement in team training evaluation can occur." To support this conclusion, they cite the Defense Science Board's 1975(3) review of research and development programs in military training which stated that "the team performance measurement problem was a fundamental stumbling block to progress in improving team training."

A research program suggested by Wagner to overcome these deficiencies included the development of a method for establishing team performance standards for both the isolated and interactive behavior of team members. The claim that interactive behavior produces a result that is not the sum of individual efforts, but is rather more like the product of them, has been voiced also by Baker (1976)(4) and by Jones (1974).(5) Neglect of this proposal, however, has led to an emphasis in research on individual skill training at the expense of research on team training and on cooperative behavior. The claim is that an effective measure of team performance cannot be a simple summation of the measures of performance of the individual members. Indeed, the team measure-of-performance function must be sensitive to such non-linear effects as the quality of interaction among them.

EXISTING METHODS FOR CALCULATING TEAM PERFORMANCE

The absence of team performance measures and the need for a rigorous method of developing a team performance measure are well documented in the literature. Since the effective interaction of team members is regularly cited as the factor that distinguishes an effective team from a mere assembly of ineffective individuals, the coordination of the members' efforts becomes important both to teaching and to maintaining team effectiveness. In order to minimize the amount of wasted or misdirected effort, the amount and quality of the effort produced by each team member to enhance in some (as yet unspecified) way the overall task effectiveness or "goal attainment."

On certain tasks a team may be able to operate at the level of its most competent member (a disjunctive model); on other tasks, the team's performance may depend upon the effectiveness of its least proficient member, or even, at other times, on the level of its "average" member. But whenever the efforts of individuals must be coordinated for task accomplishment, there is inevitably some "slippage" that prevents optimal task accomplishment by the team (Hackman & Morris, 1975).(6) As team size increases, this slippage or "process loss" becomes greater, because the job of getting all the members to function in a coordinated manner becomes increasingly difficult. When Hackman and Morris claim that team task effectiveness generally has not been as high as it should have been, based on an extrapolation of individual scores, the clear implication is that the communication/coordination process through which the talents of team members are first assessed and then brought to bear upon a given task must in some way be inadequate. Such process losses may be insignificant when the required specific knowledge or skill is obvious, or when obtaining a desired result does not involve complex teamwork; but, at other times, when sophisticated or subtle interactions are required to identify the necessary talents and apply them to the task, the role of communication/coordination becomes much more substantial, and the risk of process loss becomes consequently much greater.

Current Military Training and Testing

Following basic training, but before the new soldier goes through advanced individual training, his aptitude for a particular Military Occupational Speciality (MOS) is evaluated by means of the Skill Qualification Test (SQT). The SQT scores for an individual are designed to give a diagnostic profile of the examinee's strengths and weaknesses in a given MOS, and to determine whether that person is at least minimally qualified to perform the jobs within that MOS. But the SQT scores do not predict by themselves how well that person will perform as a team member whose skills must be integrated into overall team performance. The current, and still evolving Army procedure for evaluating team performance - that of a tank crew, for example, or a platoon, etc. - is the Army Training and Evaluation program, known as ARTEP.

Problems of Performance Measurement for Computerized Systems

For clarification we must distinguish three important entities when considering the performance measurement of a computerized system. They are: 1. the performance measures used, 2. the scores that are obtained from using the system and the measure, and 3. later tests that may be performed using the computerized system. Here, our interest is in the development of a performance measure for teams using a computer to accomplish a goal, and within that context we are interested specifically in how well the computer equipment is being used. Only physical variables, such as the time used to perform a given task or an indicator of the quality of the task performance, are involved, even though mental effort (selecting a data format, for example), as well as manual effort (data entry using a keyboard, for example), may be required to operate the system. Since the performance measure developed here is intended to reveal only how well equipment is operated, there are no variables that correspond to psychological or psychophysiological factors, such as intelligence or fatigue. Nevertheless, the system (computer equipment and team members) along with its performance measure can be used to test individual and team performance levels, to evaluate training programs, and to determine the effects of operator fatigue.

Since a performance measure for a computerized system is concerned only with measuring how well equipment is used, questions generally associated with psychological tests (their reliability, validity, etc.) are not of immediate concern to us. Only later, when the system is tested, will they be of direct interest.

Replacing these concerns, however, are two others: measure comprehensiveness and measure sensitivity. Measure comprehensiveness is evaluated by the ability of the measure to respond to each factor that affects the mission performance of the system. A measure with little comprehensiveness responds to only some important factors and is often referred to as a "rule of thumb" measure. Measure sensitivity is evaluated by the degree to which the measure reveals the effect on mission performance of changes in the performance of individual tasks or types of tasks. Measure comprehensiveness and measure sensitivity are controlled by the way tasks are defined and by the method of calculation of the effect on mission performance of the performance of each constituent task.

The fundamental principle to be observed in the performance measurement of any system is that the performance of each constituent task always has a unique effect on total mission performance. Even the same type of task performed at different times during the mission can differently affect mission performance. For instance, a data entry error occurring early in a mission that is retained in the local computer memory is likely to be easier to correct than a data entry error occurring later in the mission and distributed to many units. The lateness of the data entry error puts a time-stress on detecting and on correcting it, since wide dispersal of erroneous data increases the difficulty of making corrections. Thus, even though the task (data entry) may be the same in both instances, its effect on mission performance (e.g., on the probability of mission success) can be greatly varied.

This measurement difficulty, of determining the unique effect on mission performance of the performance of each constituent task, leads frequently to two types of errors in the development of performance measures. The most common error derives from the false assumption that the significance of the level of performance of a given type of task is independent of when that task is performed during the mission. This results in the specification of a performance measure which considers tasks as though they were performed independently rather than as coupled components of a total mission.

The second type of performance measurement error derives from the false assumption that the varying importance of task performance can be accounted for by a single scenario which describes a fixed sequence of mission states, starting from the initial conditions and proceeding to the final objective. The error here is in not recognizing that once the actual mission has deviated from the fixed scenario, the predetermined task performance ratings no longer apply. For example, consider again the data entry error which occurred with the computerized system. The team that is now attempting to recover from that error may be demonstrating superior error recovery performance, but, due to the fact that a data entry error was not included in their scenario, their superior error recovery performance cannot be properly rated or utilized.

Objectives of the Paper

The objective of this paper is to present a method for measuring the performance of teams using computerized systems. The measure is to be a function of the performance of each mission task, including any interaction among team members that may be required to complete the mission. Also, the measure shall permit the quantitative evaluation of teams as units, as well as the quantitative evaluation of individual team members.

METHOD OF APPROACH

The theory of performance measurement introduced by Connelly, Knoop, Bourne, & Loental (1969)(7) is used here to develop a measure foundation of the overall measurement performance in terms of the individual task performance effects. This theory was first applied to flight control problems in which the factors limiting performance originated in the hardware and were known. It was extended for this current study (Connelly, Comeau, & Steinheiser, in press)(8) to permit its application to team-computer systems where the factors limiting performance are not always known explicitly, but are known to exist.

Since the factors limiting performance are not always explicitly known, demonstrations of task performance at various levels that exhibit the effects of those limiting factors must be used in developing the performance measures. This empirically based method for developing measures is described by Connelly, Knoop, Bourne, & Loental (1974)(9) and is the foundation of a computer processor known as MAP, for Measurement and Analysis of Performance. MAP extracts information from the performance demonstration data and then constructs the performance measure.

There are three alternative processes contained in MAP for constructing the measure, yet it is known that one process, in which the mission task sequences are represented by means of a matrix called the Transition Matrix, provides the most compact, efficient way of computing the measurement function coefficients.

In order to describe the method for calculating a team performance measure, it is necessary to first define two types of tasks and two types of performance measures.

Classification of Tasks

The goal-oriented, or "terminal," task begins with a variety of initial conditions and ends when a specified objective is obtained. An entire mission might consist of multiple, sequential tasks for which the terminal condition of one task is the initial condition for a subsequent task. The point is, that with terminal tasks there is always a specific goal to be achieved, such that when the goal has been achieved, the task ends.

Continuing tasks, on the other hand, have no end objective, but instead require performance specified by certain criteria at each instant of time. For example, the well-known pursuit tracking tasks used in psychological studies are continuous inasmuch as the participant must constantly manipulate a control device to track a moving reference point in an attempt to keep his error as small as possible over the total test time. Typically, the error is the distance between a moving reference symbol (such as an "x") and a tracking symbol (such as an "o"), controlled by the participant. The test is conducted for as long as the experimenter has planned, and a performance score is developed as the average error over the test.

Many applied human factor problems can be cast as terminal control problems, even some that are spoken of as continuous tracking tasks. For instance, in the sighting of antiaircraft guns the term "tracking the target" is often used. But this problem can also be broken down into a sequence of terminal, goal-oriented, tasks. First, the operator attempts to acquire the target in his sight, a task which requires the reduction of large errors by the operator. Then, once the target has been acquired, the operator attempts to track it smoothly and with sufficient lead to permit a hit. If automatic lead prediction circuits are available, the operator must still continue to track the target smoothly until the initial transients in the prediction circuits can die out and the tracking aids can calculate accurate prediction. In either case, the operator must next commence firing and, if tracers are used, must adjust his tracking to make use of the tracer information. Finally, when a hit is scored, or the enemy aircraft moves out of range, the tracking task ends.

Still other tasks may be viewed as either continuous or as terminal. Thus, for example, maintaining aircraft altitude and heading over a long period of time, such as in the constant-altitude cruising phase of a lengthy flight, could be viewed as either a continuous tracking task or as a terminal problem, depending on the availability of a relief pilot or of an autopilot, among several possibilities. It is only when the fundamental purpose of a task is the achievement of well defined final conditions that the task (or mission) must be considered terminal.

Types of Performance Measures

Summary Performance Measures. A summary performance measure (SUMPM) is a set of rules for scoring each mission exercise. (Note that in order to describe the measure it is necessary to use two terms: "mission" and "exercise." A mission is the set of tasks that must be completed to accomplish a goal. An exercise is one demonstration of the mission.) A SUMPM provides measurement only of the total mission performance, and, as a result, the complete information required for a SUMPM is not available until the exercise has been completed. This property is a fundamental limitation of all SUMPM's.

Typically, SUMPM's are first formulated subjectively, and reflect the judgment of an individual or group concerning the objective of the mission and the factors believed to be important in scoring exercises. These factors may involve, for example, statements about certain desired terminal and safety conditions that must be satisfied by the exercise. But whatever the factors are, the subjective form of the SUMPM must then be converted into a quantitative form in which specific rules determine the SUMPM value from the exercise data.

In many studies, performance measurement development is terminated at the summary level, even though SUMPM's cannot provide sensitive performance discriminations, nor reveal the effect of individual and team technique on task performance.

System Performance Measures. The theoretical development of a system performance measure (SYSPM) which reveals the effect of the performance of each constituent mission task on summary performance, and, as a result, provides sensitive performance discriminations. This theory, which was developed by Connelly, Zeskind, & Chubb (1977),(10) recognizes that performance is limited both by machine factors and by human factors. Recognition that such limiting factors exist, whether or not they are explicitly known, leads to a measurement equation that permits evaluation of the effect of either instantaneous or of interval performance on the performance of the entire mission. The theory has been successfully applied to aircraft and ship control problems (Connelly, 1977),(11) and is applied here for the first time to team-computer systems.

Once having selected a particular SUMPM - that set of rules used for scoring each (necessarily completed) mission exercise - the SYSPM relates in mathematical terms the effect of the performance of each constituent mission task on the SUMPM chosen. With the SYSPM, the effect on mission summary performance of the way each constituent task is performed can thus be assessed. This is an important property since the effect of operator task performance cannot be expected to be uniform over all team-computer system states. The SYSPM function has also the further ability of being able to discriminate among the many ways both good and bad team performance can be achieved. And, since team members can and do cooperate in various ways to achieve high performance, this property becomes important when measuring the performance of teams that are to be compared.

To obtain these properties, the SYSPM function utilizes "reference-task performance" and, in addition, the effect on the summary performance of deviations from reference-task performance. A reference-task performance is defined here as an established way of performing a particular task. It may include, for example, the time required to complete the task, the number of errors permitted in attempting the task, and so on. A reference-task performance is simply the established, though not necessarily the best, way to complete the given task.

SYSPM's provide a sensitive and comprehensive performance measure for tasks and mission segments. By utilizing reference-task performance and any significant deviation from such performance, SYSPM's provide information that enables them to identify critical task components. Critical mission states in which accurate or rapid task performance is essential can be revealed by an analysis of the mathematical structure of the SYSPM function. Finally, SYSPM's permit rapid assessment of performance and provide a basis for KOR (knowledge of results) feedback for training enhancement.

A Rule for Calculating the SYSPM

From the theory of performance measurement there follows as a major result a rule for calculating the SYSPM over an interval of time. Given this rule, performance can be assessed over any length interval of time desired - over the total mission itself, for example, or over any portion of the mission - by summing over successive (preferably short) time intervals.

The rule for calculating the SYSPM over the i^{th} interval is the following:

$$\begin{aligned} SYSPM_i &= \Delta R_i + Ru_i \text{ for } \Delta R_i + Ru_i > 0 \\ SYSPM_i &= 0 \text{ for } \Delta R_i + Ru_i \leq 0 \end{aligned} \qquad (1)$$

Where $\Delta R_i \quad (R_{i+1} - R_i)$;

R_i = the resources required to complete the mission from the beginning of the i^{th} interval, given that reference performance is exhibited throughout the remainder of the mission, and

Ru_i = the resources that are in fact used during the i^{th} interval. Note that by convention $Ru_i > 0$, i.e., the resources used are always specified by a positive number.

The sum over all intervals of the SYSPM is the value of the SYSPM over the entire mission; or:

$$SYSPM = \sum_{\text{all } i} SYSPM_i = SUMPM$$

Similarly, the value of the SYSPM over any specified portion of the mission is the sum of the $SYSPM_i$ over the intervals constituting that portion.

In practical situations it is not generally convenient to think in terms of equal-length intervals defined by a running clock. Instead, the actual mission is first broken down into its separate state transitions, which may be further broken down into their constituent tasks. The intervals then correspond to the state transitions, or, in a more fine-grained approach, to the time actually taken to complete each task. As the mission progresses, a sequence of intervals is generated as each transition or discrete task is accomplished.

Discussion of Equation 1. According to equation 1, the SYSPM over the i^{th} interval is equal to the change in the resources required to complete the mission assuming that reference performance will be exhibited throughout the remainder of the mission plus the resources actually used during the i^{th} interval. When resources have been utilized effectively, the value of Ru_i will be equal to the absolute value of ΔR_i, and the $SYSPM_i$ over the interval i will equal zero. Thus the SYSPM acts as a penalty function, since its value, the "penalty," is zero when actual performance equals or improves upon expected performance, but is positive otherwise. If the resources actually used exceed the absolute value of the reduction in resources required to complete the mission given reference performance, resources have been wasted (in terms of the standard set by reference performance) and a penalty is assigned equal to the excess resources used. It is the property of the SYSPM function over each interval of time (for example, over each task) that permits correct performance measurement of each constituent task of each transition independent of the level of performance of any individual(s) on previous tasks.

For example, suppose we are working on a project that should require 30 days to complete. If we work effectively for one day, the project at the end of the day should require 29 more days to complete. Thus $R_i = (29 - 30) = -1$, $Ru_i = 1$, and the $SYSPM_i = 0$. If, however, we do not work effectively, and we require one and a half days to do a day's work, $R_i = (29 - 30) = -1$ as before, but $Ru_i = 1.5$, and so the value of $SYSPM_i = 0.5$. We have wasted half a day, and the value of $SYSPM_i$ penalizes us accordingly.

It is important to note here that the SYSPM does not require the questionable assumption of equal sensitivity of mission performance to each type of task, nor does it require measurement of deviation from a fixed scenario path. The SYSPM will properly assign each penalty as it occurs without applying to a given task a penalty due to poor performance on previous tasks.

With regard to equation 1 we now note further that the measurement of the effect on mission performance of the performance of a specific task does require a statement of how the remainder of the mission ought to be accomplished. To satisfy this requirement, we have developed the concept of reference-task performance. When reference-task performance continues throughout the remainder of the mission, we are required to state exactly what amount of reference resources (such as time, funds, fuel, ammunition, and so forth) will be used in each one of the mission's remaining stages. This formulation of the quantity R_i is the major source of difficulty in calculating the SYSPM.

The Specification of Reference Performance

Essential to the validity of using equation 1 for calculating the SYSPM over the i^{th} interval is the assumption that reference-task performance will be exhibited throughout the remainder of the particular mission. In this respect, reference-task performance may be regarded as a prediction of activity yet to be demonstrated, as a prediction of the capabilities of the present system.

Originally, the flight control systems to which the SYSPM was applied were limited in their performance entirely by the hardware in use, rather than by human factors. Because these limitations were fully represented by known equations, it was possible, given the SUMPM, to define exactly the optimal performance and to use it as the standard for reference performance. Where the SUMPM was a function of response time, for example, reference performance for the system was regarded as the time-optimal performance; where the SUMPM was a function of fuel use, reference performance occurred when the least fuel was used. The reader is referred to Connelly, et al.(1977) for a detailed presentation of the computation of the SYSPM for flight control systems.

In a computerized system involving human operators, where the factors limiting performance are as a rule not embodied in any known equations governing the system, optimal performance simply cannot be determined analytically. Nevertheless, the SYSPM may be determined by recognizing that the factors limiting performance are embedded in actual demonstrations of the computerized system, i.e., in real-life demonstrations given by human operators using the computerized equipment. From such demonstrations, the limited performance can be documented and the reference performance can be empirically established.

To provide a framework for the collection of the necessary data, and to facilitate its collection from a variety of computerized systems so that it may be applied to the specification of reference-task performance, a set of parameterized generic tasks has been developed. Ultimately, it is hoped to have tables for each of these, so that the execution time and error rates for each task type (entering data via keyboard, selecting a data format, etc.) and each parameter of a task (the number of keys on a keyboard, for example) are readily available. Thus far, from the literature and from a field study to be described subsequently (Connelly, et al., in press), only some of the generic tasks have been well defined. More work in this area is still required.

REVIEW AND DISCUSSION

This study utilized a model of an Army tactical data processing system (TACFIRE) in which the performance of each team member on each task of a specific mission (the High Burst/Mean Point of Impact Mission) was represented. In order to implement the SYSPM, one must assess for each task as it is accomplished its effect on overall mission performance in terms of deviations from expected task performance, which, in turn, is based entirely upon reference-task performance and the transition probabilities. As a result, reliable and (preferably) extensive data are required to specify the reference-task values and the transition probabilities. The results of the study are too voluminous to discuss at this time. For further discussion see Connelly, et al. (in press).

CONCLUSIONS

By presenting in full detail both the development of the SYSPM as an evaluative tool as well as its application to a problem of continuing interest to Army team training, this report has sought to draw attention to several broad and, at the same time, practical conclusions. Namely that:

1. Data collection in the field can be satisfactorily accomplished by interviewing system experts.

2. The utility of the generic method of classifying tasks now having been demonstrated, the method can be extended to include virtually all tasks involved in the operation of any team/computerized system.

3. The System Performance Measure, SYSPM, can be applied successfully to any tactical data processing system.

4. Computer scoring of the SYSPM for most tasks may be easily accomplished with only moderate compute-time and memory demands. With the storage of the expected resources required for each task at any point in a mission complete, the only work remaining to be done is the rather simple, simultaneous evaluation of equation 1. Of course certain tasks, particularly those interactive tasks not involving a computer, may always have to be scored manually in some check-list fashion.

5. The information automatically provided a computer–scored version of the SYSPM, particularly with respect to the speed/accuracy trade-off, is exactly the type required by an automatic team training system for effectively instantaneous conditioning feedback.

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THE MOTION GENERATOR FOR THE ROTORCRAFT SYSTEMS INTEGRATION SIMULATOR

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ABSTRACT

Since World War II, the U.S. Army has considerably expanded its use of the helicopter in a variety of military functions. As new missions were defined, new tactics, extended performance requirements and increased number of subsystems have imposed extreme demands on the pilot. Ground-based flight simulation is the only safe practical way to investigate the tradeoffs between a better-trained pilot and a more complex aircraft. In 1975, a joint U.S. Army and NASA study was performed to establish the future needs for the simulation of rotary-wing aircraft. As a result, a program was initiated to develop a facility that could be used by government and industry in research and development. That facility is being developed jointly by the U.S. Army and NASA at the Ames Research Center.

In 1978 the Franklin Research Center completed the development of the concept for the motion generator to satisfy the requirements of the new simulation facility. In 1979 they began the design of the unit which is to be installed at the Ames Research Center in 1982. The Rotorcraft Simulator Motion Generator (RSMG) is a new four-degree-of-freedom system to replace the synergistic motion system presently mounted on the Vertical Motion Simulator at Ames. Its extended capabilities will satisfy the requirements for research involving both fixed-wing and rotary-wing aircraft. In this way the Army/NASA goals for an advanced facility for rotorcraft simulation are to be satisfied most efficiently.

INTRODUCTION

Although the U.S. Army accepted delivery of its first helicopter 40 years ago, it was not until after the Korean War that the necessary doctrine and experience were available with which the development of a military helicopter could begin in earnest. The greatest impulse to progress in helicopter development resulted from the requirements and experiences in the Korean, Viet Nam and Middle East wars.

In the three decades since the end of World War II, the U.S. Army has considerably expanded its use of the helicopter. Originally, the helicopter was thought of as being a reconnaissance, evacuation and general-purpose aircraft that was capable of performing missions similar to those that had been performed by the light, fixed-wing aircraft. As the potential of this vehicle began to be appreciated, its use added another dimension to the battlefield by enhancing the Army's ability to conduct the land combat functions of mobility, intelligence, firepower, combat service support, and command, control and communication. Helicopters are now recognized by the U.S. Army as important replacements for traditional ground vehicles in the performance of certain missions that are beyond the capability of fixed-wing aircraft. As the helicopter has acquired these new missions, it has also acquired new tactics, new performance requirements, and a tremendous increase in the number of subsystems, most of which require some degree of management or control by the pilot.

Training alone may no longer enable the pilot to cope with the situation. It is possible that regardless of the extent of training, we are approaching the limit of the human pilot's capability. Of course, the helicopter could be made easy to fly or even to fly itself in these new missions, but such benefits are costly. Automation can significantly increase cost and complexity, and adversely affect reliability and maintainability. To be cost effective, the military helicopter must make full use of its pilot and his capabilities. However, he must not be overloaded to the extent that his mission performance is degraded or his margins for error are decreased until there is an increased susceptibility to accidents. Ground-based flight simulation is the only safe and practical way to investigate the trade-offs systematically before hardware is developed.

Over the last 20 years or so, ground-based flight simulation has become a recognized and widely accepted training tool. In the fixed-wing aircraft industry, the cost effectiveness of ground-based flight simulation in research and development has also been demonstrated (1). Flight simulators have been used to a far lesser extent by the rotary-wing industry. In 1975, a joint U.S. Army and NASA study was performed to review the functions, status and future needs for ground-based flight simulation of rotary-wing aircraft. In the course of this review, the deficiencies in current simulation capability relative to rotary-wing aircraft requirements were identified. As a result of that review (2), a program was initiated to develop a high-fidelity rotorcraft simulation capability that could be exploited by both government and industry in research and development. The simulation capability is being developed jointly by the U.S. Army and NASA at Ames Research Center.

USES OF A ROTORCRAFT SIMULATOR IN RESEARCH AND DEVELOPMENT

The 1975 Army/NASA study concluded that the needs for a helicopter R&D simulator fell into the following two categories:

1. In support of basic technology. This work consists of generic studies of stability

and control, handling qualities, controls and displays, and other aspects of the man-machine interface.

2. In support of the development of new aviation systems or improvements to fielded systems. These efforts start early in an aircraft acquisition cycle by assisting the user and the developer in performing design studies, system integration evaluations and trade-offs.

The first of these uses permits us to address the fact that current helicopter flying qualities specifications are based on an obsolete design standard. For our newest helicopters, we have had to devise poorly substantiated criteria for new missions and tasks. Therefore, in our current R&D program we are pursuing the development of a technological data base in rotorcraft handling qualities that should enable us, for the first time, to generate the criteria and the specifications on flying qualities for rotary-wing aircraft designed to perform military missions (Figure 1). Ultimately, the intent is to provide the designer with the matrix of information he needs to relate effectiveness to life-cycle costs.

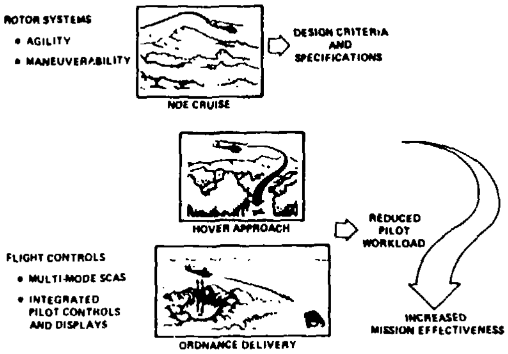


Figure 1. Helicopter Handling Qualities Research

The development of a handling-qualities specification for use by helicopter manufacturers in the design phases would benefit both the industry and the government. Experience has shown that the use of the current handling-qualities specification (MIL-H-8501A) has failed to provide more than basic guidance to industry and attempts to meet the requirements of that specification have, in many instances, resulted in undesirable flying qualities (3). Individual specifications were developed for the Utility Tactical Transport Aircraft System (UTTAS) and the Advanced Attack Helicopter (AAH) in an effort to eliminate this deficiency; but both helicopters, although judged to have superior flying qualities, also failed to meet certain requirements of their specifications (4). From an aeromechanics point of view, our most modern U.S. Army aircraft, the UTTAS and the AAH, are based on technology that is 10 to 20 years old. These aircraft, like their predecessors, will impose workloads on their aircrews during typical Army missions that will constrain the pilot from exploiting to the maximum the full capabilities of his aircraft, especially at night or under adverse weather conditions.

Rotor systems and their associated controls offer the most direct method of improving flying qualities and reducing pilot workload in the missions and tasks typically assigned to Army helicopters. Chen and Talbot (5) investigated four major rotor system design parameters to assess the handling qualities for 44 configurations of main-rotor systems that cover teetering, articulated, and hingeless families of rotor systems with a wide range of blade inertia. They concluded that within each family of rotor systems, satisfactory handling qualities could be obtained with the appropriate combination of rotor parameters. However, no single rotor system was uniformly superior in all aspects of handling qualities during typical operations. Additional experiments such as these are required to optimize the handling qualities for specific missions.

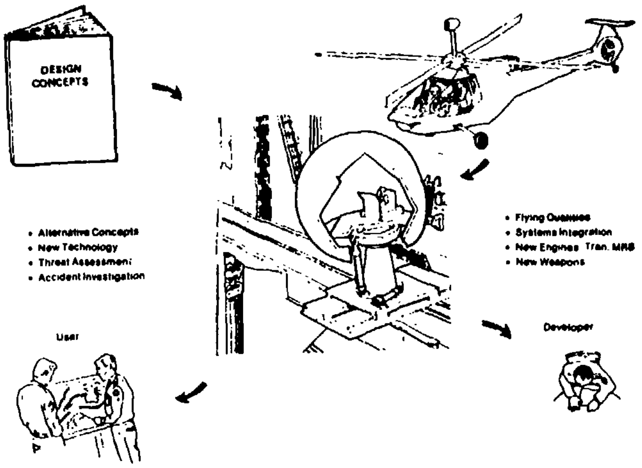


Figure 2. Systems Development Cycle

The second use of R&D flight simulators, during the development of new aviation systems for improvements to fielded systems, follows the entire life cycle of system development (Figure 2). During the program initiation phase, the simulator can be used to evaluate new aviation concepts or tactics that have been developed by the U.S. Army Training and Doctrine Command (TRADOC) to meet a specific threat. The R&D simulator also provides an ideal environment for evaluating the threat from both ground weapons and enemy helicopters. The probability of air-to-air combat between helicopters on the future battlefield is extremely high. Success in these engagements may depend on exploitation of weakness in the threat helicopter's handling qualities or in the optimization of our own flight maneuvers. It may be in this approach to establishing requirements that ground-based simulators will play their most effective role in minimizing the life-cycle cost of our future aircraft. Such evaluations can help answer the questions and support the rationale leading to a Mission Element Needs Statement (MENS). After the MENS is approved, the R&D simulator can be used in the demonstration and validation phase for evaluating the flying qualities of competing designs as well as for easing future systems integration efforts.

Manned simulation also plays an important role in establishing hardware configuration during the development of the helicopter. During the evaluation phase of a baseline design, test pilots and operational pilots are provided the opportunity, through manned simulation, to evaluate the baseline and mission scenarios with full operational freedom. This is the last point in time when changes to the baseline design can be made without extremely costly hardware retrofit. Also, actual prototype flight hardware can be incorporated into the flight simulator. Although standard bench integration test will verify electrical and, in some cases, software compatibility, only a dynamic simulation can completely exercise the equipment. Even more important, all aspects of the software can be tested in a mission enviroment well before the aircraft flies.

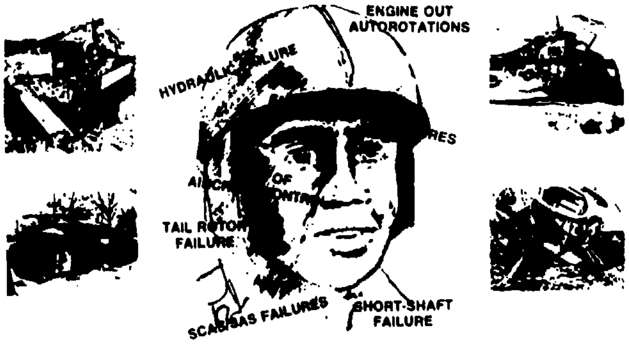


Figure 3. Aircraft Accident Investigation

Finally, the R&D simulator can be used to investigate unusual accidents (Figure 3), the understanding of which defines normal investigative techniques. One such investigation has already been accomplished at Ames Research Center. In March 1976, a Bell Helicopter Textron Model 214 helicopter crashed during hardover-control-signal testing of its Automatic Flight Control System (AFCS). The subsequent accident investigation did not conclusively establish the cause of the accident but did indicate that it was not caused by a mechanical, electrical, or hydraulic failure. It was decided to continue the investigation using the six-degree-of-freedom Flight Simulator for Advanced Aircraft (FSAA) at Ames Research Center. The results proved that removing the hardover-control-signal at the same time the pilot was taking corrective action causes large spikes in blade flapping and was the probable cause of the accident. The procedure for hardover-control-signal testing was subsequently modified and similar accidents have not occurred.

In summary, flight simulation is an important tool in helicopter research and development, both for technology-base development and for aircraft development programs. There is no question that ground-based simulation has been and will continue to be an invaluable tool. The flight simulator is to the flight dynamicist what the wind tunnel is to the aerodynamicist. The emphasis on the control of development costs and operational training costs suggests that flight simulators will play an increasingly important role in future research and development of Army rotary-wing aircraft.

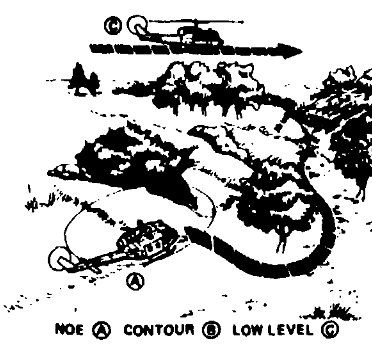


Figure 4. Terrain Flying Regimes

REQUIREMENTS OF A RESEARCH AND DEVELOPMENT ROTORCRAFT SIMULATOR

The modern battlefield has become a highly lethal place for both fixed- and rotary-wing aircraft. The formidable array of weapons that can be used against aircraft has forced pilots to abandon their normal operating altitudes in the vicinity of a battlefield. The only air space that can be considered relatively safe is below 100 feet and then only if a sufficient amount of ground cover is available. The helicopter is naturally a ground contact machine par excellence and its mission use in Army aviation is more characteristic of a flying jeep or tank than of an airplane. Helicopters fly low and slow and, especially during military missions, are close to the ground during most of their flying time. The term nap-of-the-earth (NOE) (Figure 4) has been coined by the helicopter community to describe operations in which helicopters fly only a few feet above the ground and fly around obstacles rather than over them. The environment for the pilots flying these missions is rich in detail--trees, bushes, hills and valleys. Although these terrain features offer protection from the enemy, they can be lethal to an unwary pilot. In addition, visibility factors associated with weather and darkness, and atmospheric characteristics of wind, turbulence and ground effect are all elements of the environment that may significantly affect the helicopter pilot's tasks. The helicopter crew must maneuver around and between obstacles, and navigate, communicate and proceed with the mission while maintaining awareness of threat weapons.

Current simulation capabilities cannot meet the requirements of rotary-wing aircraft when one considers all the aspects, including mission, task, aircraft characteristics, environmental conditions, instrumentation and displays, performance and workload. Many of these aspects impose requirements quite different from those met by even the most sophisticated fixed-wing simulators. The most advanced ground-based simulators in the world are available to the U.S. Army's Aeromechanics Laboratory (through agreements with Ames Research Center), but even these are not adequate to meet the Army's need to simulate nap-of-the-earth flight operations. The visual display is required to represent much more detail in the terrain and vegetation. Low flight speeds and high maneuverability allow rapid changes of flightpath to be achieved so that the field of view required for the helicopter pilot to see where he is going is wider than that of a fixed-wing aircraft. This paper, however, concerns itself with the requirement for motion. Deel and Rue discussed visual concepts (6) during the last conference.

Motion (Platform) Requirements

There is no obvious and accepted measure of motion cue requirements. It is generally agreed that motion simulation is required: (1) when expected motions are above human sensory or indifference thresholds; (2) when expected motions are within the sensory frequency range, that is, above 0.2-0.5 rad/sec; (3) if full pilot performance (e.g. tracking) is desired; and (4) when a degree of face validity or realism is required to gain pilot acceptance of the total simulation.

An example of relating simulator motion system capabilities to the maneuver envelope of an aircraft is presented in a paper by Key et al (7), which includes a description of the development of the requirements for a motion system to be used in a helicopter flight simulator.

Axis	Parameter		
	Position, rad, m	Velocity, rad/sec, m/sec	Acceleration, rad/sec^2, m/sec^2
Yaw	±0.4	±0.6	±1.0
Pitch	±0.3	±0.5	±1.0
Roll	±0.3	±0.5	±1.0
Surge	±1.3	±1.3	±3.0
Sway	±3.0	±2.6	±3.0
Heave	+7, -14	+8, -11	+14, -12

Table 1. Motion (Platform) Requirements for Critical Terrain Flight Maneuvers (from Reference 7)

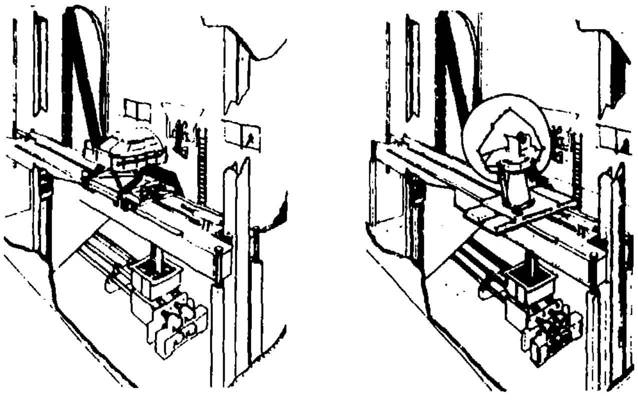
The criteria that were adopted for these requirements were based on the opinions of experienced researchers, which in turn were supported by limited test data. Flight maneuvers resulting from fixed-base simulations of NOE flight operations were analyzed to define the platform excursion requirements. These time histories were played (off-line) through a drive logic representing that of an advanced six-degree-of-freedom simulator, with the fidelity boundaries and selected operating points for each axis. The results of the analysis, in terms of the maximum excursion, velocity, and acceleration of each axis, are presented in Table 1. The requirement is that all axes produce these quantities simultaneously; this requirement is amplified by the data of Table 2, where the position of each axis at the instant that one axis reached a maximum is presented. The data are from a typical maneuver case. The significance of the data is then when one axis is at a maximum, some of the others are at large values also. A nonlinear drive logic is needed to vary the gains and washout frequencies with amplitude of motion in order to obtain as much fidelity as possible for lower amplitude tasks.

Axis at maximum position	Simultaneous axis position, % maximum					
	ϕ Roll	θ Pitch	ψ Yaw	X Surge	Y Sway	Z Heave
ϕ	100	0	31	0	92	73
θ	60	100	6	83	46	14
ψ	67	22	100	28	54	41
X	33	33	19	100	0	59
Y	87	33	38	83	100	77
Z	47	33	0	56	69	100

Table 2. Examples of Simultaneous Excursions (from Reference 7)

RSIS PROJECT PLAN

Under joint agreement, Ames Research Center and the U.S. Army Research and Technology Laboratories, Aviation Research and Development Command (AVRADCOM), have agreed to acquire the Rotorcraft Systems Integration Simulator (RSIS) to be installed at Ames Research Center. The program is now in its final phase. The definition phase started with an Army/NASA study in 1975 which led to additional studies to address the issues raised by the special requirements of rotorcraft simulation. A feasibility study of a wide-angle visual simulation system, completed by Northrop in 1977, showed that a wide field-of-view display (120° horizontally by 60° vertically) was feasible. Analyses of fixed-base and motion-base simulations of NOE flight operations have defined the cab excursions required for high-fidelity simulation motion. It was determined that the Vertical Motion Simulator (VMS) at Ames Research Center could be modified and used as the motion base of the RSIS (Figure 5). Independent design studies to assess the possible modification to the VMS were performed by Franklin Research Center and Northrop Corporation in 1978. Specifications were developed from those two studies, a competitive request for proposal was issued to industry and the contract was awarded to Franklin Research Center in 1979. The modification, known as the Rotorcraft Simulator Motion Generator (RSMG), will be delivered in late 1982. The remainder of this paper will discuss the design and the fabrication of the RSMG by the Franklin Research Center (FRC).



EXISTING VERTICAL MOTION SIMULATOR

FUTURE VMS WITH INTEGRATED RSMG AND INTERCHANGEABLE ADVANCED ROTORCRAFT CAB/VISUAL SYSTEM

Figure 5. The Vertical Motion Simulator

DESIGN STUDIES FOR THE ROTORCRAFT SIMULATOR MOTION GENERATOR (RSMG)

Motion Generator Specification

As a result of the analyses performed by the U.S. Army Aeromechanics Laboratory and the National Aeronautics and Space Administration at the Ames Research Center, specifications were developed for the Rotorcraft Simulator Motion Generator (RSMG) as shown in Table 3. The severe limitation on the weight of the RSMG was imposed so the performance of the Vertical Motion Simulator (VMS) would not be degraded from its original performance goals. In addition there were severe constraints on the operating envelope of the RSMG due to the internal dimensions of the existing VMS building structure. Most critical, of course, is in the direction of longitudinal motion where the 20 foot diameter sphere must be allowed a total displacement of 8 feet within a building dimension of 31 feet.

1. Performance

Mode	Simultaneous Displacement	Velocities	Acceleration
Longitudinal (X)	± 1.22 m (± 4 ft.)	± 1.22 m/sec (± 4 ft./sec)	± 3.05 m/sec^2 (± 10 ft/sec^2)
Roll (ϕ)	± 0.314 rad (± 18°)	± 0.7 rad/sec (± 40°/sec)	± 2.0 rad/sec^2 (± 115°/sec^2)
Pitch (θ)	± 0.314 rad (± 18°)	± 0.7 rad/sec (± 40°/sec)	± 2.0 rad/sec^2 (± 115°/sec^2)
Yaw (Ψ)	± 0.418 rad (± 24°)	± 0.8 rad/sec (± 46°/sec)	± 2.0 rad/sec^2 (± 115°/sec^2)

2. Payload

• Configuration	20.5 ft. dia. sphere section
• Gross Weight	8000 - 12,000 lbs.
• Moments of Inertia	3000 - 20,000 lbs. ft. sec.^{2}

3. Frequency Response

- Second order system natural freq. 3 Hz and damping factor 0.7
- Tolerances, ± 2 db and ± 20 degrees

4. Weight Limitation

Total weight of 4DOF system < 16,000 lbs.

Table 3. Specifications for the Rotorcraft Simulator Motion Generator (RSMG)

Studies of RSMG Candidates

A number of RSMG configurations were analyzed in an effort to meet all requirements in the most cost-effective manner (8). Brief descriptions follow.

Since the synergistic type of motion system, illustrated in Figure 6, is the most efficient machine for generating six-degrees-of-freedom (6DOF) motions it was considered first. Design calculations showed that the actuator lengths required to provide all displacements simultaneously were unreasonably long (30 feet). In addition, a failure mode analysis showed that under certain emergency conditions, the platform could assume an attitude that would cause the 20 foot sphere to strike the building wall.

Figure 6. Synergistic 6DOF Motion System

The opposite extreme is a cascaded system as shown in Figure 7 where the sphere is carried on three rotational gimbals which are, in turn, mounted on a longitudinal carriage. This configuration captures the sphere within the range of the longitudinal motion under all operating or emergency conditions. However, the weight of the

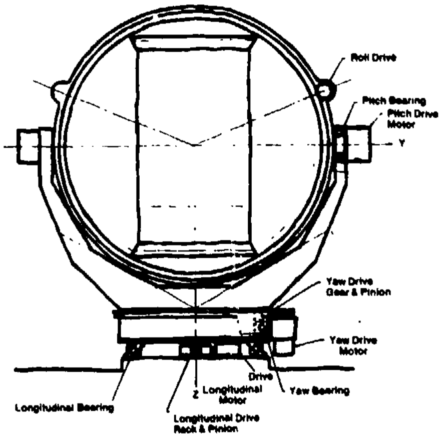


Figure 7. Cascaded 4DOF Motion System

cascaded gimbals and carriage structure not only severely escalated the power requirements of the drive system, but also far exceeded the allowable limit imposed on the total RSMG weight.

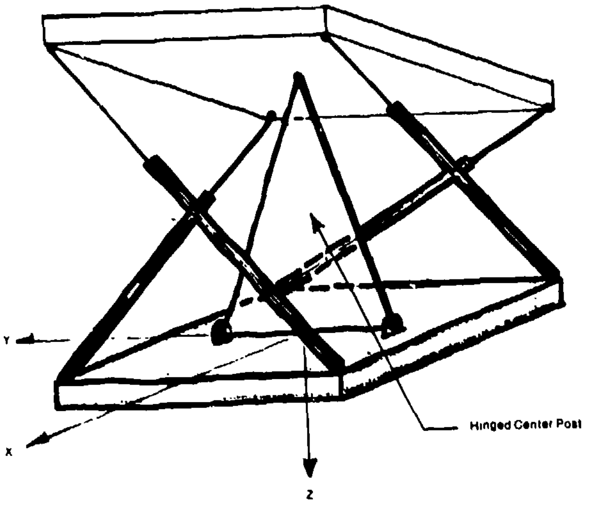


Figure 8. Synergistic 4DOF Motion System

A synergistic 4DOF configuration, shown in Figure 8, was investigated next. It has a hinged center-post that eliminates lateral motion and limits vertical motion, both of which are available from the basic VMS. Because of the minimization of moving mass, it is the most efficient configuration for generating the remaining 4DOF motions. However, again the actuators required to produce the specified displacements simultaneously were unrealistically long (34 feet) so the concept was rejected.

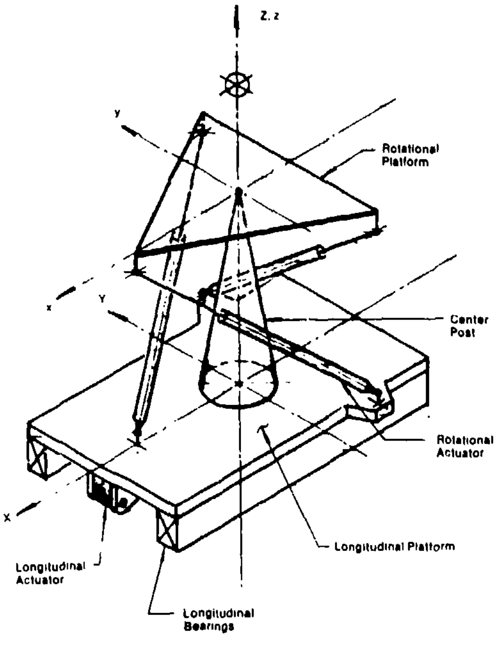


Figure 9. Synergistic 3DOF on Longitudinal Carriage

Recognizing the need to restrict actuator lengths, FRC elected to separate (or decouple) the translation motion from the rotational motions by using a carriage moving on linear ball bearings as shown in Figure 9. Here the rotational motions are produced with a synergistic arrangement of three actuators with a rigid center post restraining all translational displacements. A detailed design study of this 4DOF configuration revealed that all specified performance requirements for the RSMG could be met or exceeded. However, the overall height of the RSMG with the cockpit and dome in place required an unacceptable compromise in the available vertical displacement of the VMS.

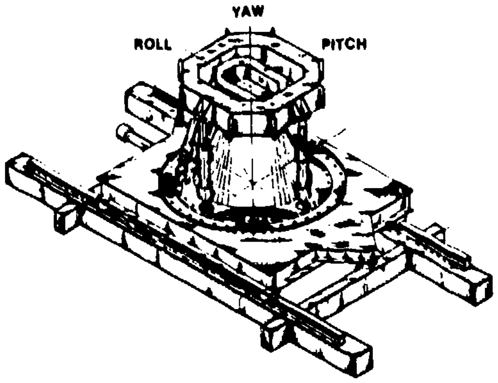


Figure 10. Final RSMG Configuration

The overall height was reduced by decoupling the yaw motion from pitch and roll as shown in Figure 10. Here the center-post is mounted on a large diameter ball-bearing carried on the longitudinal carriage. The platform is coupled to the center-post with a simple 2DOF universal joint restricting its motion to pitch and roll only. Since the actuators can now be positioned vertically and their length is relatively short, the overall height is reduced to meet the original goals for vertical motion of the VMS without impacting the ceiling of the building.

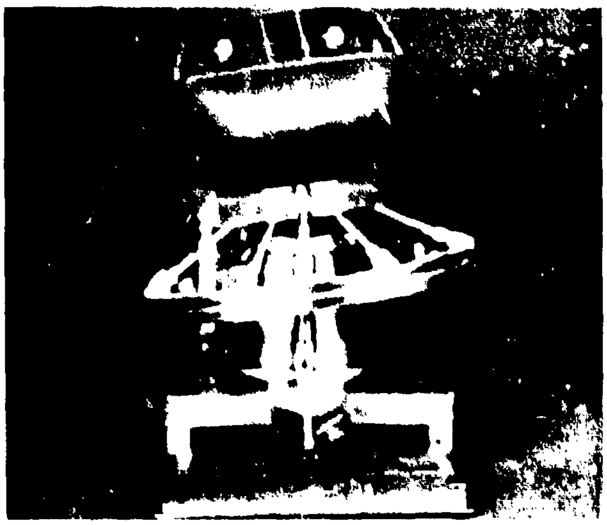


Figure 11. RSMG Model (without 20 ft. sphere)

The final configuration of the RSMG is shown in the model photos in Figures 11 (without the 20 foot sphere) and 12 (with).

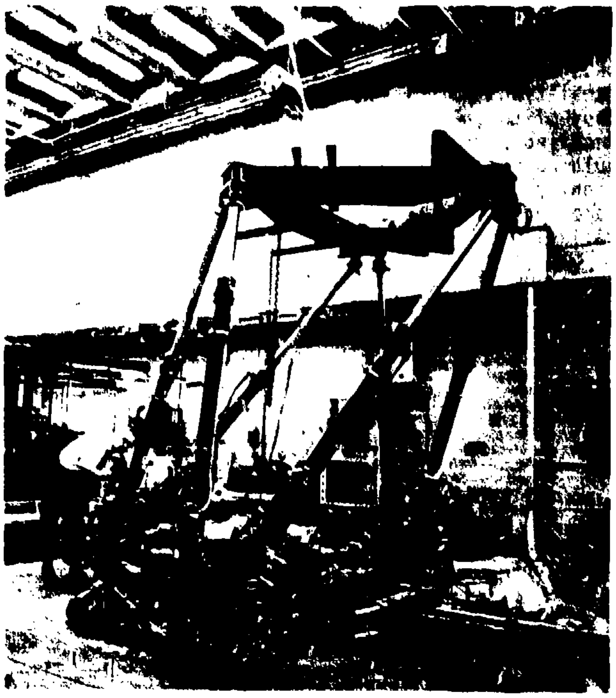


Figure 12. RSMG Model (with 20 ft. sphere)

ROTORCRAFT SIMULATOR MOTION
GENERATOR (RSMG) DESIGN

Description of the RSMG System

The total RSMG system is made up of a number of subsytems as defined in the block diagram in Figure 13. The motion base is, of course, the central element to which all other elements are dedicated. It is driven with a set of four independent electrohydraulic actuators with feedback control loops and instrumentation for stabilizing and monitoring performance. The control systems are serviced by a hydraulic power supply and electric power. The control systems are commanded from a dedicated minicomputer which, among other things, provides the interface with the NASA host computer. The entire RSMG system is integrated with a set of built-in safety systems to protect men and machines in the event of any foreseeable emergency situation. The subsystems defined in Figure 13 are:

- Motion Base
- Controls and Instrumentation
- Hydraulic and Electric Power
- Dedicated Computer
- Safety Systems

Each of these subsystems will be described in greater detail in the sections that follow.

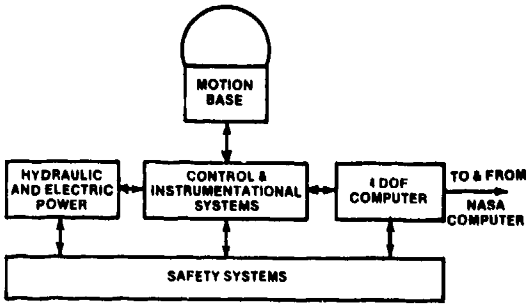


Figure 13. The RSMG System Complex

Motion Base

A sketch of the configuration of the motion base was shown in Figure 10 defining the four axes of displacements. The ± 4 feet of longitudinal motion is achieved with a carriage mounted on 32 linear recirculating-ball bearings on 2 linear tracks. Cross-sections of these bearings manufactured by THK Japan are shown in Figure 14. These bearings are precision-ground and preloaded to provide smooth noise-free operation without lost motion.

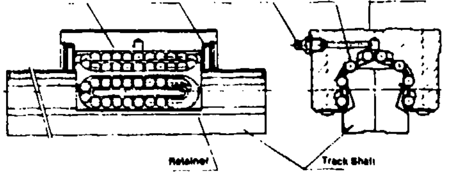


Figure 14. Cross-Sections of Linear Bearings

The longitudinal carriage is driven with a single hydraulic cylinder centrally-located between the tracks under the longitudinal carriage. The design of all the cylinders on the RSMG is a patented telescoping configuration that provides equal effective hydraulic operating areas in both directions within the overall length of standard commercial unequal area cylinders. This provides for the symmetrical application of forces, minimizes the size of the servovalve required and optimizes the smoothness of motion.

The design of this unique equal-area cylinder configuration is shown in Figure 15.

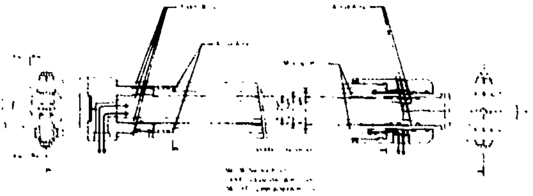


Figure 15. Typical Equal-Area Cylinder

The fixed portion on the left is made up of two concentric hollow tubes slightly shorter than the retracted length. The moving portion is a closed-end hollow tube with an annular flange that telescopes inside and between the fixed tubes. A seal is required around the moving tube and piston rings are required around its annular flange.

The left cylinder port allows the hydraulic fluid to enter the fixed center tube and impact the closed end of the moving tube. The right cylinder port conducts fluid into the annular area between the moving tube and the fixed outer tube to impact on the annular area projected by the flange. By proper selection of design dimensions it is clear that the effective area of the closed end of the moving tube can be made equal to or different from the effective area of the annular flange.

The ± 24° of yaw displacement is provided by rotating a truncated-cone center post on a large diameter crossed-roller-bearing located in the center of the longitudinal carriage. It is approximately 48 inches in diameter and preloaded to avoid lost motion. It is driven by a single, equal-area hydraulic cylinder lying horizontal and attached between the longitudinal carriage and the outer radius of the center post.

Pitch and roll motions of ± 18° are provided with a two-gimbal system mounted on top of the rotating center post. The equal-area drive cylinders are connected between their respective gimbals and the base of the rotating center post.

From the above description it is clear that, except for a minor geometrical interaction between pitch and roll displacements, the RSMG motion base is an "uncoupled" motion system. That is, individual motions are commanded independently, without the need for on-line coordinate conversion. This minimizes the requirements of the dedicated computer. It does not mean, however, that there is no coupling of the dynamics of the individual motions. Since the center of mass of the payload does not correspond with the center of rotation in the gimbal system, pitch accelerations will couple reaction forces into the longitudinal system and vice-versa.

Controls and Instrumentation

The first consideration in designing the electrohydraulic control systems is the servovalves. Over many years of experience, The Franklin Institute has developed a proprietary servovalve design that yields electrohydraulic controls that have a minimum of unwanted accelerations, commonly known as "hydraulic bump" or "acceleration noise". Current experimental tests under an Air Force contract indicate "smoothness" and/or "stability" better than 0.01g peak. The servovalves for the RSMG electrohydraulic controls are all of this special design. It involves an unconventional layout of the outlet ports of the third stage, which provides for more positive control of the outlet flow under the conditions of low actuator velocity.

To insure that the specified dynamic performance will be achieved in the operational system, each closed loop control system was carefully designed, mathematically modelled and simulated for computer analyses. The analyses performed on each of the four closed loop controls systems were:

- Frequency response
- Root locus plot
- Step response
- Force disturbance

Since the RSMG is a research simulator intended to be used with a variety of cab and visual display configurations, these analyses were performed with two extreme loads; one the cab and spherical screen described in the specifications, the other the NASA Interchangeable Cab (IC) with no external visuals. As an example of the results obtained, we will describe the design and analyses of the roll control system.

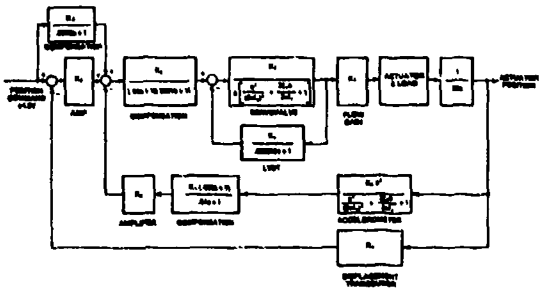


Figure 16. Block Diagram of Roll Control System

Figure 16 is a block diagram of the roll closed-loop control system. It uses a Trans-Tek angular position transducer as the primary feedback element. It also employs a Systron-Donner angular accelerometer to provide the compensation necessary to accommodate the wide range of expected loads. The position command is an analog signal from 0 to 10 volts dc. It is compared with the actual position feedback to generate an error signal which is compensated with acceleration feedback and shaping networks to command servovalve spool position. The servovalve has a Schaevitz LVDT spool position transducer in a minor loop to extend its bandwidth and responds accordingly to the error command to deliver flow to the roll actuator to reposition the load and minimize the error.

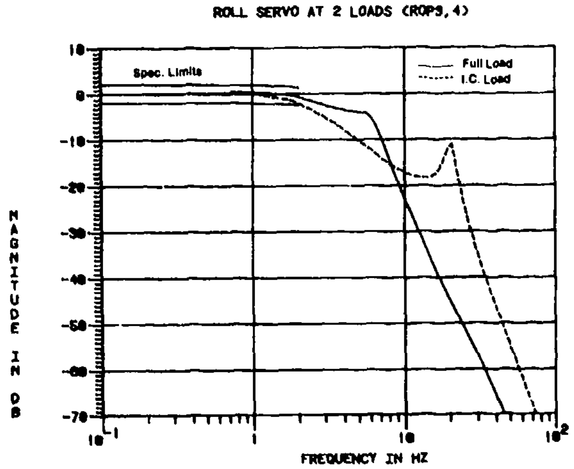


Figure 17. Frequency Response of Roll Actuator System

The frequency response of the roll actuator system is shown in Figure 17 together with the lines defining the limits set up in the specification. The analyses of the response to external force disturbances, such as coupling of reaction forces due to VMS lateral motion, indicate completely stable behavior.

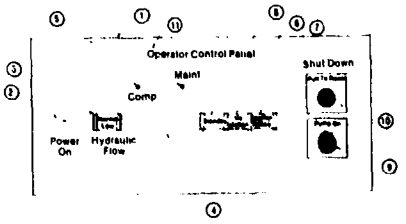


Figure 18. Operator's Control Panel

Control Consoles

There are two electronic consoles required to operate, monitor and maintain the performance of the RSMG system. One is a sloping-front console containing the Operator's control panel, the maintenance test panel, the control system electronics and all necessary DC power supplies. The Operator's panel is shown in Figure 18 indicating the simplicity of starting-up and controlling this complex machine under normal conditions. Figure 19 shows the maintenance test panel with the means to address each axis of motion separately and perform tests to insure proper performance. In the upper right corner is a computer-aided warning system that monitors critical system parameters, detects trends toward allowable limits and indicates the time to go until the RSMG is automatically shut down. This allows the Operator to use some judgment when he is in the middle of an important simulated test run.

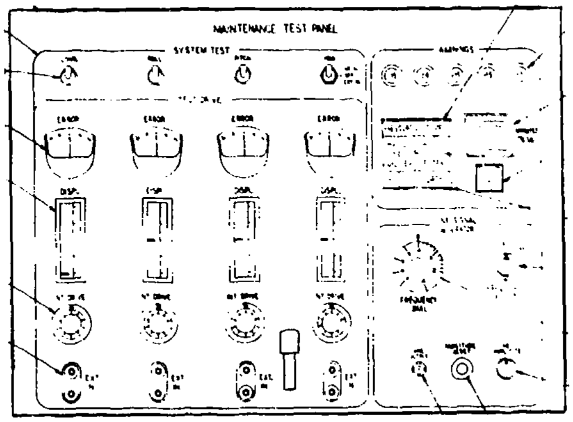


Figure 19. Maintenance Test Panel

The second electronic console is a tall relay rack containing a PDP 11/34 computer with disk unit, computer interface electronics, a system monitoring panel, a signal output panel and the safety interlock relays. It is to be located remotely from the vicinity of the Operator's console and addressed only during software changes and hardware troubleshooting.

Dedicated RSMG Computer

The central element of the RSMG computer system as a standard PDP 11/34 minicomputer with a CRT terminal and dual disk memories. To couple this computer with other subsystems three special circuit cards have been designed and built. These cards are:

- analog to digital (A/D) converter
- digital to analog (D/A) converter
- interface circuits

The A.D card is a 32 channel, 14 bit converter with analog multiplexers and instrumentation amplifiers. It accepts analog inputs from the NASA host computer, the safety systems and the maintenance test panel, and converts them to digital signals.

The D/A card is a 16 bit converter with chopper-stabilized operational amplifiers. The interface card contains circuits for accepting NASA 28-volt logic and operating lamps. It also operates the "time to go" display.

The RSMG computer system performs three major functions:

- signal extrapolation
- safety monitoring
- maintenance

The NASA host computer provides incremental analog position and velocity command signals that are updated only every 20 milliseconds. The RSMG computer uses the velocity signal to extrapolate intermediate points every 2 milliseconds, thereby making the step change in position undetectable.

The RSMG computer is one link in a redundant safety system. It not only conducts an orderly start up or shut down, it also monitors all interlocks, limits incoming signals and performs self-checking routines. The computer supplements the maintanance control panel in aiding set-up, troubleshooting and demonstration of the RSMG system. It also contains the software to aid in setting up and checking out the computer system itself.

Safety Systems

The RSMG is designed with safety as a primary goal. Emergency systems are designed to handle three levels of potentially-dangerous situations:

- excessive commands
- subsystem malfunctions
- total loss of power

Level 1 systems are built into the electronic circuits. At the input to each electrohydraulic actuator control loop there are limiting circuits to prevent excessive commands for position, velocity and acceleration. There are also "smart" circuits for limiting the impact of running into the displacement limits of the actuators. They continuously monitor position and velocity to determine the point where the actuator must start decelerating at a safe level as it approaches the end of stroke.

Level 2 systems are those that incorporate interlocks from all critical subsystems and inputs which automatically shut the motion system down in a safely-controlled manner. Shutdown can be triggered by a variety of interlocked inputs such as:

- loss of control power
- low hydraulic pressure
- high oil temperature
- excessive system error
- operator's command
- pilot's command

Shutdown occurs in a controlled sequence. Solenoid valves close to trap the fluid in the cylinder. Excess pressure is bypassed with relief valves across the cylinder ports. When the system stabilizes the condition is analyzed and the system returned to a safe position under manual control.

Level 3 emergency systems are designed to accommodate the most severe case of failure; the complete loss of electrical and hydraulic power. For this case a set of accumulators are provided to store enough energy to return the system to a safe position. The initial action is to trap the hydraulic fluid in the cylinders by closing fail-safe solenoid valves, relieving excess pressure through the cross-connected relief valves. Also included are automatic mechanical devices on the servovalve spools that control the pressure in the accumulators to "park" the system with all cylinders retracted. These devices are programmed to move the most extended cylinders at twice the velocity of the shorter ones to avoid any hazardous attitudes on the way to the totally-retracted position.

SUMMARY

In summary, we have described the specification and design of the Rotorcraft Simulator Motion Generator (RSMG). The system is intended to replace the existing 6DOF motion generator on the NASA Vertical Motion System at Ames Research Center. The extended capabilities of the RSMG will make the VMS suitable for simulating rotorcraft as well as fixed-wing aircraft. Its performance will then satisfy the requirements of the U.S. Army's long range rotorcraft R&D programs.

The RSMG is a 4 degrees-of-freedom (4DOF) motion generator to be mounted on the 2DOF Vertical Motion System. To fit within the existing building, the RSMG was designed as a relatively uncoupled mechanical system, with independent electronydraulic actuators for each axis of motion. The control systems have been designed especially to maintain stability and performance with a wide range of payloads. A computing system is dedicated to the RSMG to aid in signal handling, subsystem monitoring and maintenance. The entire RSMG system and its test subjects are protected by a sophisticated 3-level safety system that returns it to a safe attitude in the event of any foreseeable malfunction.

The RSMG promises to be a key element in the utilization of the VMS to implement the U.S. Army's Rotorcraft Systems Integration Simulator (RSIS).

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INTERACTIVE FLAT PANEL INTELLIGENT DISPLAY TERMINALS AND TECHNIQUES

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ABSTRACT

This paper discusses fully operational, user-interactive automated training equipment with sophisticated computer graphics and video that can be packaged into hardware no larger than a suitcase. Such systems have been assembled using thin-film electroluminescent display panels and transparent touch-panel overlays coupled with interactive software and microcomputer and memory technology. The display quality is comparable to or better than that of most CRT installations and the system intelligence can exceed that of many minicomputers. Incorporated touch interaction enables users to be facile with its operation without undergoing undo specialized training. Systems of this type can be used to satisfy a great majority of the Services' needs for sophisticated training and test equipment, while being completely portable and usable in a tactical environment.

INTRODUCTION

The continued growth of battlefield automated systems and generation of large quantities of data, makes it essential for users to be extremely facile with the operation of such systems without undergoing undo specialized training. To satisfy this requirement, while maintaining operator control, such systems must have a convenient means for the user to communicate with the data base and central processor. Also, for such equipment to be useful for tactical applications, it should be highly portable and rugged. There are many definitions of portable, but in this context, we refer to hardware that is easily carried by one man. There have been a number of demonstrations of effective computer based systems which meet good user-interactive standards for training purposes, configured in relatively large installations. However, the type of system described here, has comparable capability, while entirely packaged in a small suitcase. The following sections will discuss hardware and software aspects of such a system, describe a sample scenario for automated test equipment use and discuss expected further developments.

SYSTEM HARDWARE

The system hardware can be subdivided into five categories:

(1) Flat panel display
(2) Touch interactive mechanism
(3) Microcomputer to process and retrieve information, control the display and respond to user requests.
(4) Easily replaceable, non-volatile memory to hold specific software.
(5) Miscellaneous components including case, power, supplies and the like.

The following subsections will discuss the first four of these categories.

Flat Panel Display

High quality graphics and video imagery are achievable using thin-film electroluminescent (TFEL) display technology. Figure 1 depicts a cross-sectional view of a TFEL display. The display is fabricated on a single sheet of glass using inexpensive vacuum deposition techniques. When a potential of approximately 200 volts is placed across selected row and column electrodes, a yellow-orange emission as defined by the electrode intersection is seen through the transparent column electrode. By utilizing a multiplexing (x-y address) partial selection scheme, one can address the entire display, row-at-a-time in frame times comparable to standard TV rates (60 hertz (Hz)) or faster, if desired. MOSFET technology can handle the required voltage levels and integrated versions of such row and column drivers are available. Live television as well as graphics have been demonstrated on a 240 by 320 pixel resolution display panel at a pixel spacing of 68 lines-per-inch (lpi). Various other display panels, ranging in size from 2½ inches by 4 inches at 80 lpi to 10 inches by 12 inches at 50 lpi are in different stages of development. A 100 lpi panel with a total of 512 by 640 pixels is near completion.

A display monitor incorporating the 240 by 320 pixel panel dissipates a total of approximately 10 watts and weighs only 3 pounds. Recent work in developing new drive schemes is expected to reduce that power substantially. Some thermal tests have been performed and indications are that complete compliance with military temperature specifications is expected. Currently used epoxy seals between the display substrate and a protective back cover glass indicate satisfactory protection from moisture, however hermetic sealing techniques are presently being developed. Life tests performed on some sample displays indicate operating lives in excess of 10,000 hours. More complete life testing is being conducted.

Another important feature of these displays is contrast. Referring back to Figure 1, it will be noted that there is a black, light absorbing layer behind the light emitting surface and in front of the rear metallic electrodes. This layer absorbs in excess of 99.9 percent of the light impingent on the display, resulting in a high degree of legibility at relatively low luminance levels. Legibility in a direct sunlight environment (10,000 footcandles (fc)) has been demonstrated with only 15 footlamberts (fL) luminance.

Touch Interactive Mechanism

The incorporation of a touch-interactive mechanism over the display, converts it from a one-way to a two-way communicator. The effect of the touch interactive mechanism is to allow the operator to touch the surface of the display screen with his finger or other passive device, and have the system recognize where it has been touched. By correlating this touch with the displayed information at that point and with corresponding data or processes that the microcomputer can perform, the operator can query or instruct the computer via the touch. It is not necessary for him to use a keyboard or any other interactive devices such as buttons, switches, light pens, or the like. With properly written software, the touch panel can make the system completely self-instructing since the display can communicate with the user in his language and remove all ambiguity in the particular operations that the user has to take through the provision of various types of menu selection.

A number of touch panel mechanisms are possible. A common one involves the incorporation of two transparent layers (glass or plastic) with transparent conductive coatings on their insides. The pressure of a touch completes electrical contact between the layers. The Central Processing Unit (CPU) can then determine where the touch took place based either on the transparent conductor pattern or on a resistance calculation. Another mechanism involves an array of infrared (IR) light emitting diodes (LEDs) and corresponding arrays of IR detectors around the periphery of the display. The finger touch then breaks the invisible IR array, identifying where the touch takes place.

In a later section we describe a sample scenario utilizing touch panel operation.

Microcomputer

Microcomputers have sufficient computing power to perform training and test functions and drive the display while keeping cost and power consumption low. The one chosen should have at least a 16 bit word length to enable it to perform fast graphics on the display and for rapid access to the mass storage. On-board Random Access Memory (RAM) should be capable of storing the operating system software and programs necessary to interpret the operator's commands to access more information from the mass storage device. There should be sufficient input and output to interface to the display and the mass storage device.

There are a number of commercially available microcomputer boards available that adequately meet the above criteria.

The boards with 16 bit CPUs typically contain on the order of 32 kilobytes (Kbytes) of read only memory (ROM), 64 Kbytes RAM, and serial and parallel Input/Output (I/O) ports on a single moderately sized circuit board. This is sufficient to meet expected needs for the type of equipment being discussed, other than the mass storage which will be discussed in the next section. It is not the intent of this paper to suggest a particular CPU, memory or software architecture, but simply to point out that sufficient processing and memory capability is presently available in components sufficiently small to be completely packaged in a suitcase-sized container, including the display. As the microcomputer technology evolves over the next few years, the capabilities will grow further, while power dissipation and size shrink. Exemplary of this expectation is the Military Computer Family single-board-computer, which will execute the highly structured language Ada, have a 32-bit CPU and dissipate only 5 watts, all on a single board.

Memory

The mass storage device must be capable of storing all of the information needed for the particular task being performed, such as field testing of a piece of equipment.

In the case of automated testing of battlefield equipment, it is necessary that we have stored all of the pertinent test and diagnostic information about that system. Depending upon the complexity of the equipment to be tested and the level of testing to be performed, this information would typically occupy the equivalent of a number of field manuals, although in certain cases much less information than that would be required.

For less complex tasks, storage of the order of ½-1 megabytes (Mbytes) of information could be satisfactory. This is readily accommodated with semiconductor or magnetic bubble memory occupying the equivalent of one or two circuit boards. Because of the required versatility of the proposed equipment, it would be packaged as a plug-in module. For the more complex tasks, such as in the example given in the next section, memories in excess of 10 Mbytes could be required. This may be provided by magnetic disc technology which can now store 50 Mbytes in a 5 inch by 9 inch by 14 inch package weighing 20 pounds. Optical disc technology can store up to 500 Mbytes in a slightly larger package. Both of these technologies are evolving to smaller physical sizes in more rugged packages.

SYSTEM SOFTWARE

The software required to support this equipment falls into two categories. The first is that software which is the same, regardless of the particular applications being performed (e.g., independent of equipment being tested). When contact is made to the touch panel, the translation of that touch to an x-y coordinate is done with this type of software. Once an x-y pair is calculated, the computer can make a (control) decision based on it. The choices that the computer has to pick from may be in the form of a menu. The selection of one choice from the menu is zoned to a specific window of x-y coordinates (e.g., 50 < x < 60, 110 < y < 120 might define the PROCEED function). The definitions of these choices and their windows fall into the second category (equipment dependent).

Also in the first category (equipment independent) is the software that controls the display. As described in the hardware section above, the electroluminescent (EL) display is matrix addressed (point-by-point). In order to use the display, a means of accessing one pixel element and turning it on or off is needed. Also, a means of providing end points for line segments, and having the line appear on the display is necessary. In addition, a character set for textual messages must be provided. Because these features are required in all equipment tests, they also fall into the first category. All of the software in this category would reside in a small (approximately 8 Kbytes) amount of ROM that would be permanently placed in the unit.

The second category software depends on the particular equipment being tested, and therefore is resident in the removable storage referred to in the previous section. It could require millions of bytes. This removable software package (or personality module) would hold the data on measurements to be made, their nominal values, and the graphics of the various stages to be shown on the display, as well as the instructions indigenous to that particular piece of equipment.

SAMPLE SCENARIO

As an example of how such a system might function, we include a simulation of a possible test sequence for failure isolation in an AN/PRC-77 FM transceiver. We are assumming a direct support activity where an operator is using his suitcase-sized system to analyze the equipment being tested in a relatively hostile environment. The figures are actual photographs of the 240 by 320 flat panel display mentioned earlier. The operator turns his system on and is presented a menu selection asking him to identify (by touching the proper word) the particular unit under test (UUT). The menu selection presented to him would include whatever system software is presently in his automatic tester, or might ask him to insert a memory element corresponding to that unit. Figure 2 is a photograph of the next display to appear, which instructs the operator by words and graphically, how to connect his automatic test equipment to the UUT. When he has completed initial hookup, he is instructed to press PROCEED. In developing such a scenario, it is important to realize that there is complete flexibility as to the location and size of the "touch" boxes as well as the nature of the alphanumerics and graphics. This means that while the particular test equipment is being developed, user feedback and human factors considerations can strongly influence the final configurations without undo cost. Continuing with the scenario, Figures 3 and 4 step the operator through visual examination of filter FL3 and Terminal Block A57, as indicated by instructions and cursor. Figure 5 begins instruction on probe testing and at Figure 6, the test equipment notifies the operator that a failure has been detected and instructs him to proceed to the module level test. Not taking anything for granted, the operator is then instructed, as shown in Figure 7, how to open the defective module, and to tell the computer when he has finished this task. Figure 8 then presents to the operator, a drawing of the circuit board that he is confronted with. Subsequent frames will step him through testing the various components until the failure is localized. When it is necessary for the operator to communicate alpha symbols or numeric readings to the computer, his choice of symbols or a number pad will appear on the display, for touch interaction. Obviously, with a scheme like this, it isn't necessary for the operator to make any significant decisions, nor understand anything about ADP equipment other than the location of the on-off switch.

CONCLUSIONS

We have described the critical elements of a suitcase-sized system that could be a vital element for training and testing on battlefield automated systems. There is nothing original about the mode of operation of such a system other than the fact that it can be performed, with presently available hardware, in a very small package. With conventional technology, the display alone would occupy a larger package size. We are convinced that the hardware and operations described here can be revised many times over by interested workers, offering substantial improvements, and hope that this paper might act as a stimulus in that regard.

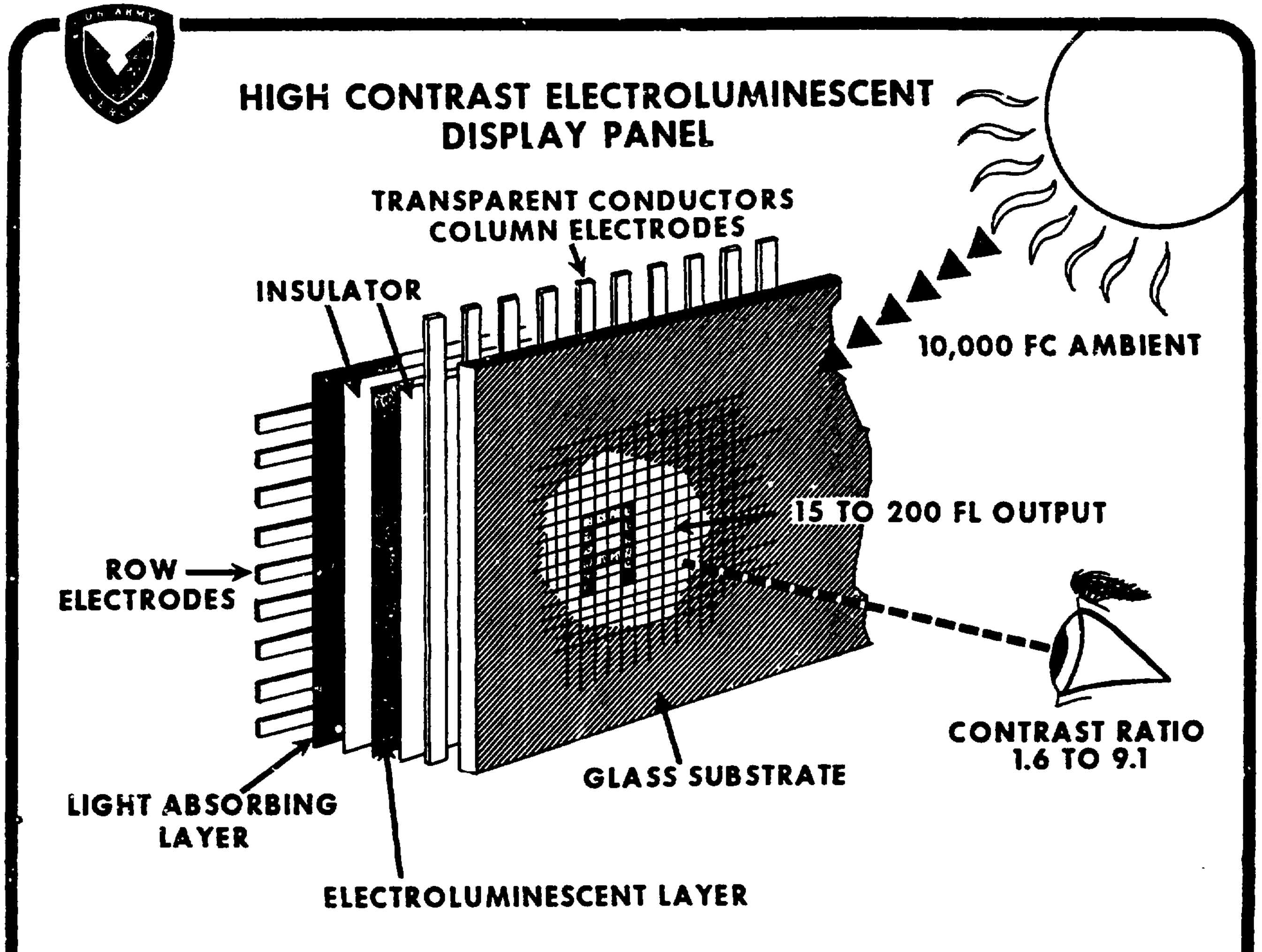
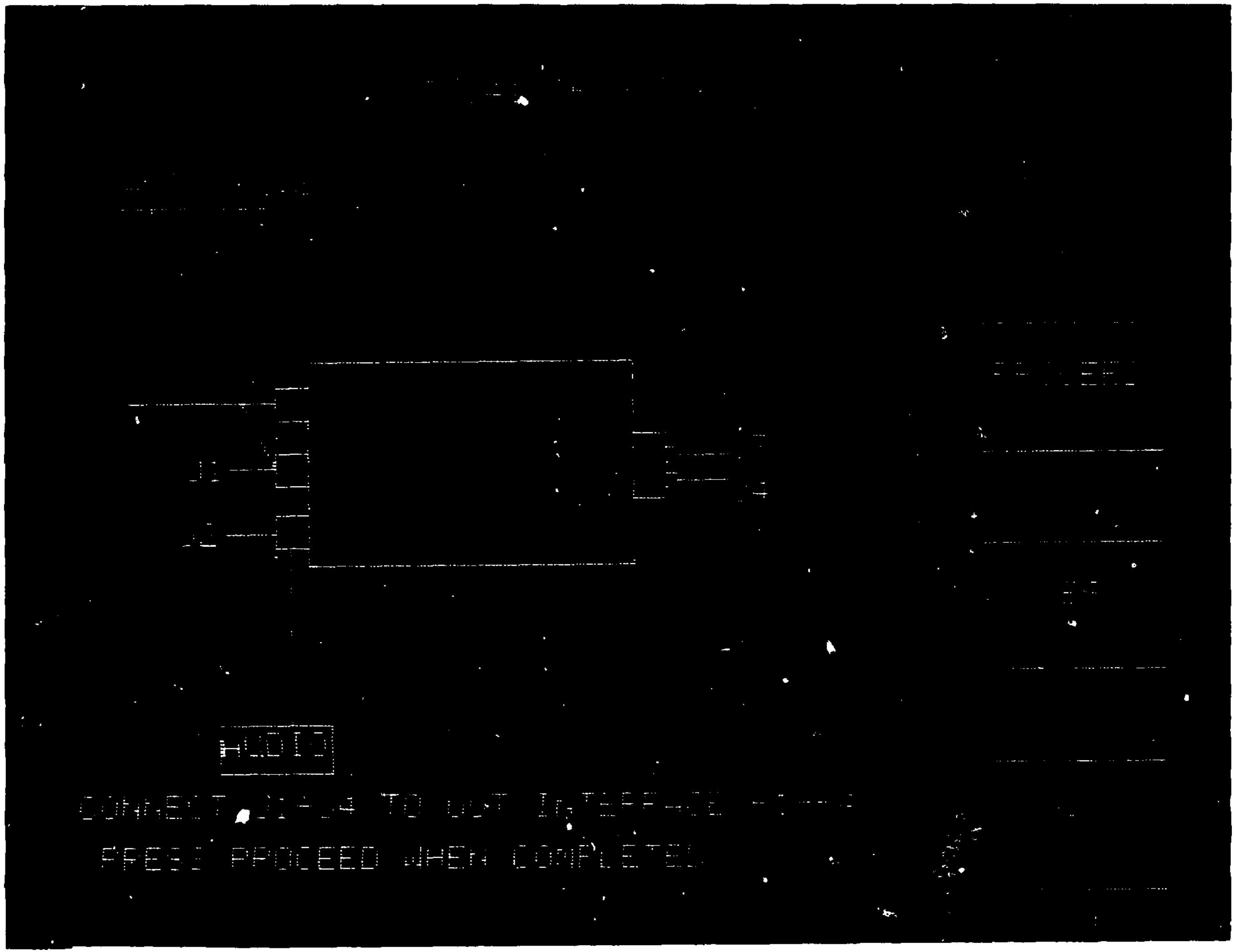


Figure 1. Cross Section of a TFEL Display



AUDIO

CONNECT [illegible] TO UUT INTERFACE [illegible]

PRESS PROCEED WHEN COMPLETED

Figure 2. Sample Scenario Frame No. 1 Connection to Tester

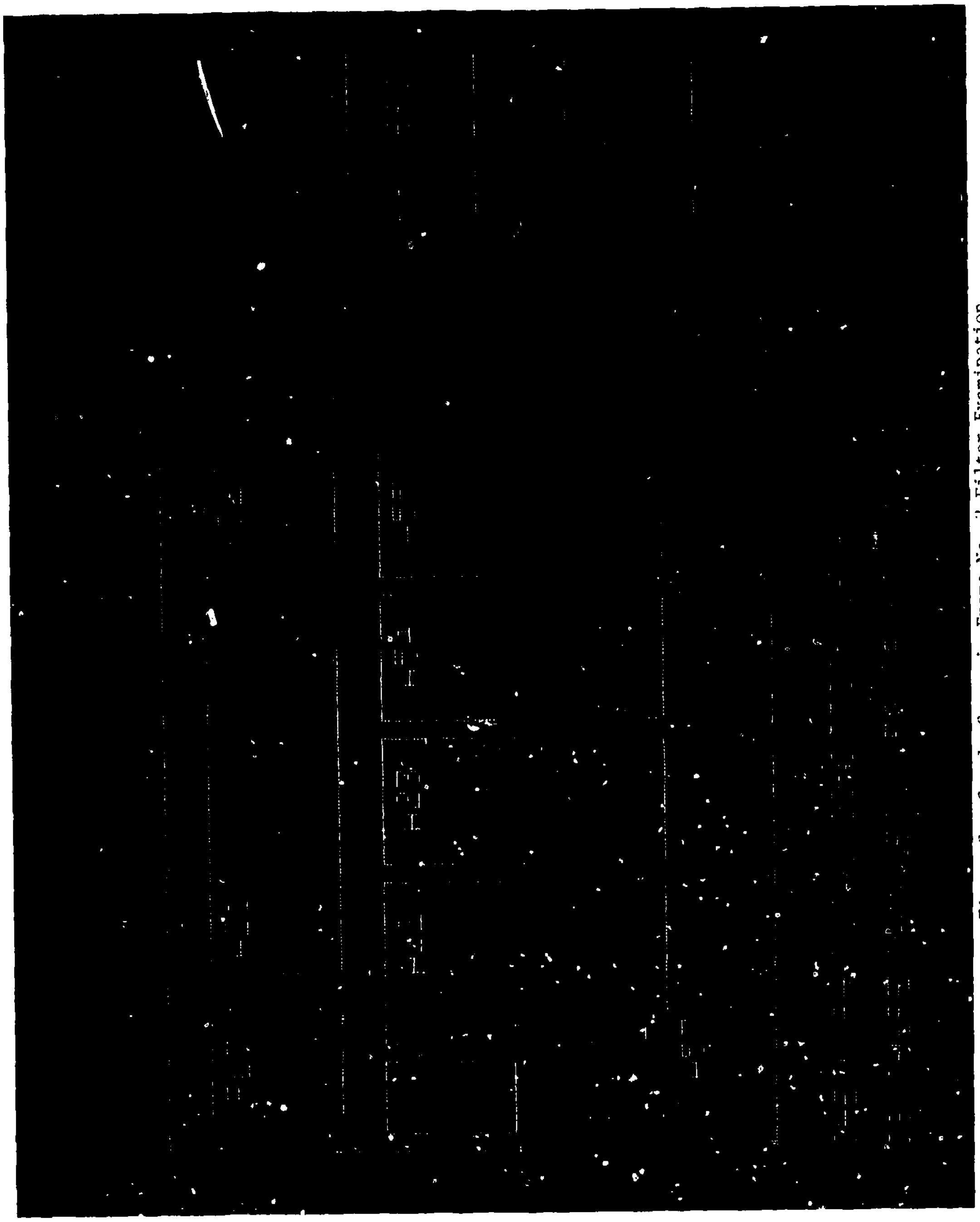


Figure 3. Sample Scenario Frame No. 2 Filter Examination

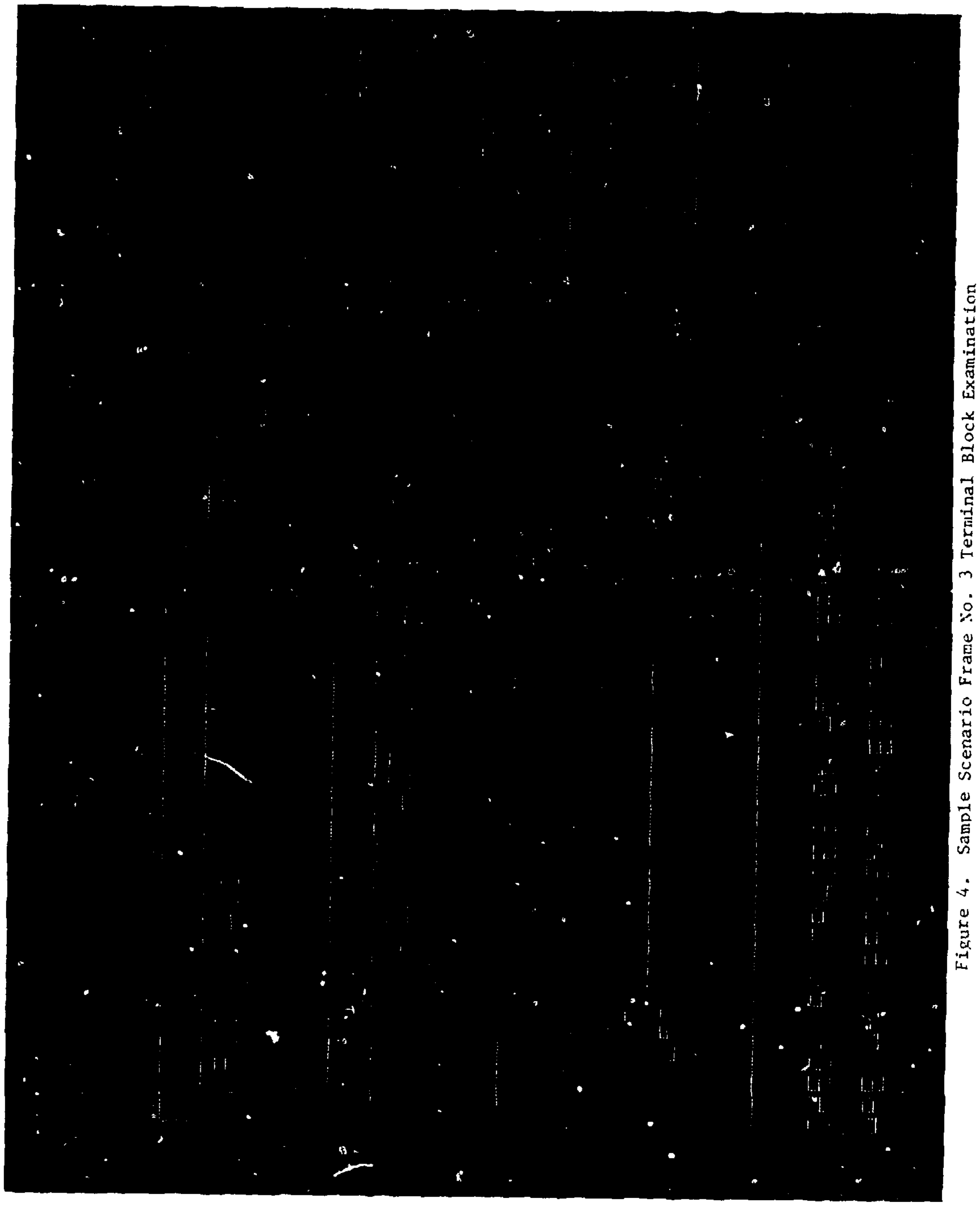


Figure 4. Sample Scenario Frame No. 3 Terminal Block Examination

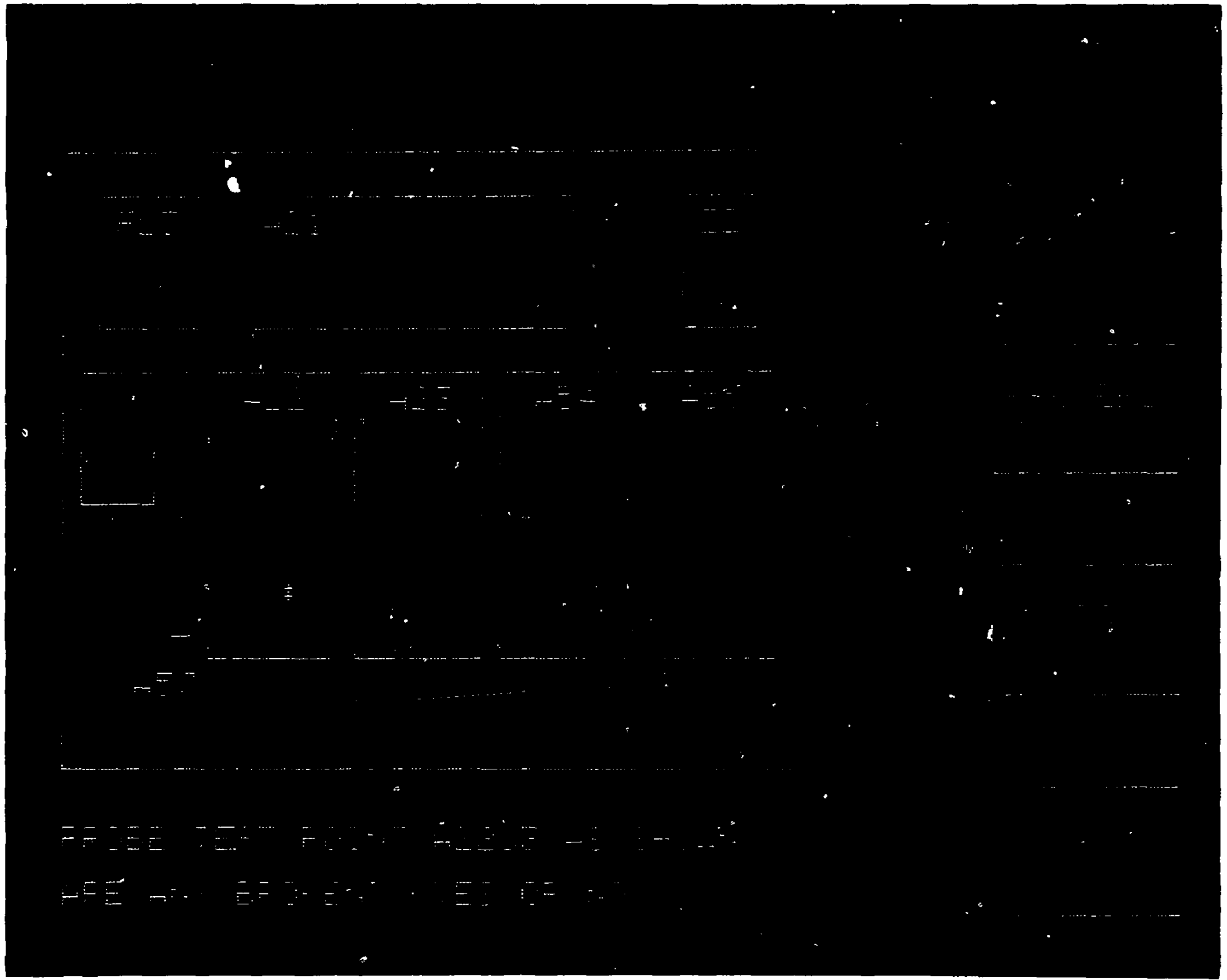


Figure 5. Sample Scenario Frame No. 4 A22 Module Test

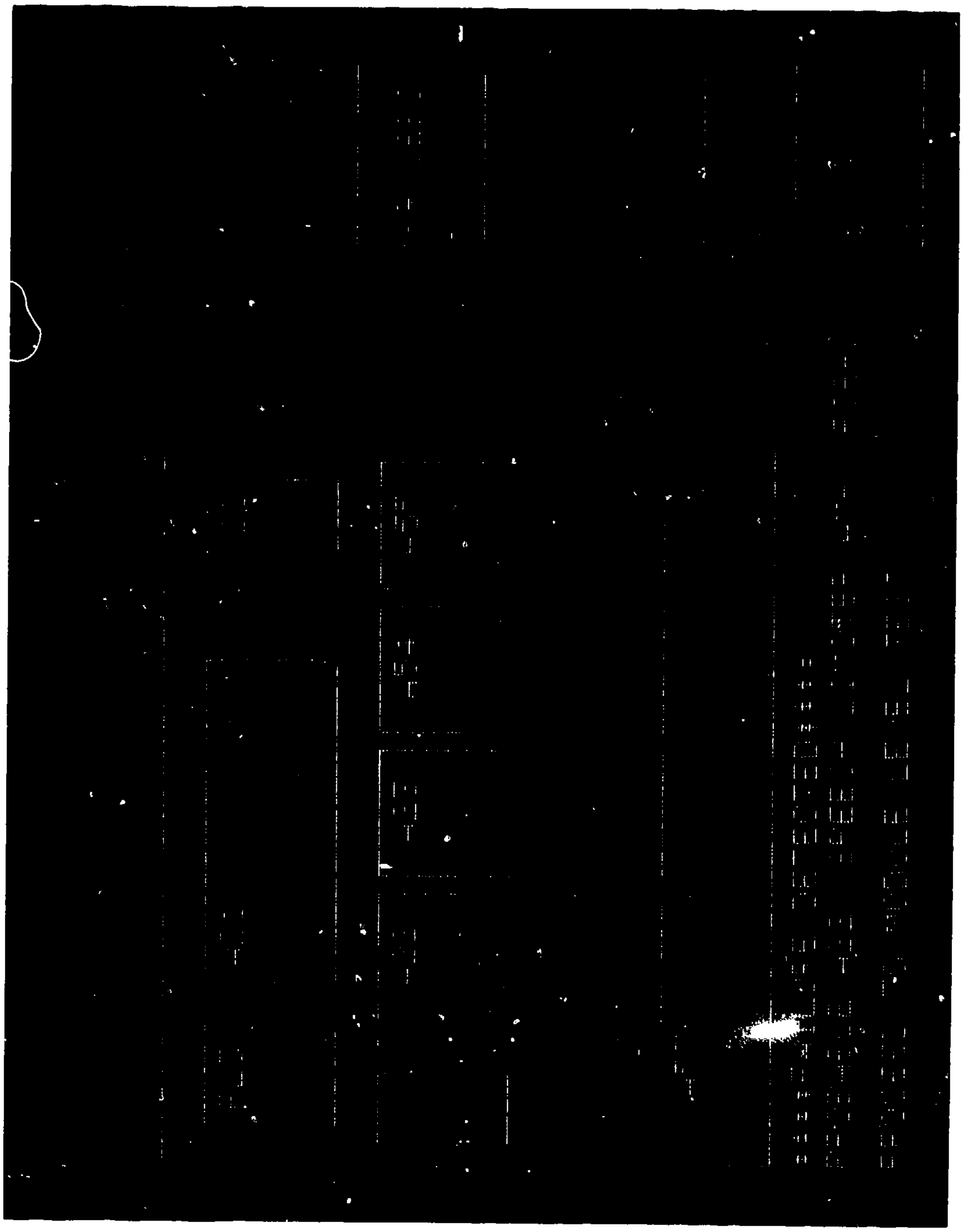


Figure 6. Sample Scenario Frame No. 5 Speech Amplifier Failure

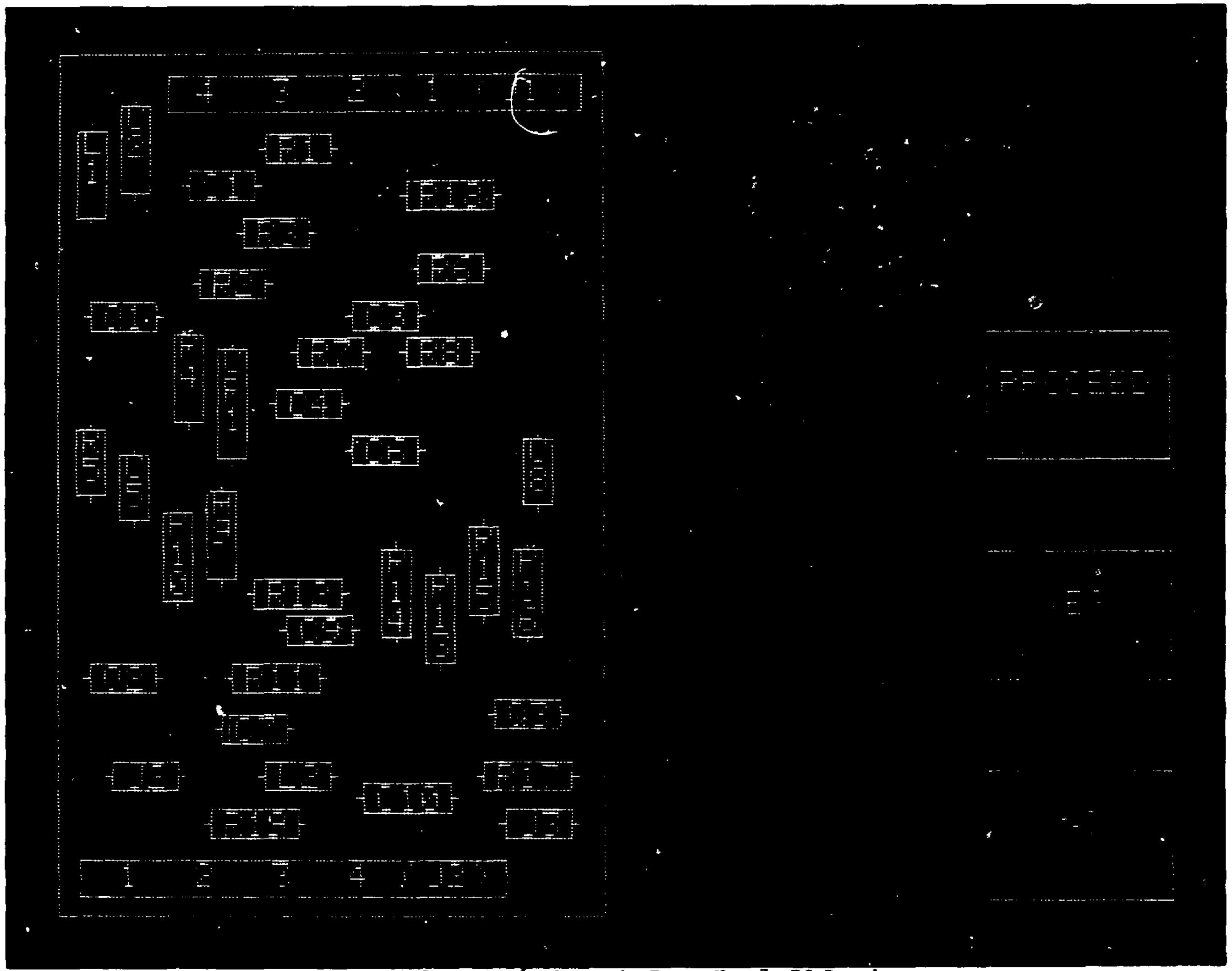


Figure 8. Sample Scenario Frame No. 7 PC Board

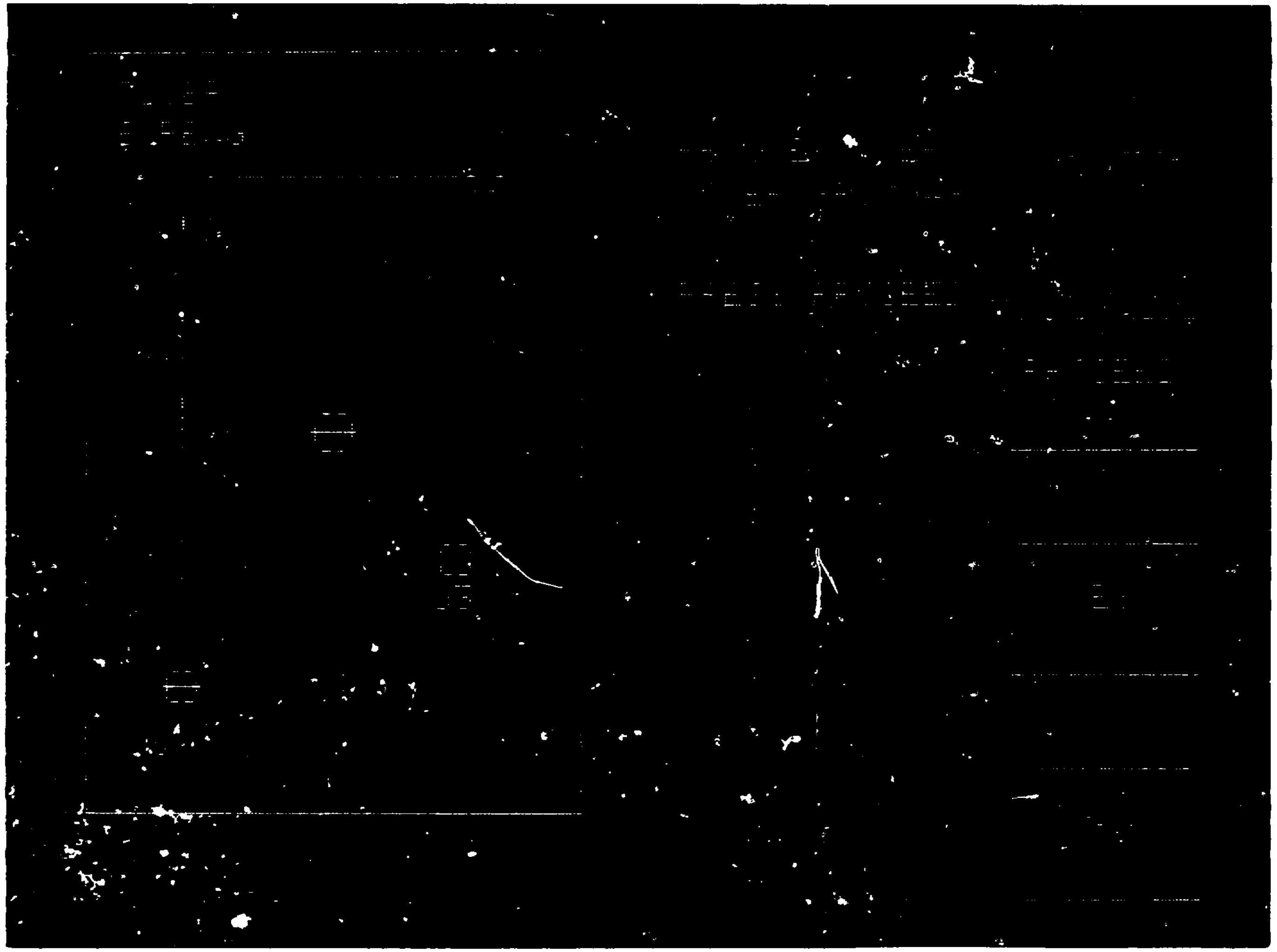


Figure 7. Sample Scenario Frame No. 6 Breakdown of A22

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ADA HIGH ORDER LANGUAGE TRAINING USING COMPUTER-BASED EDUCATION

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ABSTRACT

The Department of Defense (DOD) is spending an estimated $6 billion on software each year, and this budget is forecasted to increase by 15 to 20 percent annually. In recognition of this software cost spiral and to halt the proliferation of computer programming languages, DOD has sponsored the development of a new language--called Ada--to provide a standard, computer-independent high order language for major defense systems software. Ada is expected to have widespread application throughout DOD and will require training for thousands of individuals. Control Data is developing a solution to the Ada training problem using the Control Data PLATO® computer-based education system.

THE PROBLEM

The U.S. Department of Defense initiated Ada, the new high order language (HOL), in 1976 with the objective of eventually standardizing programming languages into one HOL. The five-year design effort involved defense departments, academia and industry from fifteen countries. Ada is currently going through American National Standards Institute procedures to become a U.S. standard and is expected to become an international standard through the International Organization for Standardization. There is widespread interest in Ada, and it is believed that a requirement for it will evolve in commercial as well as defense applications.

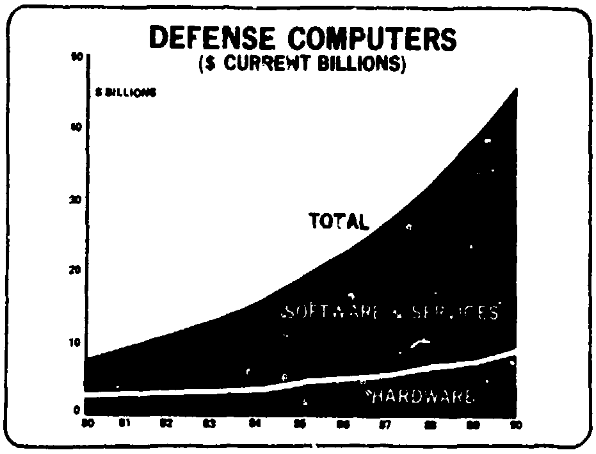

Figure 1. Software budget forecast

DOD's Software Problem

DOD is spending an estimated $6 billion on software each year and as indicated in figure 1, the software budget is forecasted to increase rapidly. (1)

In recognition of this accelerating software cost spiral, DOD established policy framework (DOD Directive 5000.29) in 1976 for advanced computer technology, including the requirement for a DOD approved HOL. The resulting development of Ada is now history, and the design of Ada culminated in the DOD "Ada Debut" on September 4, 1980.

Ada began in DOD as one of the initiatives aimed at controlling the "embedded computer" software costs. Embedded computers are those equipments procured as part of weapons systems and controlled by the DOD 5000.XX series of directives. Ada is initially being hosted on automatic data processing computers used in support of weapons systems. Furthermore, Ada is perceived as being a system design language which opens the door for training of hardware and system designers, program managers, as well as software designers.

As indicated in figure 2, the costs of computer hardware are continuing to decrease, but software costs, being labor-intensive, are rapidly increasing. A sizable portion of software life-cycle costs can be attributed to maintenance and training.

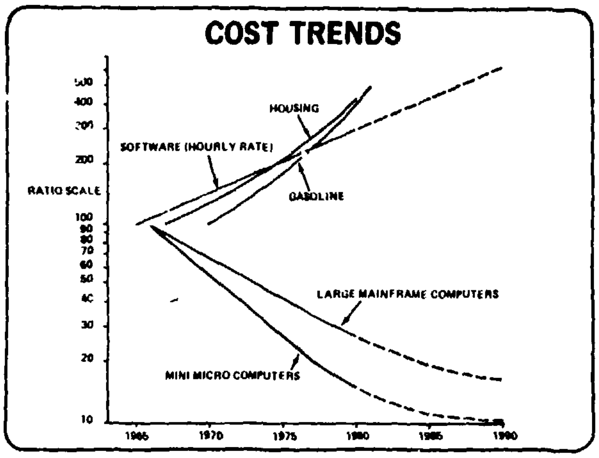

Figure 2. Hardware vs. software cost forecast

A fundamental problem confronting industry and DOD is the shortage of computer programmers. Figure 3 shows that the number of computers in the U.S. is growing much faster than the number of programmers and, unfortunately, programmer productivity is not significantly improving.

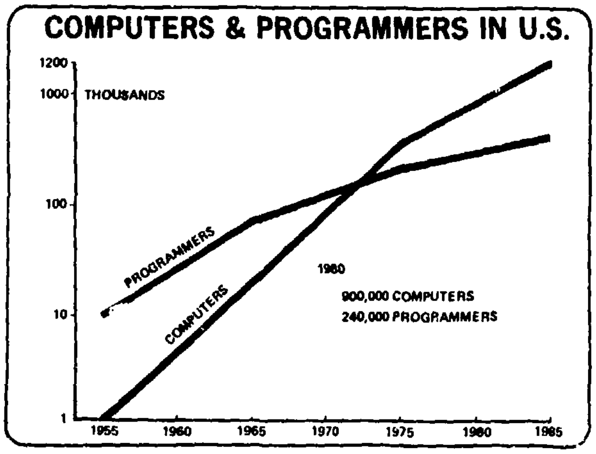

Figure 3. Growth rate of programmers vs. computers

The software labor shortfall is likely to get worse. There is an industry-wide need to recruit and train more computer people.

The Ada Training Problem

More and more computers will be used by DOD, requiring more application software. Adding this to the labor shortfall problem, and the rapidly escalating cost of software resources, makes the need for training apparent.

At least four classes of education and training are needed to successfully implement Ada throughout DOD:

1. An overview of Ada must be provided for managers and executives and as a first course for software and systems personnel.

2. A retraining course for programmers who are already knowledgeable on another HOL, such as FORTRAN, is required.

3. A complete training program from computer fundamentals through the Ada language is needed for the thousands of computer neophytes who must be trained to relieve the labor shortfall problem facing industry and DOD.

4. Unique application training on how to use the Ada HOL effectively in solving specific computer system requirements must be provided.

THE SOLUTION

Control Data is a leader in computer-based education and is currently providing hundreds of courses via the Control Data PLATO system. Control Data is planning PLATO-based courseware for Ada in three types of courses. The first will address the "whats and whys" of Ada and will culminate in an Overview of Ada course. The second course will address the "how to's" of Ada and will be a Ada Programming Fundamentals course based on the PLATO system. The third area of training will actually be a series of courses designed to provide DOD application unique training, such as "How to use Ada effectively in solving a digital signal processing problem."

These courses will satisfy the four classes of Ada training previously identified.

Individualized Instruction

Unlike traditional lecture-based instruction, where a single instructor speaks to a captive group of students, individualized instruction allows students to learn independently from sets of structured learning resources. Each learning resource is a carefully designed package of instructional materials presented by one or more types of media such as computer-assisted instruction, text, and audiovisual products (audiotapes, videotapes, filmstrips, or slide shows). These materials communicate the same knowledge presented by instructors through lectures.

Extensive research by educators and psychologists proves the importance of interaction to improve learning and strengthen retention. Multimedia individualized instruction checks students' understanding just as instructors do--by asking questions. Strategically placed questions or other response requirements elicit interactions from each student. The purpose of the interactions may be to check for understanding of concepts, require relationships to be drawn between concepts, emphasize important points, illustrate rules, or simulate procedures.

Students progress at their own rate as they work through each learning activity. Because the burden of delivering information is shifted from the instructor to the learning activities, instructors can give individual attention to each student. Instructors are freed to answer specific questions, provide encouragement, provide additional explanations to meet unique needs of individual students, and get to know each student on a personal basis. Students also receive immediate feedback on how well they are learning--they are not made to wait for quizzes given at arbitrary times whether or not they are ready.

Numerous benefits are gained from individualized instruction. Following are some of the more important benefits:

- Because students progress at their own rate, fast students are not held back and slow students do not fall behind.
- Training to the desired skill levels is more precise. Better students are not overtrained and slow students are not undertrained.
- Instructors can spend more time with students who need special assistance rather than attempting to teach to an idealized average, or slightly below average, student.
- Students are more active. They cannot sit passively while instruction goes on around them. This interaction improves learning and increases retention for each student.
- Attrition can be reduced because students are not forced to learn at an externally imposed pace they may be unable to meet. More attention can be given to specific learning problems unique to individual students; this decreases chances of failure resulting from difficulty in only one area.
- Deficiencies of the training program itself can be identified, diagnosed, and corrected quickly as a result of the concrete structure of modularized learning activities. The result is more cost-effective, efficient training.
- More precise control of training is possible because instructional materials contained in learning activities are not subject to instructors' reassignment, illness, lack of training, or forgetfulness.

In computer-managed instruction (CMI), the functions of testing, study assignments (prescriptions), and record keeping are assumed by the computer. In this application, the computer becomes a powerful tool for relieving instructors of administrative tasks. In CMI, all tests are administered on-line (on a PLATO terminal). This on-line testing enables the computer to immediately score tests, analyze item responses, and store the data in files containing complete histories of students' past performances and assignments. Decision logic tables, or algorithms, programmed into the computer can then use this pool of information to make prescriptions tailored to students' needs. These prescriptions can assign remedial work, more advanced lessons, additional tests, outside references or resources, or any one of a number of instructional alternatives desired by an instructor.

Records of learning performance stored in student data files can be examined, sorted, and arranged in any format desired by an instructor or training manager. This data may include individual scores for a given student per assignment, summary scores for all students on a given test or learning activity, number of times a particular activity is assigned, time elapsed between tests, and total hours in training.

The benefits of CMI thus lie in the precision, control, and reduced instructor burden it provides. Each assignment is constructed from a known data base. Therefore, if something is wrong with a particular assignment or test, it can be traced to the logic behind it and corrected. In traditional management modes, decisions are often based upon incomplete information or best guesses. These subjective decisions make it difficult to systematically improve a training program. A CMI program, however, can be steadily improved by building upon objective data describing each student's experience. The mass of data available can be manipulated on the computer in a matter of seconds, while it may take hours or days to do so manually. The chances of errors in transcription are also greatly reduced. This is very important when dealing with test results, where an error could mean the difference between success or failure.

In short, CMI automates most of the mechanical tasks of managing a training program. This automation not only enables instructors to spend more time with their students, it also increases control over the training environment and improves accuracy and usefulness of essential training information.

The Control Data PLATO System

The Control Data PLATO system is an interactive computer-based education system, which consists of hardware, software, a computer system, and courseware. The hardware portion consists of graphic display terminals and a communications network. The software portion runs as an application package under the control of the Network Operating System . This software supports the PLATO communications equipment, manages computer resources available at the central site, and processes all interaction between the central system and the PLATO terminal. The PLATO system runs on the CDC® CYBER 170 or CDC® CYBER 70 computer systems. Other PLATO systems, such as Micro PLATO, can be used for courseware delivery in a stand-alone mode and connected to the central PLATO system for authoring capability.

Overview of Ada

The first course, Overview of Ada, is intended to provide programmers and their managers with an understanding of the development and benefits of this new programming language. The course presents the rationale behind the design of the Ada language and a brief history of its development, as well as the economic, productivity, and reliability problems in software development. Each of the principles that were applied in an attempt to overcome the problems and produce more efficient and reliable software development is explained, along with some of the language features that were developed to achieve these principles. The purpose of this course is to introduce the Ada language so that it is viewed as a viable alternative to other programming languages.

The introduction illustrates the current economic problems faced in software development and shows why the design and development of a new language were undertaken. It highlights the history of the language, touching on key events and emphasizing the computing principles that were applied in this effort to provide greater productivity and reliability through the use of a new language.

The course explains each of these computing principles intuitively, illustrating how its application can facilitate software development. The features designed to support the principle are also presented. For example, modularity is one of the principles that was applied in the design of the Ada language. The concept of modularity is discussed, and the language feature--packages--that supports this principle is presented, along with the benefits that packages provide, such as permitting the division of labor and providing more readable code.

The course discusses other principles including reusable software, separate compilation, tasking, and strong typing. The features that were incorporated in the language to achieve these principles are also presented.

Finally, there is a discussion of the rationale for the design and development of an Ada environment. The functions that the Ada Programming Support Environment will provide and the different levels of the environment are explained.

Ada Programming Fundamentals

The second course, Ada Programming Fundamentals, is intended to provide the experienced programmer with an introduction to the Ada language. Overview of Ada is a prerequisite to this course, providing a background in the basic concepts underlying the language. The purpose of Ada Programming Fundamentals is to teach the Ada language to experienced programmers in a manner that achieves the full benefits of the new language. Teaching the syntax of the Ada language is not adequate preparation for programming with the language. Instead, many programmers need to learn a new discipline of designing and developing programs to achieve the desired benefits from the language.

The use of a top-down modular approach in designing programs enhances the effective use of the Ada programming language. A section of this course discusses top-down modular design of Ada programs and the use of the limited set of structured control structures in designing algorithms. The remainder of the course emphasizes these approaches.

The intention of this course is to provide the experienced programmer with a working knowledge of the Ada language, so that it is possible to use it to write programs. The course is not intended to cover all variations of every language feature, but instead prepares the programmer for getting started using the language.

An Example of a PLATO Course

The addendum to this paper contains screen prints made directly from the PLATO terminal showing a lesson sequence from the Ada Programming Fundamentals course. The lesson is on the Ada "IF" statement and the screen prints show the following:

- Lesson title
- Objectives for the lesson
- Flow charts of control selection
- Explanation of "IF" statement syntax
- Example of "IF" statement
- Exercise using "IF" statement

The use of PLATO graphics greatly enhances the learning potential of the CRT, or display, terminal by providing a "picture drawing" tool for the author. Students assimilate new concepts more effectively through graphics combined with text.

References

(1) Figures 1, 2, and 3 are from the DOD Digital Data Processing Study performed by an industry team chaired by Mr. David G. Stephan, Control Data Corporation, Minneapolis, Minnesota. The study was performed under the auspices of the Electronic Industries Association.

ABOUT THE AUTHORS

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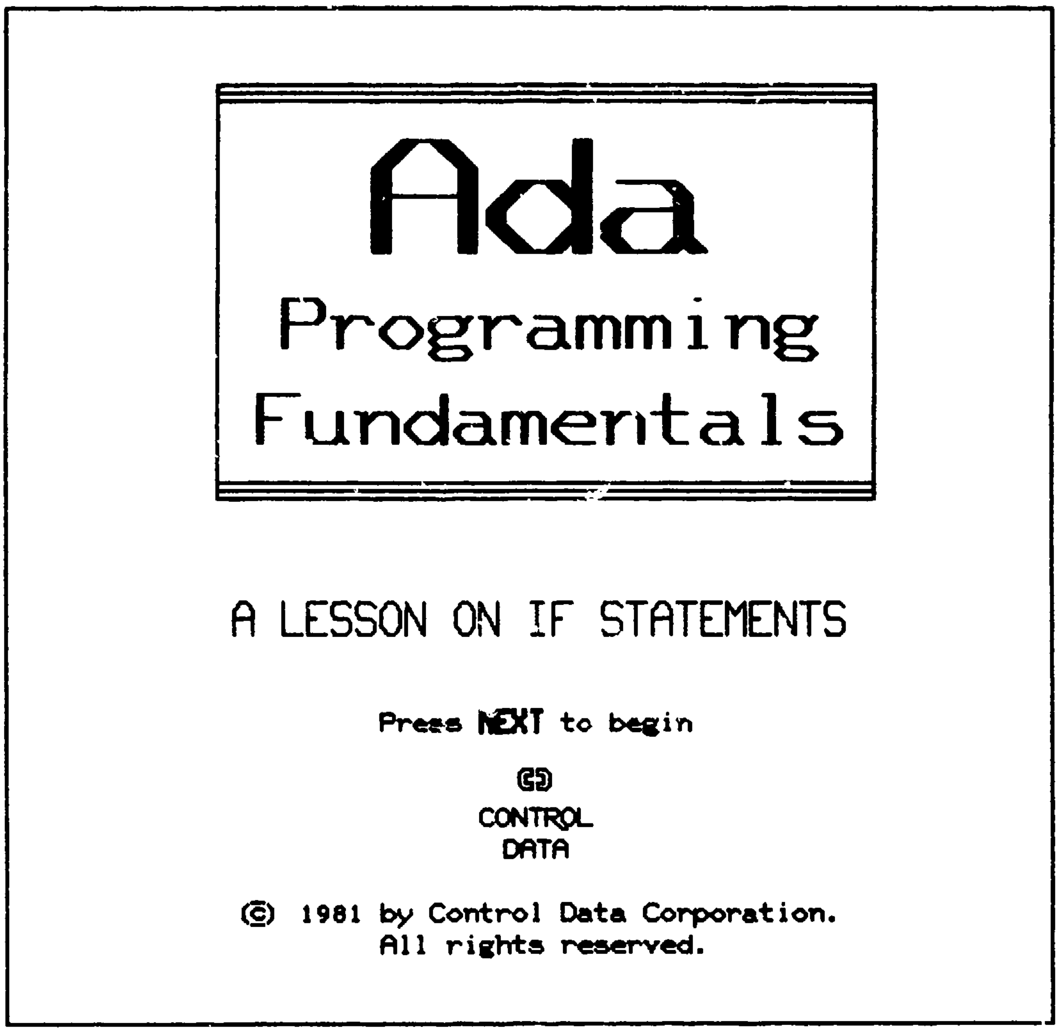
Responsible for Control Data's Ada program.

Mr. Charles B. Johnston,
Control Data Corporation.
Responsible for designing the Ada courseware on Control Data's PLATO system.

Screen Print 1: Lesson title



Ada

Programming Fundamentals

A LESSON ON IF STATEMENTS

Press NEXT to begin

CONTROL
DATA

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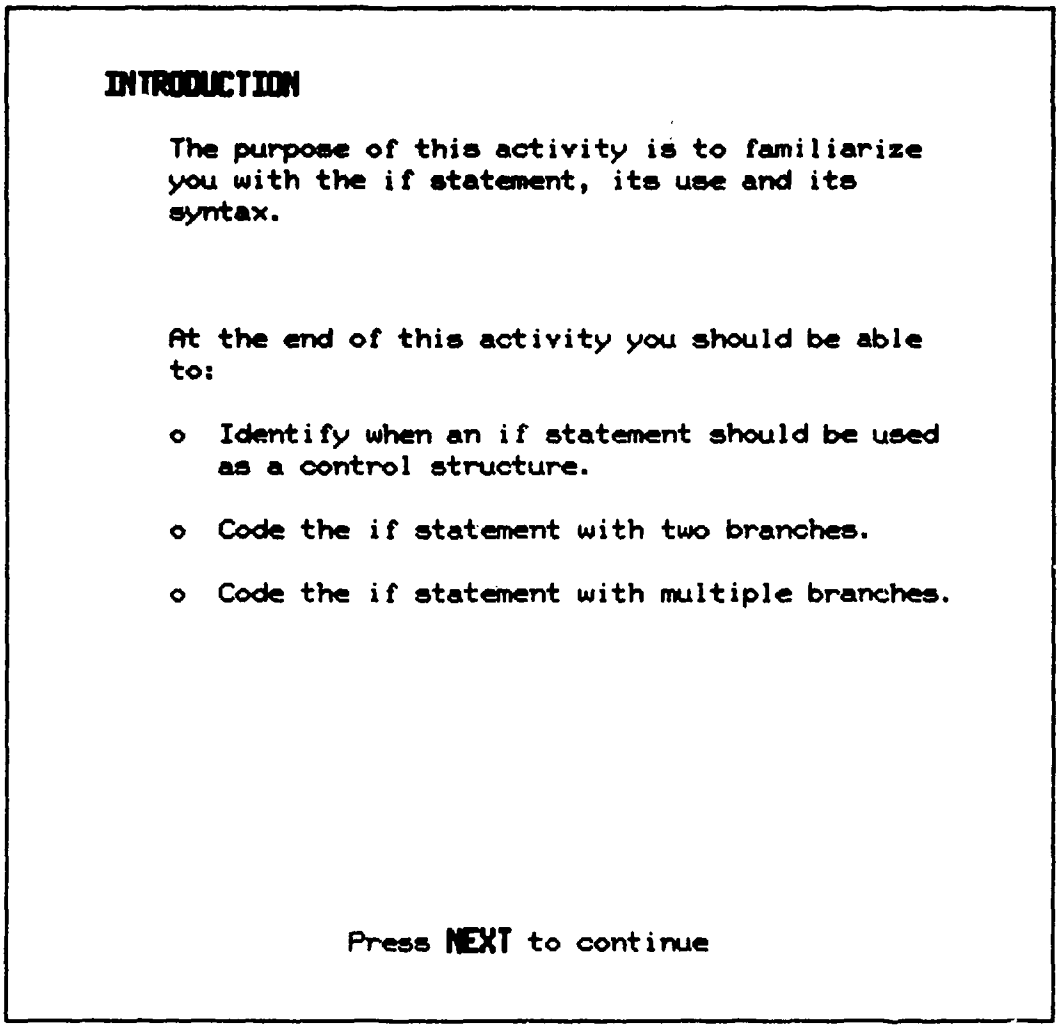
Screen Print 2: Objectives for the lesson



INTRODUCTION

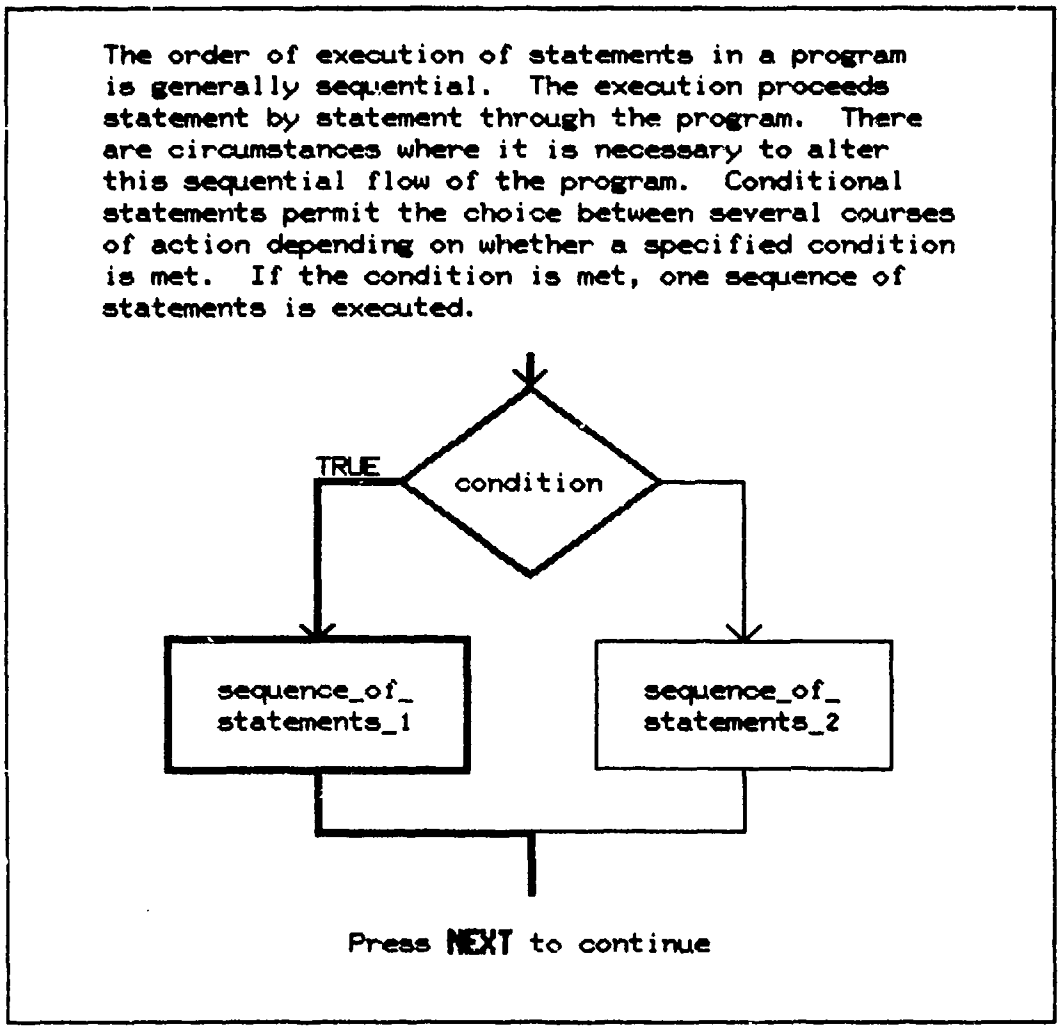
The purpose of this activity is to familiarize you with the if statement, its use and its syntax.

At the end of this activity you should be able to:

- Identify when an if statement should be used as a control structure.
- Code the if statement with two branches.
- Code the if statement with multiple branches.

Press **NEXT** to continue

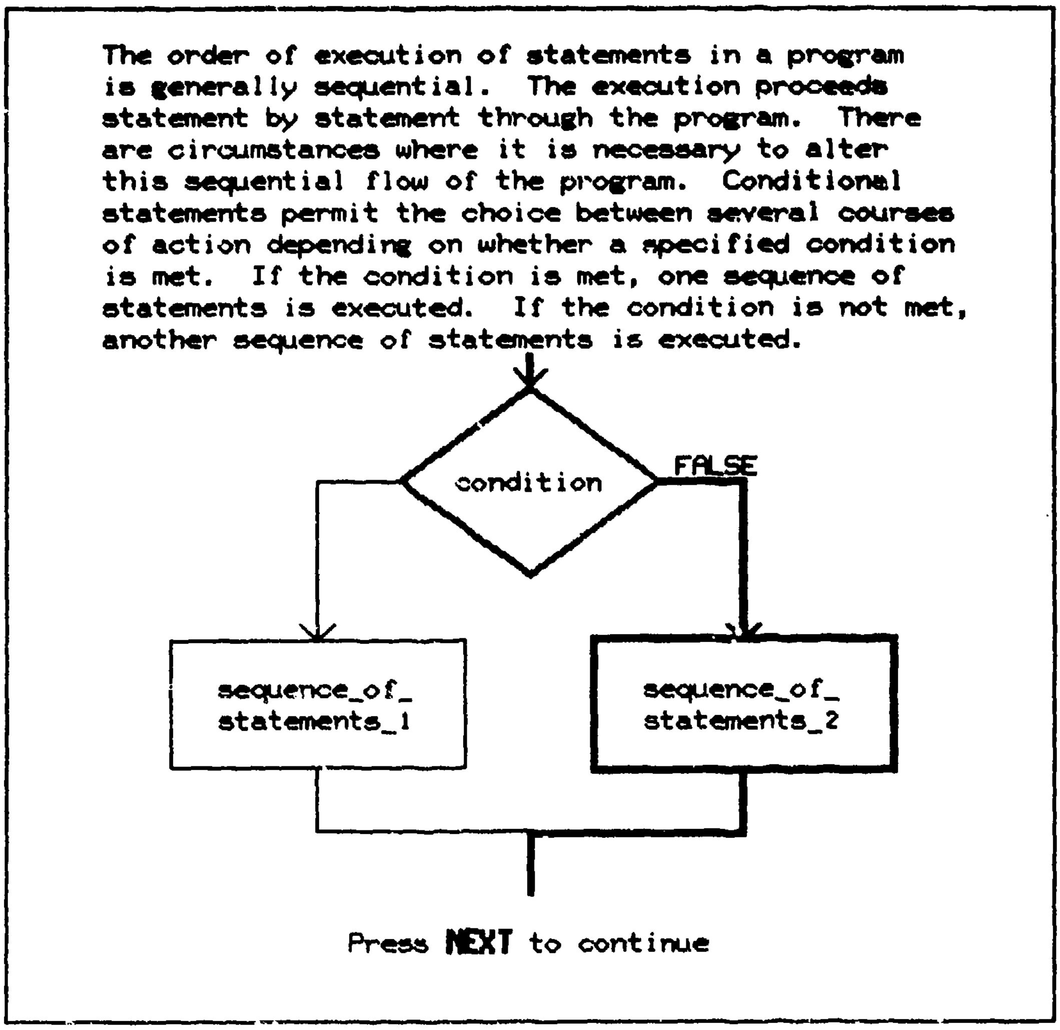
Screen Print 3, Display 1: Flow charts of control selection



The order of execution of statements in a program is generally sequential. The execution proceeds statement by statement through the program. There are circumstances where it is necessary to alter this sequential flow of the program. Conditional statements permit the choice between several courses of action depending on whether a specified condition is met. If the condition is met, one sequence of statements is executed.

Press **NEXT** to continue

Screen Print 3, Display 2



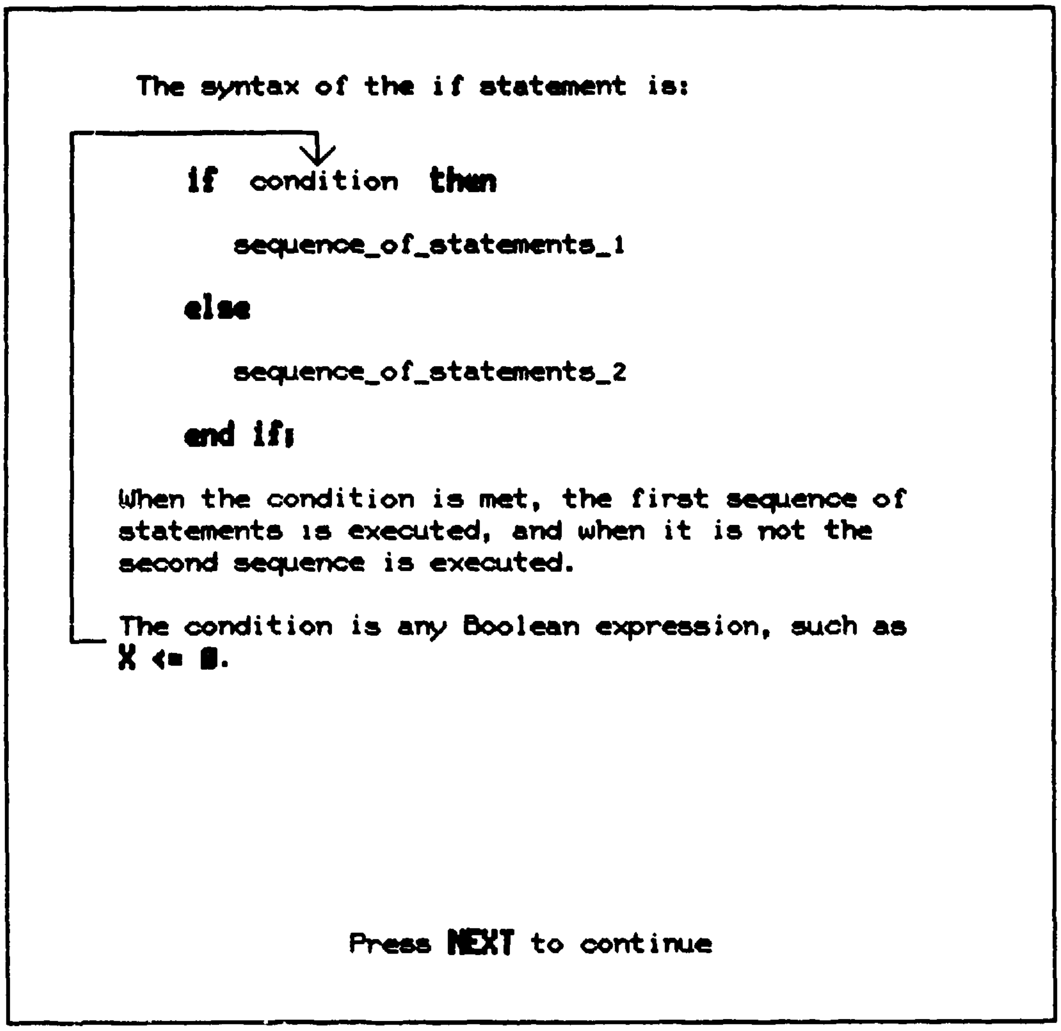
The order of execution of statements in a program is generally sequential. The execution proceeds statement by statement through the program. There are circumstances where it is necessary to alter this sequential flow of the program. Conditional statements permit the choice between several courses of action depending on whether a specified condition is met. If the condition is met, one sequence of statements is executed. If the condition is not met, another sequence of statements is executed.

Press **NEXT** to continue

Display 2 adds this sentence.

Display 2 lightens the left side of figure and darkens the right side to correspond with new information.

Screen Print 4: Explanation of "IF" statement syntax



The syntax of the if statement is:

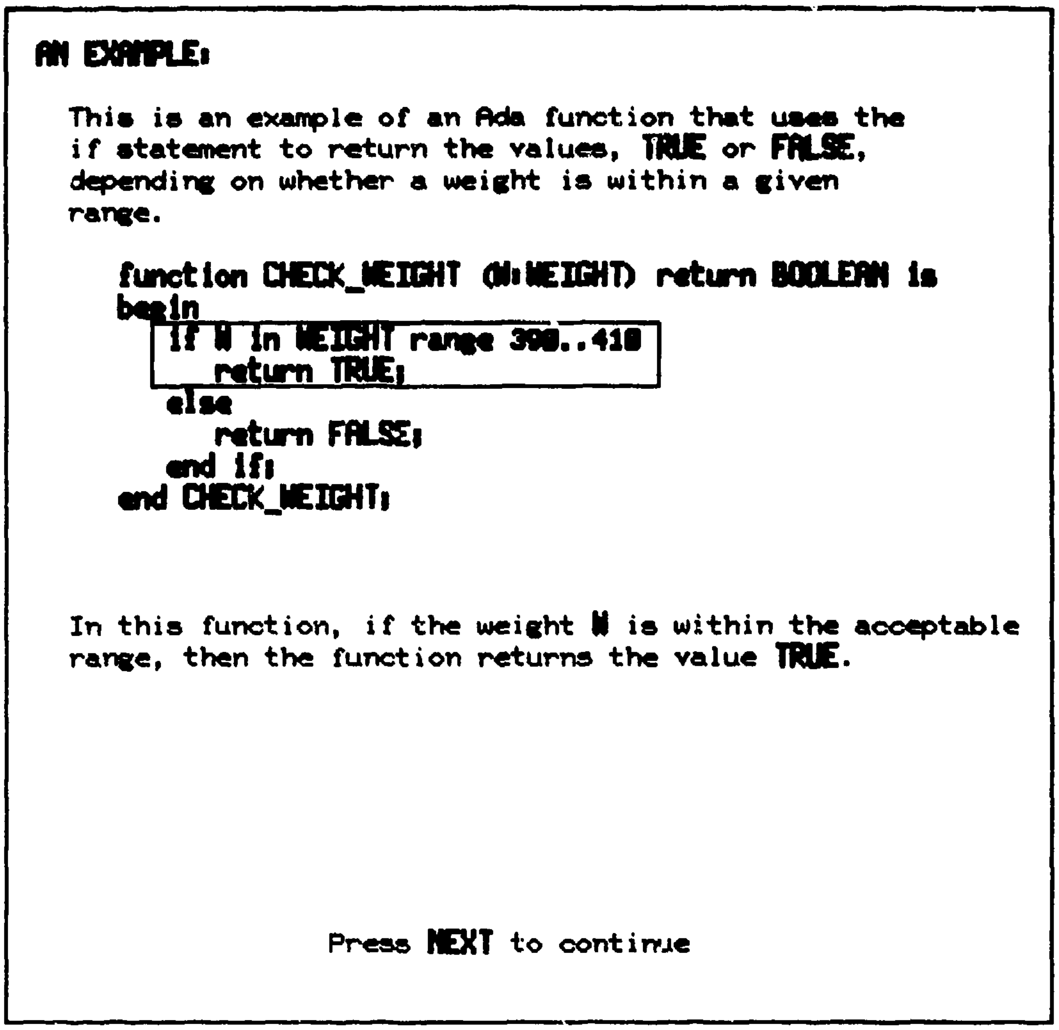
```
if condition then
   sequence_of_statements_1
else
   sequence_of_statements_2
end if;
```

When the condition is met, the first sequence of statements is executed, and when it is not the second sequence is executed.

The condition is any Boolean expression, such as **X <= 0**.

Press **NEXT** to continue

Screen Print 5, Display 1: Example of "IF" statement



AN EXAMPLE:

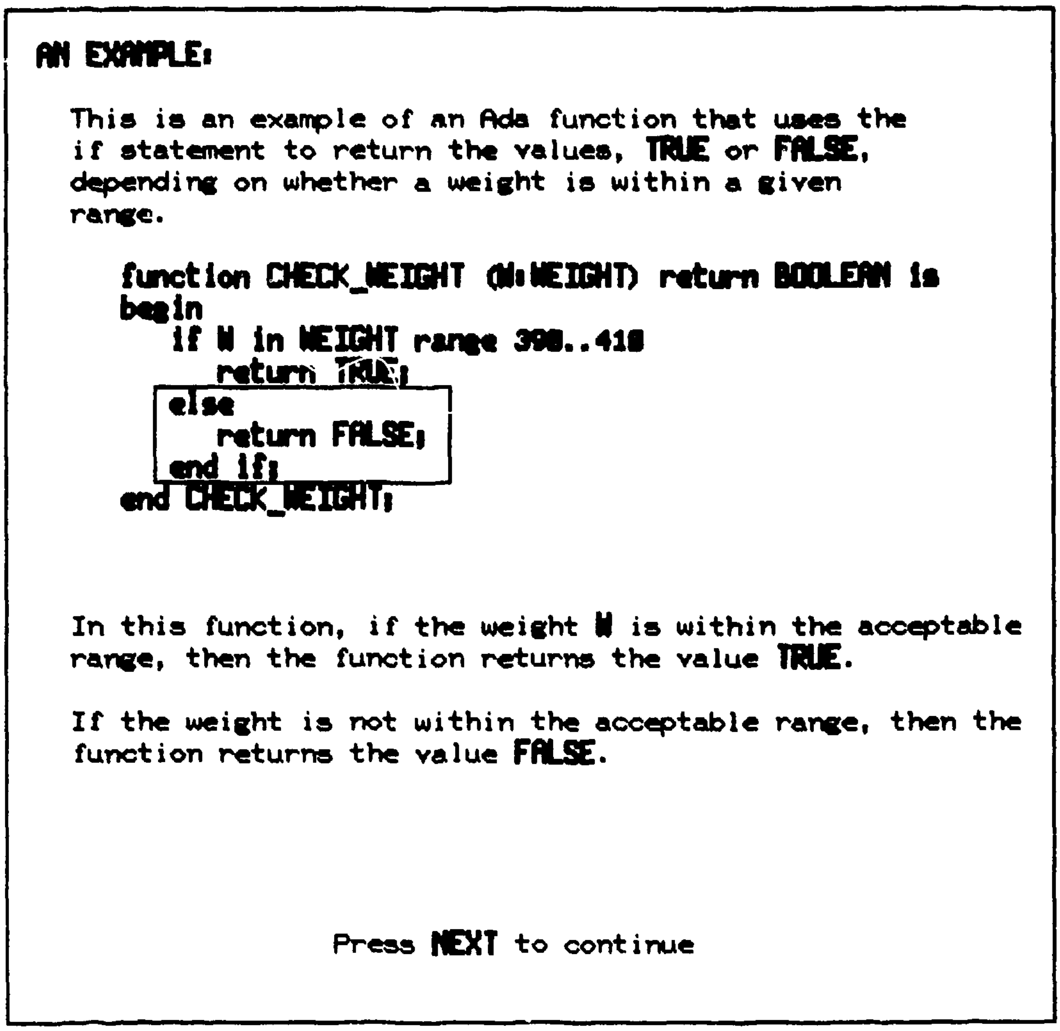
This is an example of an Ada function that uses the if statement to return the values, **TRUE** or **FALSE**, depending on whether a weight is within a given range.

```
function CHECK_WEIGHT (W:WEIGHT) return BOOLEAN is
begin
   if W in WEIGHT range 390..410
      return TRUE;
   else
      return FALSE;
   end if;
end CHECK_WEIGHT;
```

In this function, if the weight **W** is within the acceptable range, then the function returns the value **TRUE**.

Press **NEXT** to continue

Screen Print 5, Display 2



AN EXAMPLE:

This is an example of an Ada function that uses the if statement to return the values, **TRUE** or **FALSE**, depending on whether a weight is within a given range.

```
function CHECK_WEIGHT (W:WEIGHT) return BOOLEAN is
begin
   if W in WEIGHT range 390..410
      return TRUE;
   else
      return FALSE;
   end if;
end CHECK_WEIGHT;
```

Display 2 removes first box and then boxes the lower information.

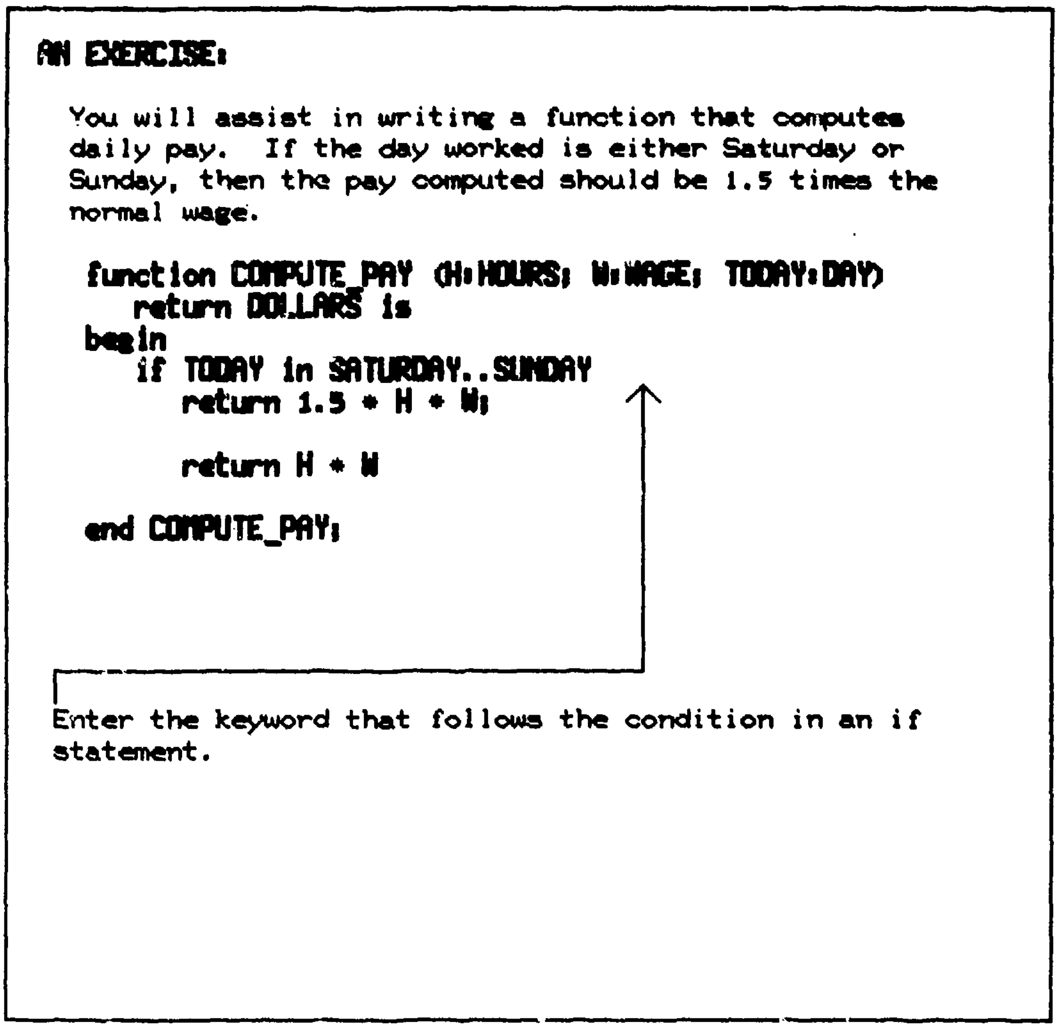
In this function, if the weight **W** is within the acceptable range, then the function returns the value **TRUE**.

If the weight is not within the acceptable range, then the function returns the value **FALSE**.

Display 2 adds this sentence.

Press **NEXT** to continue

Screen Print 6, Display 1: Exercise using "IF" statement



AN EXERCISE:

You will assist in writing a function that computes daily pay. If the day worked is either Saturday or Sunday, then the pay computed should be 1.5 times the normal wage.

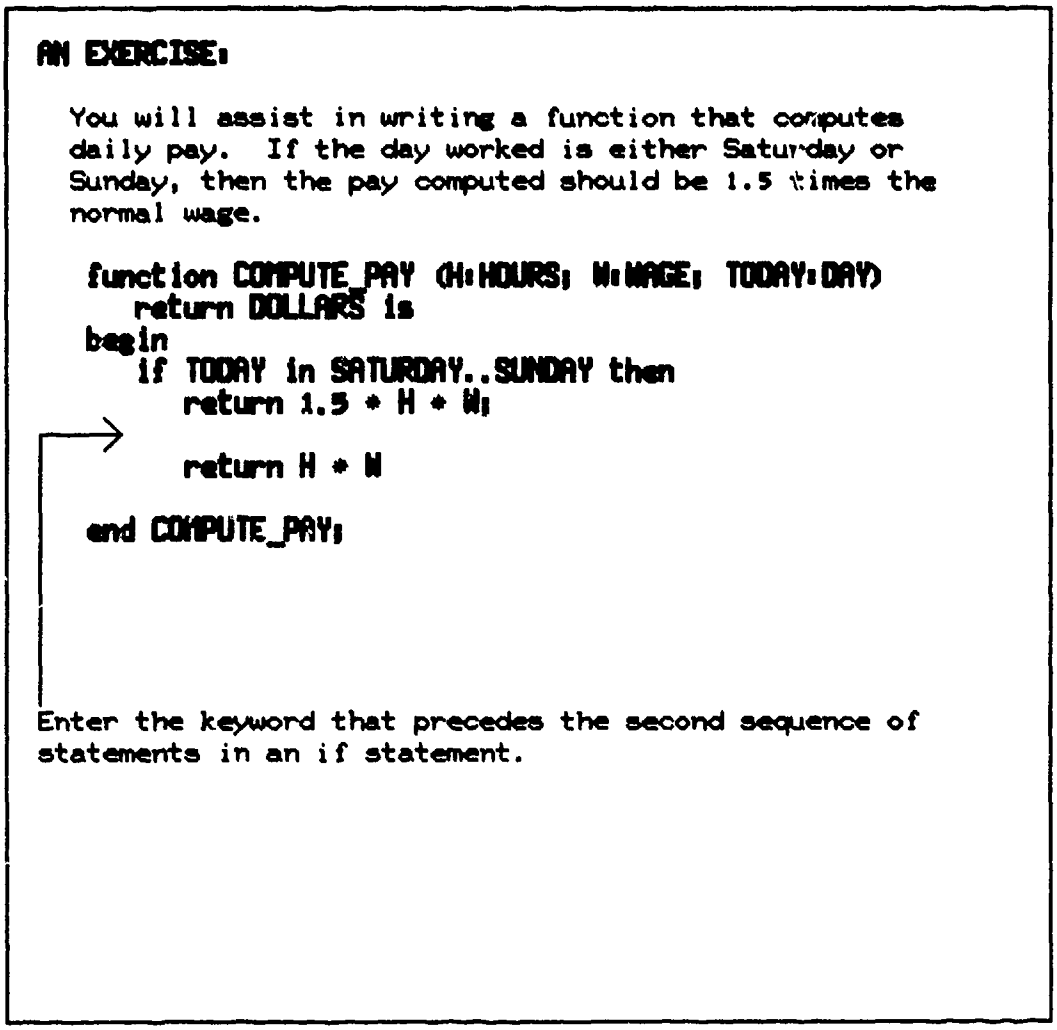
```
function COMPUTE_PAY (H:HOURS; W:WAGE; TODAY:DAY)
   return DOLLARS is
begin
   if TODAY in SATURDAY..SUNDAY
      return 1.5 * H * W;

      return H * W

end COMPUTE_PAY;
```

Enter the keyword that follows the condition in an if statement.

Screen Print 6, Display 2



AN EXERCISE:

You will assist in writing a function that computes daily pay. If the day worked is either Saturday or Sunday, then the pay computed should be 1.5 times the normal wage.

```
function COMPUTE_PAY (H:HOURS; W:WAGE; TODAY:DAY)
   return DOLLARS is
begin
   if TODAY in SATURDAY..SUNDAY then
      return 1.5 * H * W;

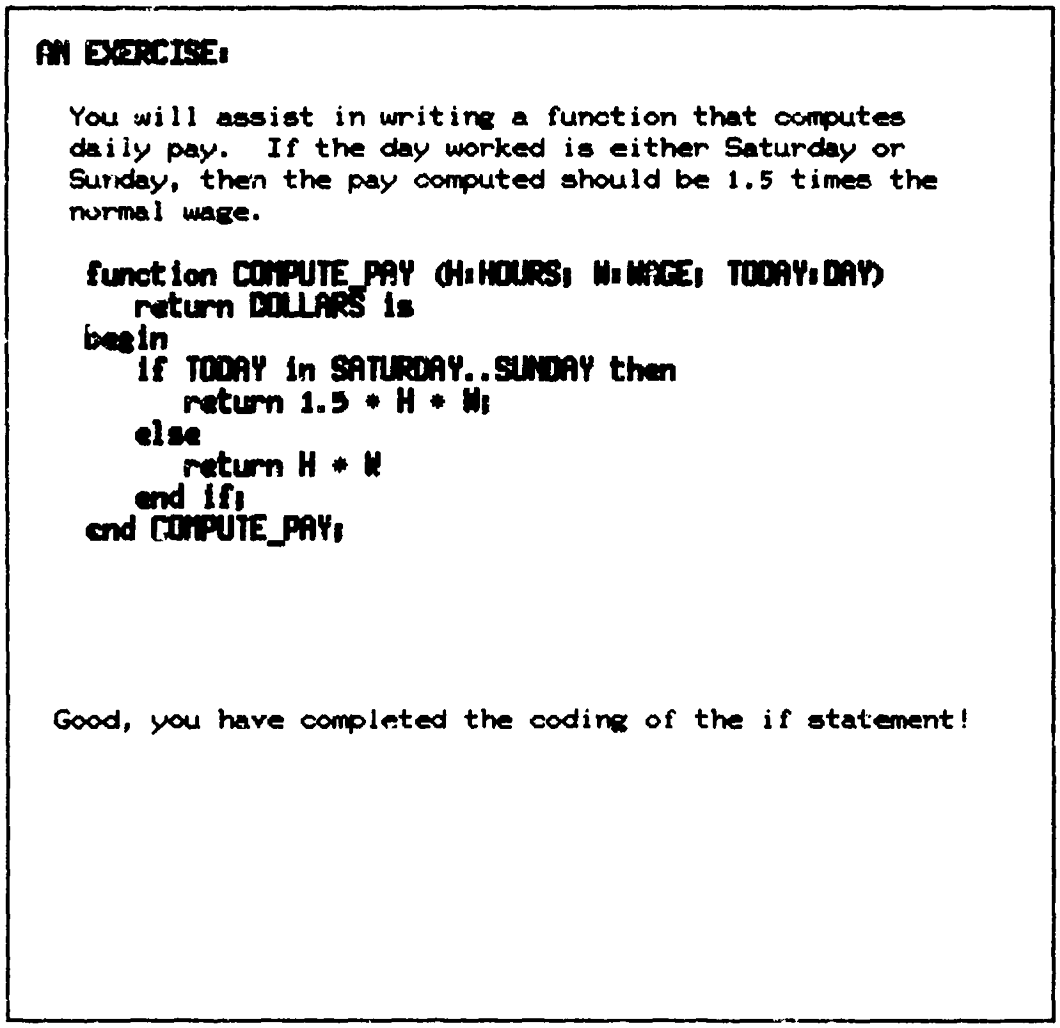
      return H * W

end COMPUTE_PAY;
```

Enter the keyword that precedes the second sequence of statements in an if statement.

Upon completion of first direction, second direction appears.

Screen Print 6, Display 3



AN EXERCISE:

You will assist in writing a function that computes daily pay. If the day worked is either Saturday or Sunday, then the pay computed should be 1.5 times the normal wage.

```
function COMPUTE_PAY (H:HOURS; W:WAGE; TODAY:DAY)
   return DOLLARS is
begin
   if TODAY in SATURDAY..SUNDAY then
      return 1.5 * H * W;
   else
      return H * W
   end if;
end COMPUTE_PAY;
```

Good, you have completed the coding of the if statement!

Feedback for correct answer appears.

SOFTWARE/HARDWARE INTEGRATION - "THE MOMENT OF TRUTH"

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ABSTRACT

Integration of system software and hardware is without a doubt the system development activity which enjoys the greatest management visibility. It is during this phase of system development that past sins of superficial analysis and design of both software and hardware surface to be seen by all and where system completion often appears to follow an asymptotic course to infinity.

This paper provides a brief summary of the software development practices followed in implementing the software for the Multi-Environment Trainer (MET), a complex multi-computer naval ship trainer, and an in-depth discussion of the procedures used to direct the day-to-day software/hardware integration activity. Actual experiences, good and bad, are discussed and findings expressed in terms of problem solutions and recommendations.

INTRODUCTION

System Description

The MET system is a tactical team/subteam trainer designed to simulate multiple-ship tactical operations. The functions being simulated span the under sea, surface and air environments and include operations in the Bridge, Combat Information Center and Sonar areas. The MET trainer is designed about the use of eight computers (SEL 32/75) configured in two groups of four processors, see Figure 1. Each group of four computers performs a set of dedicated functions in real-time which simulate the operation of a single PCG or PGG class ship. Data exchange among the eight computers is accomplished via a block of shared memory, while access to required peripherals is controlled by a program directed peripheral switch.

Software Description

The MET software architecture is characterized by five subsystem areas: Master Control, Passive Sonar, Active Sonar, Radar and Off-Line Processes. The first four subsystem areas represent the real-time portion of the MET software which resides in each of the two sets of four MET computers. The remaining software, which does not execute in real-time, is referred to as Off-Line Processes and includes such programs as Diagnostics, Daily Readiness, Data Base Generators,etc. Execution of the MET software resident in each computer is directed by a simulation executive which operates under control of the SEL Real-Time Monitor (RTM) operating system. Computations performed by all of the MET computers generate values which contribute to a large and resonably complex system data base which is made available to each of the processors in real-time. The MET programs, with very few exceptions, have all been written using FORTRAN-77.

One of the more challenging aspects of the MET software has been the fact that it interacts with a large complement of operational shipboard equipment, e.g. ship control consoles, sonar control consoles, bathythermographic and depth recorders, torpedo, MK-75 gun and Phalanx fire control consoles, SPS-40B and 55 radar consoles, MK-92 fire control consoles and various and sundry analog, synchro and discrete devices.

Software Status

At the time of this writing, implementation of the MET software has been completed and all program modules have been unit-tested and submitted for integration. The software/hardware integration activity is in its final stages and the system is rapidly approaching customer acceptance testing.

SOFTWARE DEVELOPMENT

Software Concepts

Before getting into the discussion of software/hardware integration, which is the principal topic of this paper, I believe it will be germane to the discussion to briefly review the procedures which were adopted and enforced during the MET software design and implementation phases. Software development was accomplished by establishing Chief Programmer Teams for each of the five subsystem areas. Each of the teams was fully responsible for the design, implementation and test of all the software required by a particular subsystem and each contributed one or two of its members to participate on the software/hardware integration team.

Development of the software was predicated upon the preparation of a Unit Development Folder (UDF) for each unit of code generated. The basic unit of code on MET was the Computer Program Module (CPM). The UDF served as the central historical source of development information for a given CPM and the basis from which contract deliverable documents were prepared.

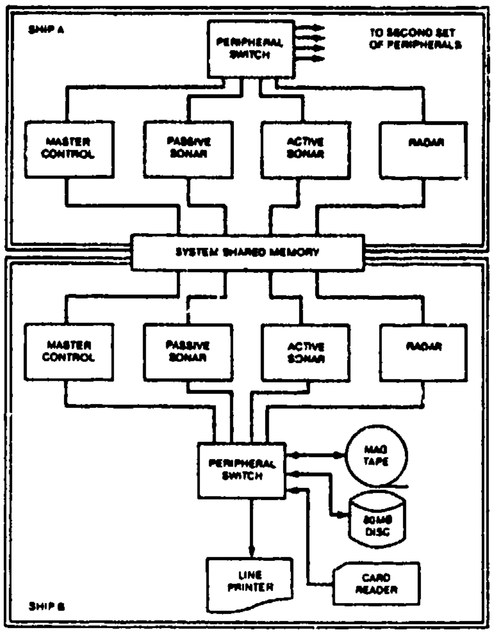

Figure 1 Met Computer System Configuration

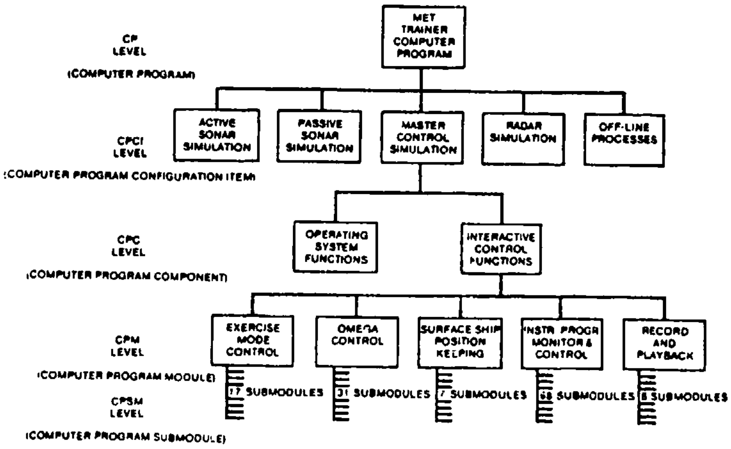

Figure 2 Met Software Work Breakdown Structure

The MET software design was developed hierachically from the top down in accordance with a software work breakdown structure of five levels. These levels satisfied the objectives of grouping related functions and identifying units of code down to the lowest level controlled. Figure 2 illustrates the structure of MET software and expands one of its subsystem areas.

Program modules and submodules were made to satisfy stringent conditions of size (200 FORTRAN statements or less), function, testability and reference to specific requirements in the contract specification. All were written using FORTRAN-77, which includes the structured programming language constructs of IF, THEN, ELSE, DO UNTIL, DO WHILE etc., which contributed to the generation of clear, easy to follow code.

Software Design

The software design was accomplished by the preparation of five basic documents which defined the system performance, design and implementation specifications. These documents were utilized as the basis for the conduct of the Preliminary and Critical design reviews. The five documents in question were:

Program Performance Specification (PPS) - The PPS document was based upon an analysis of the contract specification and described the functions to be performed by the system. This description included the equations/algorithms which were to be implemented to simulate real-time functions and the performance characteristics/operational ranges of these functions. Data Input/Output diagrams were included to illustrate the flow of inputs to and outputs from the various system function modules.

Interface Design Specificaton (IDS) -The IDS document was based upon the PPS, the contract specification and a description of the system hardware. The IDS described in detail the flow and content of signals and data messages passing between the digital computer processors which comprised the system.

Program Design Specification (PDS) -The PDS document was based upon the IDS, which defined the data interfaces between the digital processors in the system, and the PPS, which specified all of the functions to be performed by the system. The PDS provided a description of how the system being designed would satisfy the performance requirements specified in the PPS. Included was a definition of the software architecture, the identification and description of each computer program module to be implemented, the inputs and outputs required and produced by each CPM, and diagrams which illustrated the flow of control and data between the CPMs.

Program Description Document (PDD) - Preparation of the PDD was based upon the three predecessor documents described above and included a detailed definition of the implementation characteristics of each CPM. The PDD constituted a "code-to" level document and included a logic flowchart of each CPM and CPSM in the system, accompanied by a narrative keyed to the flowchart.

Data Base Design Document (DBDD) - The DBDD was developed in parallel with the PDD and included a detailed definition and description of each data item stored in the system data base and accessed by the real-time system software. Included were the definitions of variables, constants, tables, indexes and flags.

The unique characteristic of the MET software design phase was that a preliminary version of each of the above listed documents was prepared prior to the generation of a single line of application code. This procedure was strictly enforced to maximize the thorough understanding of each CPM design and to minimize the number and severity of problems which always surface during the software/hardware integration phase.

Software Implementation

Implementation of MET software was accomplished in accordance with a standard procedure which included five activities: Unit-Test Plan, Code, Code Review, Unit-Testing and Unit-Test Review, see Figure 3.

Unit Test Plan - The unit test-plan consisted of: a narrative which described the manner in which a module was to be tested; a list of the functions to be performed by the module in question including appropriate references to the contract specification items being satisfied; and a series of test cases which had to be executed in order to demonstrate that each of the functions were being performed correctly.

Code - The code was generated based upon the flowchart and narrative contained in the Program Description Document (PDD) and with the testing requirements of the unit-test plan in mind. In practice the unit-test plan and coding were generated concurrently.

Code Review - A code review was conducted following code generation and consisted of a review of the code logic, to ensure compliance with the logic contained in the module flowchart and a review of the code commentary to ensure a direct correlation with the PDD narrative. At the time of code review it was a requirement that all flowcharts and PDD narratives had to be "red-lined" to reflect the "as coded" condition of the module in question.

Unit-Testing - Test of a module was accomplished in accordance with the unit-test plan for that module. All of the test cases were executed and all test results (console outputs, memory dumps, etc) were retained in the unit development folder for that module for later verification.

Unit-Test Review - A review was performed at the conclusion of module unit-testing which consisted of a careful inspection of the unit-test plan, all test cases (inputs and

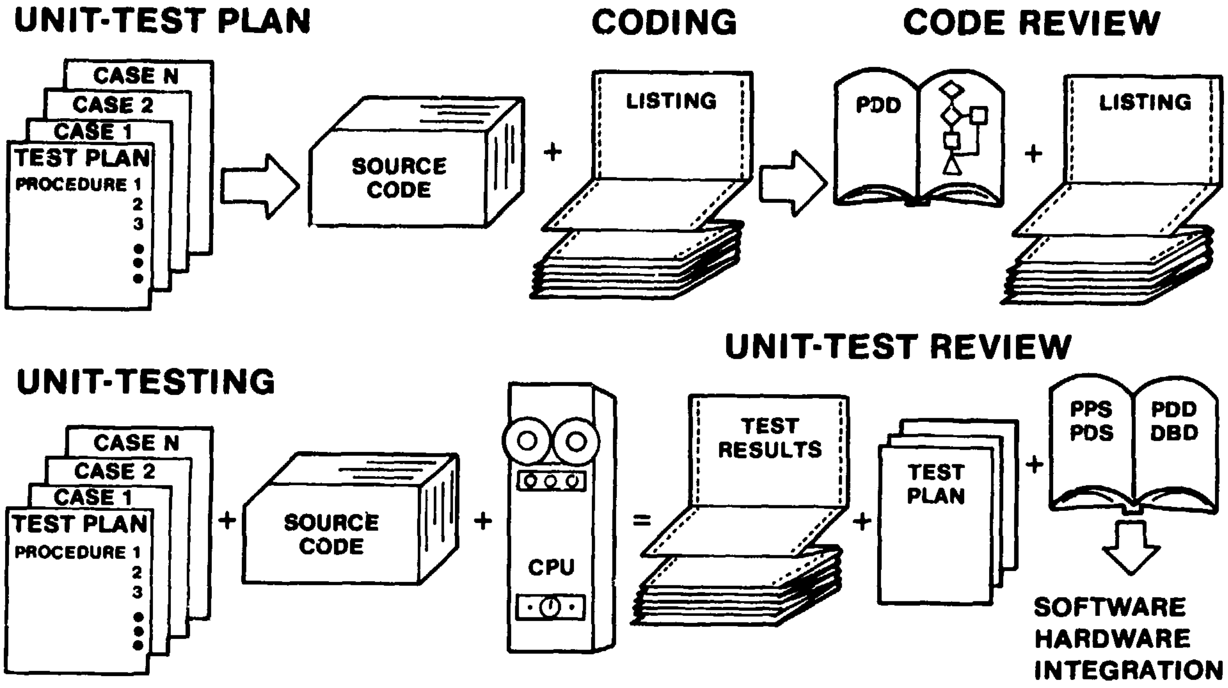

Figure 3: Software Implementation

anticipated outputs) and associated documents, (the PPS, PDS and PDD were required to be "red-lined" to reflect the tested module). Conclusion of a successful unit-test review resulted in the submission of the module source code to the project software library in preparation for software/hardware integra tion.

Conclusions Regarding Software Implementation

Documentation Before Coding -Software implementation was accomplished very nearly on schedule. Several decisions contributed to its success, not the least of which was the decision to document the design, to the PDD level, before the generation of application coding was begun. The documented design at the "code to" level ensured that the various system problems were thought through completely before coding was started. As a result, coding of the MET software was accomplished much more rapidly than planned.

Review at Every Step - Standard development procedures were established for program implementation i.e., Unit-Test Plan, Coding, Code Review, Unit-Testing and Unit-Test Review. This procedure incorporated frequent review of the implementation activities which contributed significantly to identifying problems early.

Weekly Status Meetings - A number of charts and graphs were prepared to measure progress. These were updated on a weekly basis and used to illustrate the status of implementation. Weekly status meetings were held with all members of the software development teams in attendance. Status was obtained by reviewing each item due that week and determining if it had been completed or not and if not, why not. If necessary a new promise date was established. In this way, individual engineers were given an opportunity to modify and sometimes establish schedule dates. This process created an environment wherein the meeting of schedule dates became a matter of professional pride. In addition, the meetings provided a needed forum where problems could be aired and resolved and where management could applaud good individual and team performance.

SOFTWARE/HARDWARE INTEGRATION
THE PROBLEM

Software/hardware integration includes those activities which result in assembling all of the software components into subsystems, exercising the functions of each subsystem with attendant hardware, and isolating and resolving interface and design problems. All subsystems, including hardware, are then exercised together producing a total system operated under various load conditions to demonstrate that all functions for which the system was designed operated in accordance with that design.

Moment of Truth

It is during this process of integrating software with hardware that past sins of superfical analysis and design of both software and hardware surface to be seen by all. It often seems that the software/hardware integration process may never end, that there will always be just one more bug to resolve.

Experience has shown that the integration phase of any system development is often characterized by several of the following types of problems with which the reader may emphathize.

Random Integration

Systems are comprised of many components, both hardware and software. It is not unusual for the enthusiasm for integration to be translated into a frantic effort to leap forward in assembling the various system components in order to make grand and glorious system integration breakthroughs. Individual members of the integration team may have specific knowledge of a particular system area which they may feel can be integrated independently rather quickly, considering the expertise avaliable to do the job. Some individuals are proponents of top-down integration while others are more convinced that botton-up is the only way to go for sure, hence, if not otherwise directed each brings his or her particular bias to bear on the integration activity.

It is not uncommon that energies, enthusiam and personal motivation of members of the integration team result in several aggressive uncoordinated thrusts to get the system put together. Frequently these efforts conflict with one another and converge to a point where the process comes to a grinding halt with no further forward progress possible. At this point the integration teams must fall back, regroup and resolve to do some planning.

Recurring Familiar Problem

The objective of the integration activity, of course, is to surface software and hardware problems so that they can be resolved. As the reader is probably aware, the integration environment is usually a frantic one, with personnel working multiple shifts to get the system integrated within the schedule, which has usually been somewhat compressed by this stage of the project. Illusive problems are pursued with stealth and diligence into the late hours of the evening with notes being generated on scraps of paper which identify various anomalies surfaced in the course of isolating a particular problem. Who has not had the experience of trouble-shooting a problem which becomes more familiar as it is isolated only to recognize after several minutes or hours that it is a problem which was discovered several days before, but forgotten or mislaid in the meantime? Everyone involved resolves to improve the problem reporting procedure so as not to repeat the experience of finding the same problem over again.

Software/Hardware Instability

If wishes could be granted during system integration one would opt to be given an opportunity to debug software on hardware known to be operational or to trouble-shoot a hardware problem with the same piece of software (unmodified) which had surfaced the problem. Alas, all too frequently several perverted permutations of the above conditions come to pass. For example, a program performed a function successfully at 10:00 a.m., but would not work after lunch. Nothing "really significant" had occurred in the interim except that a hardware engineer swapped several computer boards from one processor to another and removed a cable! Is it ever possible to keep the hardware base stable?

In another case a problem with hardware had been reported in excruciating detail by an integration programmer. The hardware engineer pursued the problem the following morning only to discover that he could not reproduce the problem, thereby casting considerable doubt on the credibility of the problem report. Upon closer inspection it was discovered that an "unrelated" modification had been made to one of the programs used in the test which by chance altered the test conditions. Is it ever possible to keep the software base stable?

Inadequate Planning

Regardless of competence, dedication and other sterling management qualities, every project must suffer the occasional trauma of inadequate planning, critical considerations that simply went unnoticed until some manner of crisis emerged. Consider the case where the computer fails and the problem resolution is isolated to a particular circuit board which has not been spared. That board, of course, is the type which enjoys a ninety day replacement time and is known by many to have been a high failure-rate part. Or the situation where only one engineer is an expert on a particular aspect of the system and no one is assigned to back him up in the event, heaven forbid, he should disappear from the project.

SOFTWARE/HARDWARE INTEGRATION APPROACH

The problems identified above are undoubtedly familiar to the reader and in the final analysis, considering human nature being what it is, they may be impossible to elminate entirely. Much, however, can be done to minimize their effect. The following paragraphs discuss the procedures established and used on the MET project and the actions taken which in the author's view contributed in large measure to a reduction of the anguish associated with these problems.

Integration Plans and Procedures

In order to reduce the more bizarre aspects of the random integration activity discussed above a careful examination was made of the entire system and its components. A top-down approach was used in viewing the system and it was decided that four levels of testing were required, if the integration process was to be conducted in an orderly manner, see Figure 4.

CPM Unit-Test Plans/Procedures (Level 4) - The lowest level, (Level 4), Unit-Test plans and procedures were developed for each computer program module (CPM). These unit-test plans/procedures, as previously described, consisted of a test plan narrative, (which described the testing approach), a function list, (all functions performed by the CPM) and a series of test case descriptions (inputs, outputs, anticipated results) see Figure 5. Level 4 testing was intended to demonstrate that a particular CPM successfully performed all of the functions for which it was designed. In this way, as each CPM was entered into the project software library, following the successful conclusion of the CPM unit-test review, a high level of confidence was established that the individual CPM components worked.

Component Group Testing (Level 3) -Level 3 testing really constituted the first attempt at integrating software modules with the equipment required to support the functions that the modules performed. To ensure that firm direction was established for use by integration team members in assembling the various system software and hardware components, detailed plans and procedures were developed for all level 3 testing.

Level 3 integration testing consisted of assembling a group of software modules within a subsystem and exercising them as a unit. Module groupings were selected on the basis of the functions they performed i.e., related functions which could be tested independently of other function groups.

Integration plans for level 3 consisted of: a narrative, describing the approach used to aggregate and test the modules and related hardware; a list of functions to be demonstrated in the course of integration; and a set of detailed step-by-step procedures to be followed in executing each functional action, see Figure 6. The function list identified the function(s) to be demonstrated, the CPMs which would be active during the exercise of the function in question, and the hardware and other support software required to run the test. The step-by-step procedures indicated: the action to be taken (e.g., activate aircraft 6); the device at which the action was performed (e.g., instructor console); and the expected result (e.g., aircraft 6 indicated as active on the vehicle selection tableau).

If the anticipated result was observed to be correct, that procedure step was checked off, otherwise a comment was entered which described the actual result and what was incorrect about it. As problems were surfaced each was documented on a System Problem Report, a procedure discussed in a later paragraph.

Subsystem Testing (Level 2) - The testing performed at this level was directed toward the operation of a complete subsystem, (i.e., Master Control, Passive Sonar, Active Sonar and Radar). As can be seen from Figure 4, level 2 testing is simply a further integration of all the module groupings which together comprise a subsystem. Integration test plans, identical in format to level 3, were generated which provided guidance for conducting a step-by-step demonstration of an entire subsystem. Some interactions between subsystems were exercised under conditions of maximum load e.g., all aircraft active and being tracked, all weapons being fired at the same time, maximum number of surface ships and submarines active, etc. Once again as problems were surfaced they were documented using the System Problem Report.

Lessons Learned - Experience during the MET integration indicated that generation of Integration Test Plans (ITP) was instrumental in forcing the required attention and thought to the questions of integration sequence, schedule requirements for various hardware components and the need for moving from single to multiple-shift operations.

Initially, level 3 ITPs were generated in parallel with and slightly ahead of the integration activities. There were occasions, however, when working to resolve a problem took precedence over the continued preparation of integration procedures. When this situation occurred a whiplash effect was felt. That is, after the problem was solved, the integration effort slowed down to a near halt while the procedures needed to continue the integration effort were generated.

In retrospect, I am convinced that preparation of the level 3 integration procedures should have taken place prior to the initiation of software/hardware integration. Availability of these procedures would have ensured a smoother integration activity and a more efficient utilization of human and computer resources. The level 2 integration plans and procedures, however, were completed prior to the performance of subsystem testing. Level 2 integration was accomplished more rapidly and without diversion.

Integration Team Responsibilities

Computer-driven training systems such as the MET are comprised of both hardware and software, as a result development is most often accomplished by groups of software and hardware people who work in close cooperation to define functional interfaces during the system definition phase. Following this phase the groups generally work independently to implement the system design. At a point in the schedule (integration) the two groups come together to assemble both aspects of the system. In an integration environment where software people are responsible for software integrity and hardware people for hardware integrity it is

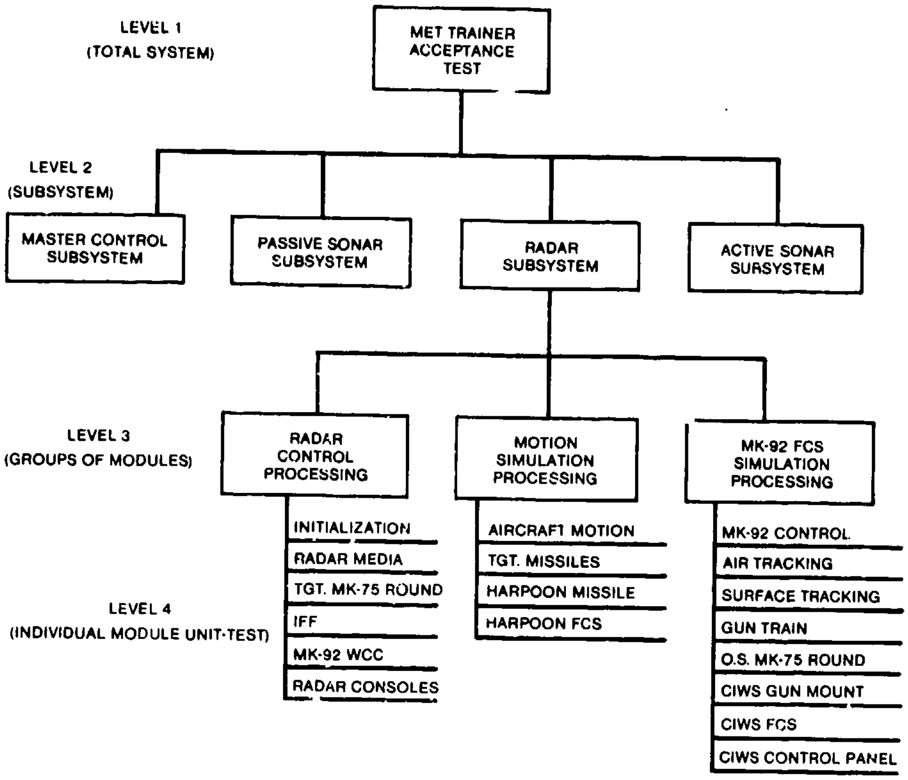

Figure 4: Hierarchy of Integration Test Planning

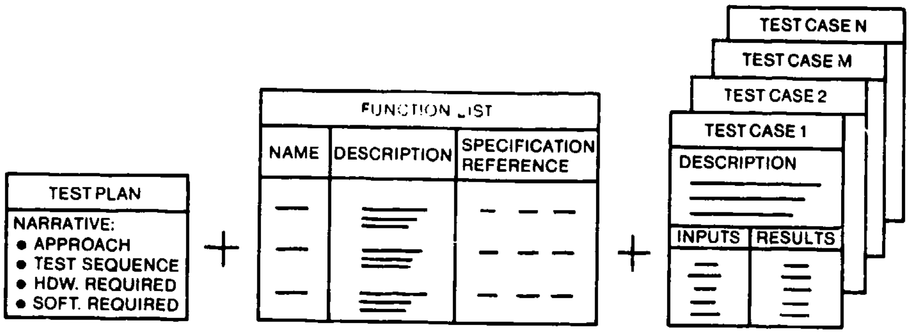

Figure 5: Unit Test Plans

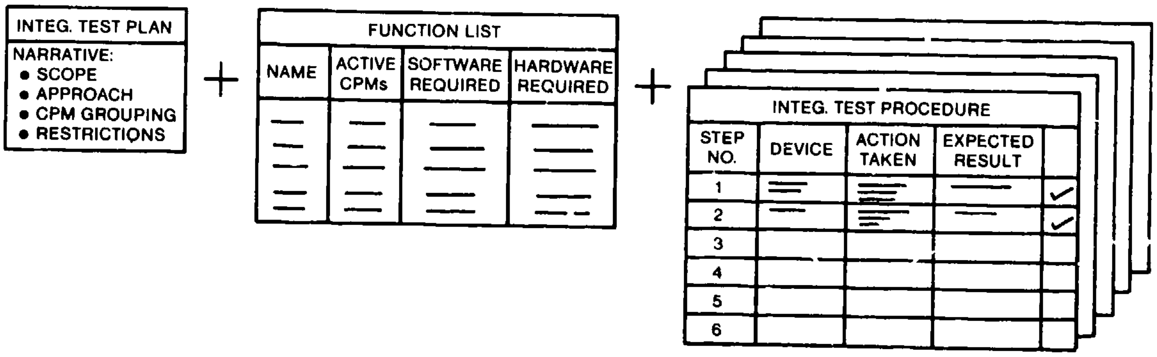

Figure 6: Integration Test Plans

not unusual to find a considerable amount of finger-pointing. When a problem is surfaced which cannot be easily ascribed to either area the blaming of hardware by the software people and vice versa has been known to occur, a practice which is definitely counter-productive to getting the job done.

MET integration teams were established for each subsystem and contained both hardware and software people. The integration team leader, whether of software or hardware persuasion, was given responsibility for all aspects of subsystem integration. This organization tended to lessen any parochial feelings among team members. A common motivation was established that all of the problems surfaced were "team problems" and these were dealt with in a remarkable atmosphere of comradeship and truly shared responsibility.

Lessons Learned - Granting the integration team leader full responsibility over both the hardware and software included in a subsystem did provide him with the flexibilty to change priorities of certain activities which increased the probability of remaining on the integration schedule.

Problem Reporting & Resolution

As was previously stated, one of the objectives of the integration activity is to surface problems and resolve them. Regardless of the difficulty of isolating a problem it seems as if it is even more of a chore to document it. Claims of "It will take me less time to just fix it than write it up..." or "I won't forget this one, I'll fix it tomorrow..." are frequently uttered to salve the conscience of an integration team member who has decided that he or she does not have to document a problem.

Problem reporting during software/hardware integration is a time when benevolence in management is a self-defeating indulgence. No exceptions should be tolerated - all problems large or small must be documented as they are encountered during integration. If this rule is not enforced it is certain that problems will be forgotten only to be rediscovered time and time again at great cost in both time and frustration.

System Problem Report (SPR) - An SPR form was designed for use on the MET project which served as a vehicle for documenting all problems, software and hardware. The form was used to record a problem identification number and descriptor, date encountered, originator, a brief description of the symptoms and an educated guess as to the cause. The SPR was submitted to the software Quality/Management (Q/M) group representative who maintained the problem log and other status charts, see Figure 7.

An interesting attitude developed among some members of the integration teams. Some teams generated large numbers of SPRs while others spawned but a few. It was discovered that certain individuals regarded the generation of SPRs as an indication that their software/hardware would be considered by managment to have been poorly designed and/or implemented; hence, they were not inclined to generate SPRs. It became necessary to advise all members of the integration teams that the only way to measure progress was by comparing the number of SPRs generated to the number resolved.

If SPRs were being generated and resolved and the integration procedures were being executed at a resonable rate this was interpreted as progress. However, if few SPRs were generated and the integration procedures were not moving ahead very quickly this was interpreted as no progress and frowned upon. It took quite some time to get the SPR procedure accepted and used by all team members, however, once accepted it served the integration activity well.

Software Change Report (SCR) - The SCR was utilized as a vehicle for closing out an open SPR which found its resolution in a modification to a program. The SCR contained information which described the change being made to the program in question and identified the SPR which was being resolved by the SCR. The SCR was also used by the project software librarian as a request to perform an update to the software baseline maintained in the project library.

Figure 7 illustrates the procedure followed to control SPRs and SCRs. The integration team surfaced problems which they recorded on the SPR form which was then submitted to the software (Q/M) representative who maintained and published SPR log, SPR list and SPR status reports. Integration team members pursued the problem and devised a fix which would resolve the problem. If the fix was implemented in software, the SCR was written and the source code updates generated and submitted to the software Q/M representative who tasked the project librarian to perform an update of the library source code for the module being changed. The modified module was then recompiled and the updated version placed on the integration disc to support continued integration activities.

Lessons Learned - It became apparent very early in the integration phase that given any opportunity, integration team members would often opt not to document problems. It is recommended that a firm practice, requiring that all system problems be documented, be established and rigorously enforced throughout the integration period. The status of SPR generation versus SCR production provides a fairly accurate picture of integration progress. When the rate of SCR generation exceeds SPR production it may be fair to assume that integration is converging to a state of completion.

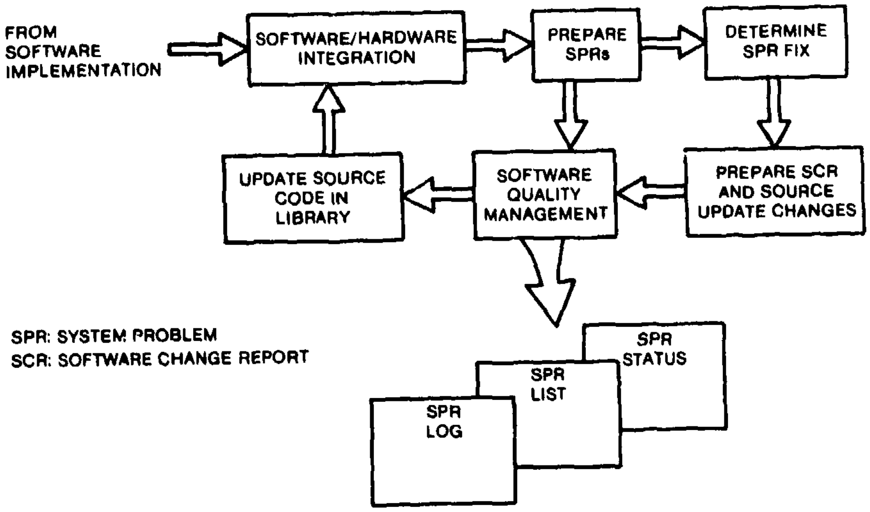

Figure 7: SPR & SCR Control Procedure

Software/Hardware Configuration Control

Integration testing is frequently described as the checking-out of marginal software on marginal hardware. There may be some truth in such characterizations. If that be the case, no effort should be spared to minimize the number of variables in the integration environment which contribute so much to confusion. The integrity of the software and hardware baselines being used by the integration people must be preserved. That is, no change should be made to programs or equipments unless they are strictly controlled and made known to all members of the integration team.

Project Software Library - Control of the software baseline during integration was accomplished by the establishment of a Project Software Library. As modules successfully completed the Unit-Test Review process they were entered into the library. The software project librarian, who was a member of the software Q/M group, was tasked with providing a copy of the controlled programs (load modules) to the integration teams. As a result all integration was performed on a known software baseline.

As problems were encountered and resolved, integration personnel prepared source update commands for each resolution and completed an SCR which not only described the change, but was also used to close a corresponding SPR. On a periodic basis (sometimes daily) the librarian performed an update of the programs in the library, increased the revision number of the modules which had been changed, recompiled these modules and resubmitted updated load modules to the integration teams for continued use. No changes were accepted for library update unless accompanied by an SCR.

A similar procedure was followed to control the system data base. On a periodic basis (usually weekly) the accumulated data base changes were gathered up by the librarian and a data base update performed. Copies of the revised data base were then made available to each of the integration teams for use. Representatives of the software Q/M group performed all of the functions concerned with the configuration control of source code and data base.

Hardware Change Control - The MET trainer hardware configuration is comprised of eight SEL 32/75 computers with attendant peripheral devices, several cabinets of CUBIC developed interface equipments, sonar sound generation hardware, digital radar landmass video generation hardware and a large amount of government furnished shipboard equipment. Some thirteen hundred or so cables are required to interconnect the various equipments, which provides some indication of the configuration complexity.

The software/hardware integration activity was initiated somewhat prior to the completion of the hardware development effort, which meant that software people were testing programs on available hardware while engineering personnel continued to install and power-up other equipments. Many strange occurrences were observed during this period which required a considerable effort to decipher. Some events were never explained. Supposedly trivial tasks like disconnecting cables to affix identification labels or swapping of like circuit boards between cabinets occasionally had a disruptive effect on the integration activity. Cable identification, which should have had no effect on the integration in progress, was occasionally accomplished by tugging on a cable which might have been tangled with another cable which, when jerked to and fro, tended to disturb system operation. Likewise the swapping of boards often resulted in moving a problem from one place to another.

Several actions were taken to stabilize the hardware configuration. Hardware status boards were posted with the current condition of various equipments. Cabinets were sealed and log books attached to each cabinet with a standing rule that authorization to enter the cabinet had to be obtained and if any change at all was made, it had to be entered in the log book for that cabinet. This ensured that a migration history of moving boards was available. An access list to particular cabinets was maintained identifying only those engineers who could be granted permission to break the seal and enter a cabinet. Hardware quality control tasks were scheduled to be carried out during specific periods (usually weekends) to eliminate the conflict with on-going integration activities.

Lessons Learned - The control of the software baseline was effectively maintained with the procedures described; however, control of the data base was not accomplished as well as it could have been, due to the fact that the data base update tools available were too slow (took too long to run on the computer). This situation caused data base updates to be performed on a weekly basis for a time, when in reality it would have been more productive and supportive to the integration activity to have performed data base updates more frequently.

As regards the control of the hardware baseline, the overlapping of the integration activity with that of equipment installation is not especially productive and is, in fact, counter to one of the basic axioms of integration, namely, minimization of the number of variables during testing. All equipment should be installed and verified to be operational, to the maximum extent possible, prior to the initiation of software/hardware integraton.

Integration Status Monitoring

The integration activity is by nature an effort which suffers advances and reverses. Because of its proximity to the end of the contract and the fact that it is a culmination of the design and implementation phases, it enjoys a wide management interest. Providing management with a tangible assessment of integration status is a delicate undertaking, to say the least. In fact, it is rather difficult to predict the number of problems which will be encountered in the course of integration, or how long it will take to isolate any given problem. Several techniques, which are described below, were utlilized to monitor the status of the MET integration.

Configuration Control Board (CCB) - A configuration control board was established which consisted of software, hardware and management personnel. Participating on the CCB were the program manager, engineering manager, software manager, integration team leaders and the software Q/M representative. Other individuals were requested to attend as their contributions warranted. The CCB was convened at least once a week and on occasion several times a week, depending upon integration progress or lack thereof.

The CCB reviewed integration progress against the plan, and the progress made in the closing of SPRs. Specific problems encountered during the week were discussed and action items allocated to various individuals. CCB meetings were chaired by the software Q/M represenative who was also responsible for the preparation of meeting minutes and SPR reports. The board successfully dealt with the prioritizing of many activities which contributed significantly toward keeping the integration activity reasonably on schedule.

Integration Activity Charts - Three principal mechanisms were utilized to assist in tracking integration progress: integration activity charts, PERT-type graphic charts and SPR/SCR generation curves. An integration activity PERT-type chart was prepared which identified the integration activities which had to be performed before the system could be considered ready for acceptance testing. This chart graphically portrayed activites, duration and time sequence and was updated regularly. Updating was accomplished by indicating percent completion of an activity using a color code of BLACK to indicate effort accomplished, GREEN to indicate effort accomplished ahead of schedule and RED to indicate effort which had not been accomplished and was behind schedule.

An integration activity chart was prepared in columnar form, as shown in Figure 8, which listed all of the integration activities along with their scheduled completion date and space to record the actual completion date. This chart was heavily used by the CCB during each integration status meeting. Activities on this chart were highlighted (in color) as they were

NO.	ACTIVITY	SCHEDULE DATE	ACTUAL DATE	COMMENTS
	MASTER CONTROL			
1	**PERIPH. SWITCH - DISC**	—	—	
2	PERIPH. SWITCH - CARD	—		
3	**PERIPH. SWITCH - PRINT**	—	—	
4	**SET O.S. ENVIRONMENT**	—	—	
•	•	—		
•	•	—	—	
•	•	—		
•	•	—	—	
N	•	—		
	PASSIVE SONAR			
1	AMBIENT NOISE	—		
2	INVERSE BEAM FORMING	—		
3	OCEAN CHARACTERISTICS	—		
		—		
		—		
N	•			
	ACTIVE SONAR			
1	INTERRUPT PROC.	—		
2	**HSD READ**	—	—	
3	INTERNAL CLOCK	—	—	
•	•	—		
•	•	—	—	
•	•	—		
N	•	—		
	RADAR			
1	TARGET DETECT	—	—	
2	A SCOPE/B SCOPE	—	—	
3	WCC INTERFACE	—		
4	CONTROL MODULE	—	—	
•	•	—		
•	•	—	—	
•	•	—		
N	•	—		

☐ COMPLETED ACTIVITY

Figure 8: Integration Activity Chart

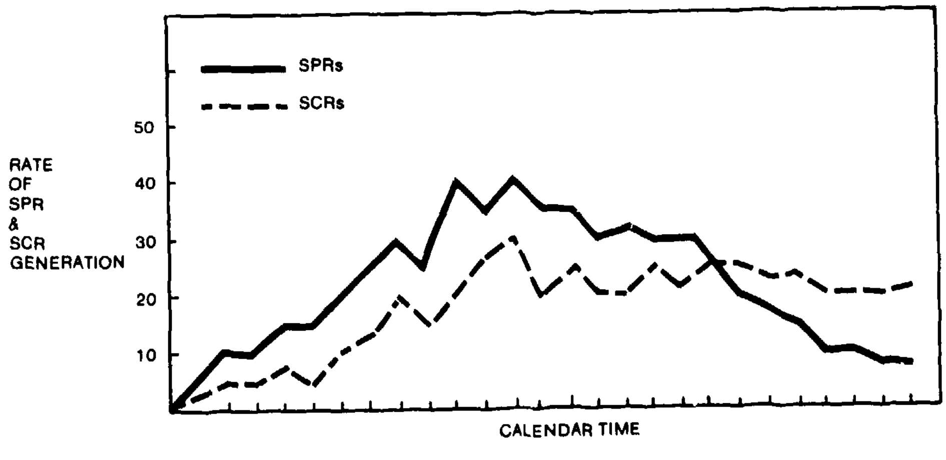

Figure 9: SPR/SCR Generation Graph

completed. No percentage activity completion was reflected on this chart, hence, it provided a conservative view of integration status.

Graphs of the number of SPRs and SCRs generated, plotted as a function of time, provided an insight into the progress being made. The general slope of the SCR curve indicated whether or not the integration teams were successfully closing problems out and provided an approximation (by extending the curve) of when all problems would be resolved and integration completed (see Figure 9).

Lessons Learned - The techniques utilized to monitor the status of integration have proven very useful in indicating not only where the integration activity was but also how it was likely to proceed. The accuracy of presentation and utility of the techniques is directly proportional to the amount of energy applied to the identification of the integration activities. If the integration activity chart is accurate and truly represents all of the tasks which are required to integrate the system, the chart will be invaluable in assessing status.

The SPR/SCR graph was felt to be a good indicator of overall integration status when considered in light of the activity chart. If the activity chart indicated a low activity completion and the SPR/SCR graph showed low SPR generation it was a clear indication that the integration was staggering and required review and assistance. On the other hand if the activity chart indicated a reasonable completion of taks and the SPR/SCR graph showed a brisk SPR/SCR generation one could conclude that integration was progressing without serious impediment.

SUMMARY

Software/hardware integration is an activity which is eagerly approached by all members of the system devlopment team because it embodies the sweet challenge of making the whole system work. As exhilarating as integration is, it is nevertheless an activity which is frequently besieged by all manner of pitfalls, each of which contrives to extend the schedule and complicate the job to be done. Successful integration is certainly enhanced by orderly and thorough software and hardware design and implementation. Without a doubt superficial analysis and design of system software and hardware components will surface to haunt the integration activity. Valuable time and effort will be expended going back to effect redesign and modifications.

Considerable emphasis was placed on a thorough design of MET software. In fact, the detailed software design was completely documented before the coding activity was started. Software implementation was heavily monitored by the conduct of design reviews, code reviews and finally, unit-test reviews. All of these activities , I believe, contributed to increasing the confidence that each software component had been thoroughly tested before being made available for system integration. Similar attention must be given to the design, fabrication, installation and test of all hardware components.

Even after all reasonable precautions have been taken to reach the point of system integration, a formidable task remains to be contended with, one which is frequently attended by problems of planning and configuration management and problem monitoring. These problems were alleviated on the MET project by: the development of detailed integration plans for the various levels of the system architecture; the organization of integration teams possessing both software and hardware skills and the authority over all aspects of a subsystem; and the establishment of firm procedures to control not only problem reporting and evaluation, but also the software and hardware baselines.

The MET software/hardware integration effort was significantly enhanced by the active participation of customer personnel from the Naval Training Equipment Center (NTEC) who were present as observers during much of the level 2 and 3 integration testing. Their participation resulted in the generation of meaningful commentary as the system was assembled and provided a basis of common knowledge which was taken into the formal system acceptance activity.

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TECHNIQUES FOR AVERTING PROBLEMS IN DEVELOPING TRAINER SYSTEM SOFTWARE

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ABSTRACT

Short schedules and changing requirements are common problems encountered when software is being developed for training systems. This paper explores techniques used by Technology Service Corporation (TSC) to overcome or avert such problems while developing the B-52 OAS Part Task Trainer for the Training Services Division, Keesler Air Force Base. Techniques for dealing with limited resources (time and budget) include carefully exploring, and assigning priorities to, system capabilities to determine the more important requirements; and employing a top-down approach. Planning for changing requirements calls for identifying capabilities that may change; constructing a well-documented software design with application-oriented modularity; and scheduling a design freeze, with late requirement changes incorporated after completion. The paper presents step-by-step descriptions of each technique and provides examples relating directly to the part task trainer.

INTRODUCTION

The U.S. Air Force B-52 bomber is receiving a major modification in the form of the Offensive Avionics System (OAS), scheduled for deployment in 1981. Used by the B-52 radar navigator to perform navigational and offensive weapon delivery tasks, the OAS replaces older ASQ-38 equipment and automates some previously manual functions.

A weapon system trainer (WST) is being built for the B-52 as a part of the major weapon system modification. The WST is scheduled to be completed in the 1983-1986 timeframe, which leaves a gap between deployment of the OAS and availability of the WST. Crews using the first OAS-modified B-52 will need a trainer in the interim. To meet this need, TSC, in conjunction with the Training Services Division, Keesler Air Force Base, has been contracted to design the software and configure four B-52 OAS interim trainers to be used by the Strategic Air Command (SAC) in their OAS conversion training program.

In approaching this assignment, TSC recognized that, in developing software for the interim trainer, two major problems also found in other software projects would be encountered: limited resources (short schedules and budgets) and changing requirements.

Short schedules are a function of the relation between the training device and the actual system. A training device cannot be specified until the actual system is designed, but it is needed as soon as the actual system--either a new one or a modification to the existing one--is operational, if not before then.

Meeting the schedule and cost constraints is then complicated by deciding which functions can reasonably be provided by the training system. The first choice of the users may be a trainer that gives a completely realistic simulation of the device. It is, after all, difficult to identify those skills that can be effectively trained with other methods, such as classroom instruction, low-cost training aids, or the system itself. The cost of such a trainer, however, may be beyond the available time and budget.

The second problem, requirement changes during development, commonly occurs because both the trainer and the system are being developed at the same time. Any changes to the system under development must be reflected in the trainer; and, by extension, since modifications to the system are likely, these same modifications must be supported by the training device.

This paper presents techniques that TSC has found to be effective in minimizing, and sometimes averting, the impact of these problems. These techniques are now being used to develop the B-52 OAS Part Task Trainer (PTT). Before detailing them, we describe the trainer as a point of reference.

DESCRIPTION OF THE PART TASK TRAINER

The interim trainer is a part task trainer, addressing some of the tasks, procedures, and conditions the crewmembers must handle with the OAS. The crews receiving training will already be skilled B-52 navigators. The focus of the PTT will therefore be on procedures training; specifically, those procedures unique to the new OAS. For example, the PTT must respond exactly as the OAS would to all commands (button pushes, switch activations, etc.), but only those features used directly in navigational and weapon-targeting procedures need to be displayed in the simulated radar video.

The PTT is laid out physically to provide stations for the two crewmembers required to operate the OAS, as well as a position for an instructor (Figure 1). Included in this layout is a mockup of the OAS crewstation, comprising 16 operational panels, four monochromatic display monitors, and two trackballs. The instructor's position is equipped with a CRT console for setting up and monitoring the training sessions. The hardware configured for the part task trainer is composed of the five independent subsystems depicted in Figure 2.

Before we describe the software and the approaches to lessening the impact of major problems in developing it, an overview of what is actually simulated by the software is necessary.

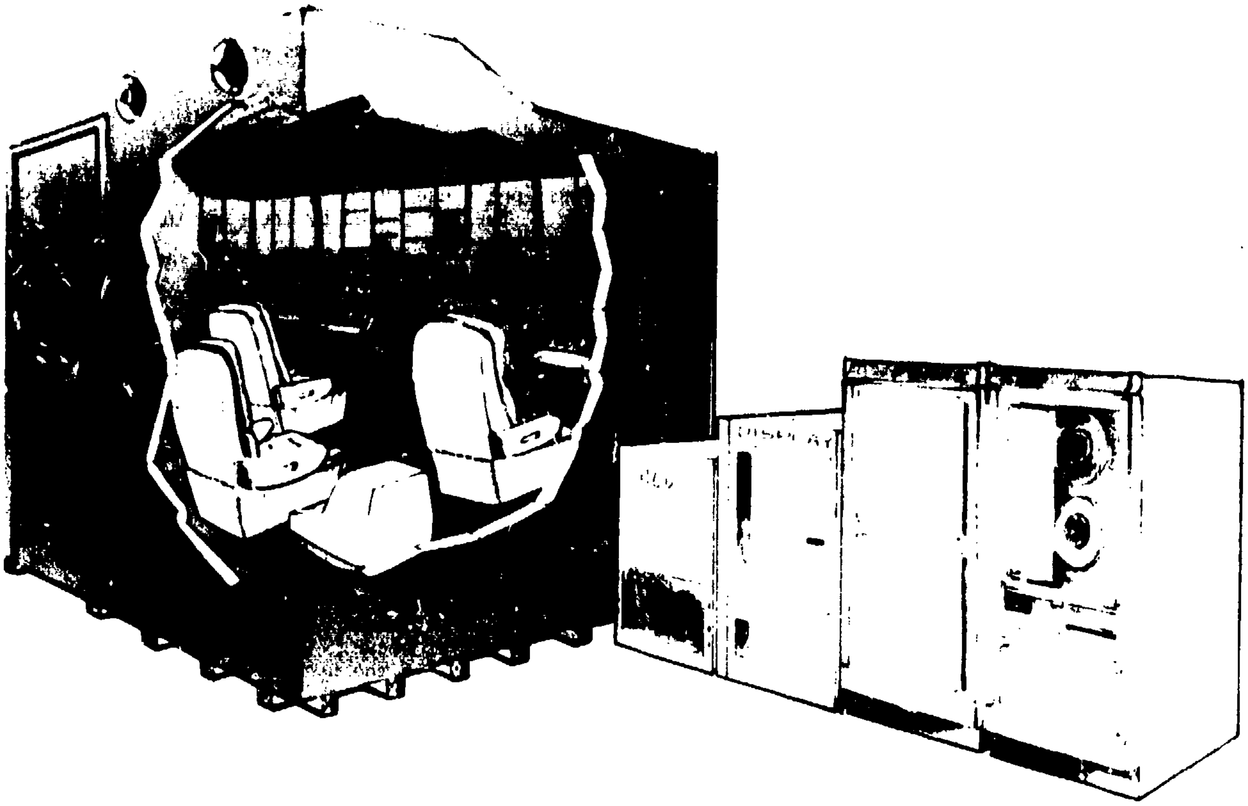

Figure 1. B-52G/H OAS Part Task Trainer

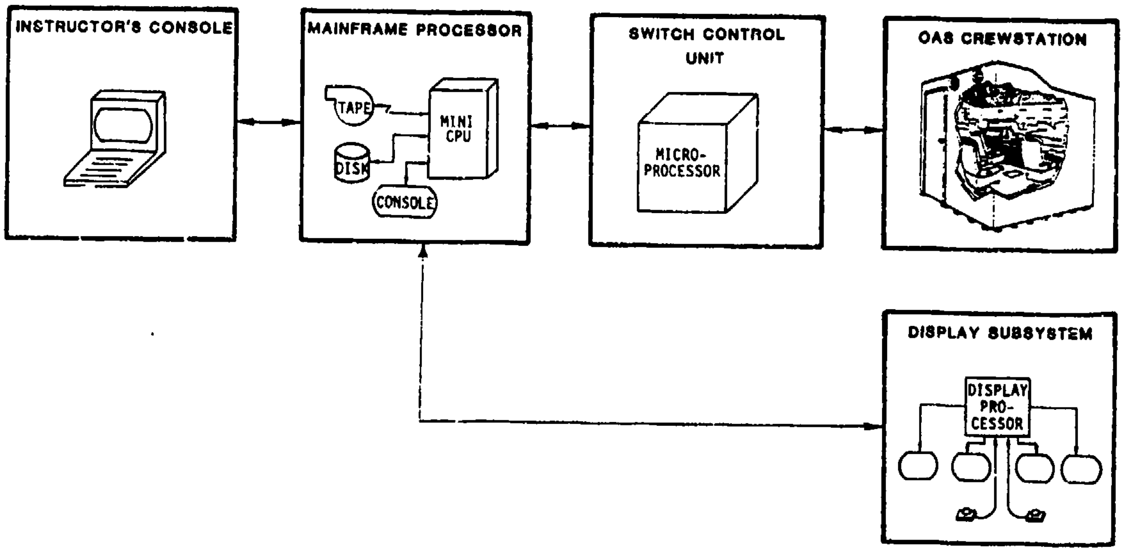

Figure 2. OAS Part Task Trainer Block Diagram

The OAS will automatically navigate the B-52 according to a predefined flight plan. The crewmembers will be able to monitor, update, and override this automatic navigation system, using the OAS equipment and a variety of navigational procedures supported by the PTT. The trainer will also support OAS procedures to perform in-flight refueling; preparation and delivery of Air-Launched Cruise Missiles (ALCMs), Short Range Attack Missiles (SRAMs), and conventional bombs; and backup procedures used when certain OAS failures occur.

As envisioned in the PTT, the instructor will be able to select a flight plan from a set of canned scenarios or modify any canned scenario to generate a new flight plan. The canned scenarios are representative of actual training missions, and scenarios of up to five hours of flight time can be generated within a region covering the Western United States. Sufficient terrain features, navigational fixpoints, and target areas are included within this region to define at least 100 different realistic scenarios. Navigational charts are used to generate synthetic radar imagery for display of these features, fixpoints, and target areas.

The instructor will also have the capability to inject faults and malfunctions at any time during the training session. With the ability to steer the aircraft off the flight plan and to accept corrections from the OAS crewmembers for recovery, the instructor will be acting as the B-52 pilot. He will also monitor crewmembers' actions and will be able to freeze the training session at any time, give additional instruction, and then resume the session.

As this brief description indicates, the PTT is a complex training device. This complexity can be further increased when the development of software for such a device is constrained by brief schedules and changing requirements. In the following sections, we present a collection of methods that we have found beneficial in a number of applications. We first discuss methods for reducing and overcoming schedule problems, and then techniques that facilitate incorporation of requirement changes.

SOME SOLUTIONS TO TIME AND BUDGET PROBLEMS

As mentioned in the Introduction, completion of the training device must coincide with or precede that of the weapon system, often resulting in short schedules. In addition, schedule slips may occur, owing to inaccurate estimates and the vicissitudes of daily life: illness, employee turnover, machine failures, and requirement changes. Specific methods TSC uses to anticipate potential schedule problems and to avoid cost overruns include carefully exploring, and assigning priorities to, system capabilities to determine the most important training functions; and employing a top-down approach so that a very limited, skeleton system that performs some of the required functions is developed first, followed by versions that successively add more capabilities until the system is complete. These two techniques are actually interconnecting, with assigning of priorities to different functions contributing to the definition of development stages or versions in the top-down approach. Careful choice of programming language and computer system, and incorporation of a programming design language also contribute to averting schedule problems and are discussed at the end of this section.

Assigning Priority

The system specification usually details the functional requirements; these functions, however, can be further ranked by the user into such categories as:

1. Necessary for training.
2. Important function without which the system will be marginally useful.
3. Important function definitely desired by the user but which could be taught, if need be, using another medium.
4. Nonessential or desirable function.

The user's initial ranking of system functions may place all functions in Category 1, and convincing the user of the importance of ranking them may be difficult (or even impossible) until schedule slips occur. It is hoped, however, that discussions with the user will be fruitful for identifying the more critical training functions. This ranking can then be used in top-down development as part of the process of identifying the successive versions.

Top-Down Development

In top-down software development, described by Yourdon, (1) the high-level design of the system is followed by implementation of a barebones system that performs some of the required functions, followed by versions that successively add more capabilities until the system is complete.

By contrast, in the classicial, bottom-up approach, the entire system is designed, coded, debugged, and then integrated. If a scheduling problem occurs, the developer and user may find, when the deadline arrives, that although 100 percent of the code is written, nothing works. The same schedule slip with the top-down approach will find a working version that may provide 75 percent of the total system functions. And although the user will not be satisfied with 75 percent of a system, that 75 percent will be more acceptable than 50,000 lines of code that are useless because they have not been integrated.

Furthermore, a user is more likely to have confidence in your ability to finish the job if he can see a working version of the partial system. For example, Version 1 of the PTT, described below, was valuable because we were able to demonstrate it to the customer, which was more effective than telling him 10,000 lines of code had been written. And, if the versions are carefully defined, the customer may be able to start training with the current version while the training device is being completed.

The most important functions, decided by the priority ranking discussed above, are scheduled for implementation in the early versions, the less important, in the later. This scheduling of functions in versions is a compromise between the logical steps required to develop the software and the desire to provide intermediate working versions that are useful for training. For instance, the radar position fix procedure may be the most important training function; however, since it requires panel inputs, radar graphics, trackball control of the crosshair, simulation of aircraft flight and navigation systems, etc., intermediate versions are defined to develop the basic building blocks, and then the position fix procedure is scheduled for implementation in the next version.

On the PTT project, the users (SAC) were very cooperative in ranking the priority of training funcions. From this ranking, we defined seven versions (Table 1) for the top-down development of the PTT. The first three versions provide a logical development of the basic functions of the system required to support the operational procedures scheduled in Versions 4 through 7. Versions 1 through 4 have been implemented, and Version 5 is under way. The estimated time to complete each version ranges from four to nine weeks.

Version 1 may appear so basic as to be trivial. Its completion, however, was a significant event because, for one, this version required that two of the four system interfaces work: input received from the instructor's console, and output generated to the display subsystem. Yourdon discusses in detail the advantages of top-down development in testing major interfaces early in the development cycle.(1) Often these interfaces are where problems occur, and such problems are usually the most difficult to correct. Second, in this first version, although only three of 12 tasks are implemented to any degree, these three tasks are scheduled and communicate with each other, exercising a majority of the system executive routines that handle task interfacing, another area where significant problems often occur.

Version 2 added considerably more capabilities: all subsystem interfaces were exercised; inputs from one switch panel were processed by the software, allowing evaluation of response times; and most alphanumeric display formats and static radar video were displayed. Version 4 should be adequate for training the first B-52 crews, because ALCM and SRAM procedures training is not required for them; and Version 5 is expected to provide 90 percent of the necessary training functions.

TABLE 1. OAS PART TASK TRAINER VERSIONS

Version 1

- Instructor starts system in Run mode
- Aircraft flies in a straight line
- Display prime mission data, left-hand-side data

Version 2

- Instructor maneuver aircraft commands
- Aircraft flies default scenario
- Crewmember inputs from Integrated Key Boards (IKBs):
    - Select MFD
    - Select Format
    - Select Menu
    - FLY TO Command
- Display:
    - Static radar video
    - Static alphanumeric data

Version 3

- Instructor select/preview command
- Instructor's real-time parameters display
- Navigation errors modeled
- Crewmember inputs:
    - Remaining IKB functions
    - Radar Navigator's Management Panel
- Display:
    - Dynamic radar video (default format)
    - Dynamic alphanumeric data

Version 4

- Procedures:
    - Bomb run
    - Auto fixpoint sequencing
- Crewmember inputs:
    - Bomb panels
    - Special weapons panels
- Display:
    - Crosshair and residuals
    - All radar video formats

Version 5

- Procedures:
    - ALCM weapon procedures
    - SRAM weapon procedures
    - High altitude calibration
    - Radar position fix
    - OAS initialization
- Crewmember inputs:
    - Weapons Control Panel

Version 6

- Instructor commands:
    - Fault
    - Wind
    - Alternate nav heading error
    - Missile all/none status
    - Freeze/resume
- Procedures:
    - Alternate true heading calibration
    - OAS bus failure
    - Panel failures
- Crewmember inputs:
    - Remaining panels

Version 7

- Instructor capabilities:
    - Edit/save scenario
    - Post-run mode
- Procedures:
    - Point parallel rendezvous
    - Alternate bomb run
    - Terrain correlation fix
    - Low altitude calibration
- Display altitude ribbon

To show how the top-down development relates to the actual code written, Table 2 tabulates the estimated effort to complete each task and library of routines for each version. It shows that, in Version 1, a major portion of code in the library routines for error handling, data passing, input, output, etc., was developed and exercised to support a very small amount of task code. By Version 2, nearly all library routines were operational. This information is also beneficial in explaining to the customer how much effort goes into a Version 1 to produce what may be a small subset of visible functional capabilities.

TSC has found that, using top-down development, the high-level design for the system should be completed before any versions can be implemented. That is, the system executive routines which perform such functions as input/output, data base control, and intertask communication must be defined, as well as each task and data base. These definitions should include the functions of each entity, and all inputs and outputs at the functional level. For example, the task that provides the instructor's display should identify the current aircraft parameters of speed, heading, and altitude as inputs from a named data base, but would not have to specify the format of the data base. Given this high-level design, implementation of each version can proceed and the developers can be assured that no major problems will be discovered in Version 5 that could, for instance, necessitate a redesign of code developed for Version 1.

Top-down development also makes estimating easier, as well as having other advantages. The software staff prefers it because, instead of one long cycle of design, coding, and integration, the project is segmented into shorter cycles of design, coding and integration for each version. The completion of each version results in the software team having a feeling of accomplishment and enthusiasm to tackle the next version. Having several such cycles makes estimating the time to complete the remaining versions easier. By contrast, in the bottom-up approach, knowing how long it took to design and write all the code does not help to estimate how long it will take to integrate.

Programming Language and Computer System Choice

Short schedules also encourage careful choice of programming language and computer system and support software. Coding time is significantly reduced when high-level languages are used instead of assembly language. Any inefficiencies in program size caused by the high-level language can usually be offset by purchasing more memory. As for inefficiencies in execution time caused by the high-level language, those portions of code detected as causing timing problems can be rewritten in assembly language.

Using a language with which the programmers are already familiar also helps. In the B-52 OAS PTT, the IFTRAN language was used. IFTRAN is a structured FORTRAN language used by TSC for nearly all programming projects.

The minicomputer selected for the PTT is compatible with TSC's in-house system; therefore, the PTT project was able to draw upon a pool of programmers experienced with the system and a library of routines and software tools. The vendor-supplied operating system also provides many of the capabilities required for real-time systems: multitasking, semaphores, priority levels, mapped I/O, etc., thus minimizing the number of executive routines to be generated. The vendor-supplied software includes capabilities to facilitate software development: timesharing with virtual memory management that allows several programmers to develop and test code simultaneously,

TABLE 2. PERCENTAGE OF SOFTWARE DEVELOPED FOR EACH MAJOR MODULE, BY VERSION

VERSION	1	2	3	4	5	6	7
TASKS:							
COM	5	30	40	50	60	70	100
INO			70	70	70	70	100
CRW		80	90	90	100	100	100
RIK		40	50	60	70	80	100
NIK		40	50	60	70	80	100
RNM			20	40	80	90	100
WPN				15	70	90	100
AIR	5	30	40	80	90	100	100
MFD		20	50	60	80	90	100
PMD	30	40	40	80	90	90	100
XHR			5	50	80	90	100
RDR		30	40	75	90	100	100
LIBRARIES:							
IO LIB	30	70	90	100	100	100	100
EXEC LIB	50	90	100	100	100	100	100
DB LIB	80	100	100	100	100	100	100
Q LIB		100	100	100	100	100	100
NAV LIB	80	90	100	100	100	100	100
ERR LIB	60	75	75	100	100	100	100

and a source-level debugger that allows programmers to debug on-line in the high-level language.

Another suggestion for speeding up progress in software development is to have project management intervene when design discussions drag on. When the programming staff is undecided over alternative methods and no outstanding risks are identified, the chief designer must pick one method and continue. The method that is most straightforward to implement should be the one selected.

Program Design Language

Finally, it is important that development standards not be abandoned because the schedule is short. For instance, at TSC, the first step in software development is to express the design in PDL (program design language). PDL is an English language description of the design with a few structured programming keywords such as IF, ORIF, ELSE, REPEAT, WHILE. Expressed in PDL, the design is structured, machine-independent, and understandable by nonprogrammers, such as the user. Figure 3 is a sample PDL listing of a routine that controls cursor movement on a menu-driven display.

The entire software team reviews the PDL to ensure that the PDL is understandable by everyone, to detect errors and omissions, and to suggest improvements in the design. Once the design is approved, code is generated and also reviewed. Code is inserted in the same source file with the PDL, and preprocessors allow the listing of PDL only, code only, or code with PDL inserted as comments.

Use of PDL and reviews significantly shortens the integration and documentation phases of the software process in the following ways. First, PDL design reviews eliminate many of the errors that are normally not detected until software integration. Second, reviews of PDL and code ensure that each person knows enough about all the software to detect and correct many errors quickly without involving other team members. Third, software debugging is easier with PDL embedded as explanatory comments in the code. Fourth, keeping PDL and code together ensures that coding changes are also reflected in the PDL. Thus, at project completion, PDL listings can be used as final program documentation. Finally, the requirement that the software design be expressed in PDL ensures that the design is documented--and not in a disorderly set of notes or stored in a programmer's head. Thus, if the programmer becomes ill or leaves the project, the disruption is minimized because another programmer can get "up to speed" more easily.

SOME SOLUTIONS TO THE PROBLEM OF CHANGING REQUIREMENTS

Requirement changes during development of a trainer device are unavoidable when the system simulated by the trainer is undergoing simultaneous development or modification. In such a situation, a freeze should be invoked on the trainer design so development can proceed without upheavals and delays caused by changing specifications. Following completion of the software, an update phase should be planned to allow incorporation of backlogged change requests.

On the PTT project, the OAS was being built while TSC, with considerable help from SAC, was writing the functional specifications for the trainer. This task required an understanding of how the OAS would work in order to define how the PTT should support the procedures identified as training requirements. Difficulty in obtaining and understanding existing OAS documentation and coping with changes to the OAS resulted in a significant schedule slip. Working with these specification changes had one benefit: the software team recognized the need for a flexible software design to accommodate the inevitable changes in the future and obtained a good understanding of where changes might occur in the OAS.

Even when the actual system is stable throughout development of the trainer, future changes to the weapon system which must be reflected in the trainer are likely. Accepting the fact that changes are unavoidable, the trainer developers should be encouraged to provide flexibility for future changes. Design tradeoff decisions should favor the straightforward, easily modifiable approach over a more efficient method requiring a complete redesign if one of the requirements changes. As an example, one technique used by TSC is to provide many of the system parameters in separate data files that can be easily changed without affecting any of the code which uses this data.

Some of the techniques suggested for helping to meet short schedules also facilitate incorporating requirement changes: producing PDL ensures that the software design is documented, making it easier to see the impact of a change; using a high-level language and PDL as comments in the code makes the code more understandable, facilitating coding changes; and reviewing PDL and code results in a more flexible design and code to accommodate future changes.

SUMMARY

We have discussed why shortened schedules and changing requirements are often associated with the development of training systems. These conditions increase the probability of schedule slips and cost overruns or delivery of an unacceptable training device if the development plan does not adequately provide means of dealing with them. Several techniques used by TSC to minimize the impact of problems caused by schedule slips and requirement changes were presented. These techniques are being applied to the B-52 OAS Part Task Trainer, which was briefly described.

A major technique for dealing with potential schedule problems is top-down development. As described with specific examples from the PTT, top-down development entails the implementation of successive versions of the trainer so that, if delays occur, a working version of the partial system is available on the original deadline while development of the complete device continues. An important part of the definition of versions for top-down development is ranking the priority of training requirements to schedule the more critical functions in the earlier versions, maximizing usefulness of the working versions while the trainer is completed. Program design language as well as design and code reviews are other

```
          TITLE BUFFER KEYBOARD INPUT (BKI)                                                        8:55:13  06/22/79
C
CD        ****************************************************************************************
CD        NAME:     CURSOR TAB                          TASK:  BKI
CD        PURPOSE:  POSITION THE CURSOR ON THE MENU IN ACCORDANCE WITH THE
CD                  CURSOR POSITION ENTERED BY THE USER.
CD        METHOD:   A CIRCULAR SCHEME IS EMPLOYED.  THE CURSOR ALWAYS CIRCLES
CD                  AROUND IN THE SAME COLUMN OR THE SAME ROW.  WHEN AT THE
CD                  BOTTOM OF A COLUMN, A DOWN TAB CAUSES THE CURSOR TO
CD                  'CIRCLE' TO THE TOP OF THE SAME COLUMN.  WHEN AT THE
CD                  TOP OF A COLUMN, AN UP TAB CAUSES THE CURSOR TO 'CIRCLE'
CD                  TO THE BOTTOM OF A COLUMN.  THE LEFT
CD                  AND RIGHT TABS HAVE THE SAME EFFECT.  THAT IS IF THERE
CD                  EXISTS ANOTHER COLUMN (POSSIBLE ONLY IN COMMAND SELECT)
CD                  THEN LEFT OR RIGHT POSITIONS THE CURSOR IN THE NEXT
CD                  COLUMN.
CD        INPUT PARAMETERS:
CD                  CURRENT INPUT STATE (FOR BKI)
CD                  COMMAND ID
CD                  PARAMETER ID
CD                  CURSOR KEYSTROKE (FROM MOC KEYBOARD)
CD        OUTPUT PARAMETERS:
CD                  COMMAND ID (UPDATED)
CD                  PARAMETER ID (UPDATED)
CD                  COMMANDS FOR THE MOC TO POSITION CURSOR
CD        DATA BASE USAGE:
CD                  NONE
CD        INVOKING METHOD:
CD                  INVOKE CURSOR TAB
CD        INVOKED BY:
CD                  COMMAND SELECT KEYSTROKE (TO POSITION CURSOR)
CD                  PARAMETER SELECT KEYSTROKE (TO POSITION CURSOR)
CD        BLOCKS INVOKED:
CD                  NONE
CD        ****************************************************************************************
                    BLOCK CURSOR TAB
1                   .   IF DOWN CURSOR KEYSTROKE
2                   .   .   IF AT THE BOTTOM OF A COLUMN
3                   .   .   .   PUT CMNDS IN MOC BUFFER TO POSITION CURSOR AT TOP OF COLUMN
2                   .   .   ELSE : NOT AT THE BOTTOM OF A MENU
3                   .   .   .   PUT CMNDS IN MOC BUFFER TO POSITION CURSOR AT NEXT ROW DOWN
2                   .   .   ENDIF
1                   .   ORIF UP CURSOR KEYSTROKE
2                   .   .   IF CURSOR IS AT THE TOP OF A COLUMN
3                   .   .   .   PUT CMNDS IN MOC BUFFER TO POSITION CURSOR AT BOTTOM OF COLUMN
2                   .   .   ELSE : NOT AT THE TOP OF A MENU
3                   .   .   .   PUT CMNDS IN MOC BUFFER TO POSITION CURSOR AT NEXT ROW UP
2                   .   .   ENDIF
1                   .   ORIF KYSTRK IS LEFT/RIGHT AND NOT IN PARAMETER SELECT INPUT STATE
2                   .   .   IF THERE ARE TWO COLUMNS & MENU COMMANDS IN THE NEXT COLUMN
3                   .   .   .   PUT CMNDS IN MOC BUFFER TO POSITION CURSOR INTO NEXT COLUMN
2                   .   .   ENDIF
1                   .   ORIF KEYSTROKE IS A HOME KEYSTROKE
2                   .   .   PUT CMNDS IN MOC BUFFER TO POSITION CURSOR AT TOP OF MENU
1                   .   ENDIF
1                   .   IF CURRENT INPUT STATE IS COMMAND SELECT
2                   .   .   MODIFY COMMAND ID
1                   .   ELSE : CURRENT INPUT STATE IS PARAMETER SELECT
2                   .   .   MODIFY PARAMETER ID
1                   .   ENDIF
                    ENDBLOCK : CURSOR TAB

          CD        ****************************************************************************************
```

Figure 3. Program Design Language (PDL)

techniques that help to avoid schedule slips and facilitate requirement changes.

Programmer familiarity, ease of use, and availability of required operating system functions and software tools are factors which should be considered in selecting the computer for the training device in order to help meet shortened schedules.

REFERENCE

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ANTI-ARMOR MISSILE FLIGHT SIMULATOR

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ABSTRACT

This paper describes a missile flight simulator developed to train DRAGON gunners. It is also being adapted to a variety of similar anti-armor weapons. The system employs a terrain board with enemy armored vehicles moving in a variety of attack scenarios. When the gunner fires the missile he hears computer generated rocket sounds and experiences the weight loss, recoil and smoke of the missile launch. When the smoke clears he views the missile as well as the target. The gunner's aiming error is measured using a microprocessor controlled diode matrix array. The matrix detector senses an IR emitting diode which is located on the miniature target. The flight equations of motion for the missile are solved by a 16 bit microprocessor every 0.02 seconds in each axis using gunner aiming error, gravity, drag and side thruster accelerations as inputs. A second coordinated 16 bit processor controls a display that plots both vertical and horizontal aiming error for analysis of the gunner's performance. Experienced DRAGON gunners have tested the system and attested to the realism and training potential.

INTRODUCTION

Training in the firing of modern anti-armor weapons is expensive. Each live round costs thousands of dollars.

This paper describes a system that uses advanced electro-optics and microprocessor technology to enable training of DRAGON gunners at a reasonable cost.

The DRAGON is a command-to-line-of-sight guided missile system. Fired from a recoilless launcher, the missile is tracked optically and guided automatically to the target by electrical impulses transmitted via a wire link. Firing the missile is accomplished by depressing the safety and squeezing the trigger. No other action is required of the gunner except to keep the sight cross hairs on the target. However, to score a hit the trainee must overcome many perturbations that can spoil his track.

When the trainee fires the training device he hears the gyro wind-up noise and then the initial explosion of the rocket motor. He experiences a weight loss due to the rocket exiting the tube as well as a recoil force. Momentarily he is blinded in the sight by simulated smoke. The trainee must overcome such launch transients. He must then track the target smoothly and ignore the simulated missile which he can see in his sight. Thruster rocket firing sounds are included as well as the final hit or ground impact explosions. A visual indication of hit is also inserted into the gunners sight.

During missile flight the instructor can monitor two displays. These displays show:

1. The gunner's sight picture and the DRAGON's location

2. A plot of gunner aiming error versus time and the gunner error tracking limit envelopes. Thruster firings are annotated on the display.

This system uses a 16 bit microprocessor to solve the flight equations every 0.02 seconds in each axis using the gunner's aiming error, gravity, drag and thruster rocket acceleration as inputs. The solution also incorporates the dynamic performance of the tracker (See Artist's concept).

Key features of the system are summarized below.

- Smoke Obscuration
- Recoil
- Weight Loss
- Missile superimposed on gunner's view of scenario
- Sounds - thruster firings, launch, hit and miss explosions
- Gunner aiming errors versus time displayed in real time

- Can operate for night scenes to simulate a thermal sight
- Missile position versus time which can be recalled along with gunner aiming errors in azimuth and elevation for analysis
- Cost of expensive tank target and missile not required for training
- Target hit or miss distance determined by solving DRAGON flight equations in real time
- Number of thruster rockets ideal versus actual displayed for each scenario
- Portable
- Record and play back capability
- Can operate with and without an instructor
- Operator's pull down force on DRAGON launcher and eye cup pressure is measured
- Variety of target speeds and motions simulated
- Trainer flies like real missile because of computation of flight parameters

The system has been tested by both U.S. Army and U.S. Marine Corps DRAGON gunners. Further development of the trainer is now being accelerated.

SYSTEM APPROACH

The system is shown in Figure 1.

Targets in this system are miniature models. Models were chosen because they have better resolution than either computer generated imagery or a movie display. In DRAGON a 6X scope is utilized. In other weapons even higher power sighting scopes are utilized, thus demanding a high resolution visual scenario.

Models are moved on a terrain board using a stepper motor under the control of a single chip microprocessor. Located at the center of aim of the target is an infrared emitting diode (IRED). Engagement scenarios are stored in the Personnel Interface Processor (PIP) and one is selectable from the instructor's console by an input terminal. The stored scenario programs contain the tank target's velocity, direction and range. Located in the DRAGON launch tube is a photo diode array camera. This 100 x 100 matrix camera is boresighted to the gunner's sight and used to determine the gunner's aiming error (GAE) which is input to the DRAGON Flight Simulator Processor (DFS). This processor solves the DRAGON flight equations and provides DRAGON status to the Personnel Interface Processor (PIP). The PIP controls the graphics units which inserts the missile, smoke, hit, etc., into the gunner's sight. This processor also controls the Gunner Aiming Error (GAE) display on the Instructor's Console. This display plots GAE versus time, in real time. The DRAGON Flight Simulator Processor produces launch and target explosions, thruster rocket firings and gyro noises. The thruster rocket firings are delayed to allow for the speed of sound versus the visual phenomena of the rocket firing which is optically inserted in the DRAGON gunner's sight. Rocket thruster noises are attenuated as a function of distance.

A CCTV is located on the DRAGON tube and boresighted to the gunner's 6X sight. This TV provides the instructor the same view seen through the gunner's sight. The Gunner's Sight Picture Display is located on the instructor's console. The DRAGON rocket as seen by the trainee is also mixed into the gunner's sight picture visual display.

SUBSYSTEM DESIGN APPROACH

Electro Optics Subsystem

Gunner aiming errors are determined using a 100 x 100 matrix camera. Functionally the camera is similar to a Vidicon camera except that the sensor has been replaced with a solid state photodiode array matrix having 10,000 pixels. The choice of lens determines the field viewed by the camera. Using a 125mm focal length lens and a model distance of 22 feet, the available field of view is 1.05 ft or 48 milliradians. This FOV will accommodate the maximum excursions allowed for DRAGON i.e., 32 mr horizontal and 22 mr vertical.

For a 1.05 ft FOV one pixel represents 0.126 inches on a terrain board.

Since the array is square the lengths in the X and Y axes are identical. The magnification of the camera is the ratio of the FOV to the length of the array:

$$\text{Magnification} = \frac{\text{FOV}}{\text{Array Length}}$$

where the array length is = 0.24 in. (0.60 cm total width/height) in both X and Y.

$$M = \frac{1.05 \times 12}{0.24} = 52.5$$

The static resolution is the array element spacing imaged into the object plane.

Resolution = Magnification x element spacing

Resolution = 52.5 x 0.0024 in = 0.126 in.

This is equivalent to ± 7.5 inch resolution on a real world tank at a scaled range of 2640 feet.

This means the smallest detectable change in a stationary object we can detect is 0.126 inches using a 125mm focal length lens. If a longer focal length lens is used the FOV is decreased and the resolution is improved.

Accuracy also depends on: image sharpness, contrast, vibration or movement of the object, light level and threshold setting of the camera.

The camera used is blemish free.

An IRED is located on the target and the center of the IRED's energy calculated to determine hit location.

Because the IRED produces uniform illumination, the threshold setting on the camera can be adjusted to a fixed level, thus eliminating background interference.

Data from the photodiode array are electronically scanned to produce a sampled-and-held video output signal. The amplitude of each pixel is proportional to the incident light intensity integrated over the interval of one frame period. The camera essentially detects light to dark transitions of the digital area. The scene present on the camera is a light circle on a dark background. Transition data from the camera, stored as a digital line-by-line picture of the array, is handled by an interface unit. The DRAGON Flight Simulator Processor determines the GAE from the transition data.

Microprocessor Subsystem

The microprocessor subsystem includes six units with five being housed in the system chassis. The principal function of each of the separate units is:

1. Personnel Interface Processing (PIP)
2. DRAGON Flight Simulation (DFS)
3. Sound Generation (SG)
4. Target Control (TC)
5. TV Display (TVD)
6. Photodiode Array Processing (PAP)

System I/O is processed by the PIP, which is covered in the Computer Graphics and Video Subsystem section.

Target control is detailed in the Miniature Target Board section.

Descriptions of the DRAGON Flight Simulator and the Photodiode Array Processor follow in the next two sections.

DRAGON Flight Simulator

The McDonnnell Douglas Astronautics Company, Titusville Division, under Contract N61339-80-M-3518 provided a set of simplified equations and a computer program that approximate the DRAGON missile flight as directed by the gunner.

Six-degree-of-freedom equations are required to express the complete missile dynamics. Solutions of such equations were examined and simplified as much as possible by McDonnell while still maintaining a statistically accurate representation of weapon performance. Some of the simplifying assumptions were:

1. Missile dynamics should be represented by a point mass solution,
2. Small angle approximations to be used,
3. The effect of tracker sampling on missile trajectory while in the linear field of view to be neglected.

The six-degree-of-freedom equations thus modified were exercised and compared to results obtained from the complete equations of motion. Modification to the thrust level and guidance parameters were made to tailor the trajectory to the more exact results. Sufficient comparative analysis was conducted to assure that the simplified equations gave acceptable results over a range of crossing and stationary target conditions and with a variety of gunner aiming errors.

Figure 2 is the DRAGON simulation block diagram. The variables correspond with those of Figure 3 which defines the important horizontal angles. These, and a similar set of vertical angles, were used in the McDonnell BASIC program which iterates the differential equations of motion using a "Delta Time" of 20 milliseconds. Thus a 10 second missile flight requires the generation of 500 solutions of the equations of motion.

The BASIC program was rewritten for an Intel Microprocessor Development (MDS) System. The resulting program, while able to reproduce the McDonnell results, required several minutes to complete the 500 solutions for a simulated 10 second missile flight. It was, therefore, unsuitable for real time training.

An investigation of other floating-point-math techniques usable with Intel SBC-86/12, 8086, computers showed that real-time solutions of the missile flight could not be accomplished without using an 8087 coprocessor. The non-availability of the 8087 made it necessary to abandon the convenience of FP-math and recast the equations using integer arithmetic. This required close attention to the choice of suitable units for the variables because of the limited range of integer numbers: (-32,767, +32,767). Down-range distances, for example, are expressed in 2-inch units; 1000 meters (39,370 inches) being considered to be 19,685 "Down-range" units. Cross-range units are 0.05 inches for distances and 0.1 milliradians for angles. Unit selection is a compromise between the conflicting requirements of the desire to display variables over a wide range and the need to reduce the quantization distortion while not exceeding the allowable integer range. Many comparisons between the integer and BASIC program results have verified that good approximations to the DRAGON Flight characteristics are provided using integer arithmetic. Comments by experienced DRAGON gunners also support the validity of the approximations.

The DRAGON Flight Simulation Program includes five modules:

1. Main-DRAGON-Module: A "Driver" module which calls other modules.

2. DRAGON-utility: Includes a number of start-up and other general procedures.

3. DRAGON Flight Module: Includes the integer math missile dynamics, provides missile location information to the PIP, stores location data for possible reprise, and does the initialisation of flight variables.

4. DRAGON IR: Analyzes the IR-spot data array provided by the DRAGON XF module.

5. DRAGON XF: Transfers line-by-line data provided by the photo-detector line array processor into a complete picture array.

The first three modules are written in PLM 86; an Intel high level programming language. The last two are in 8086 assembly language. Total program code require slightly under 4K of ROM memory. Variable memory requires about 1K of RAM.

As noted previously, the program ROM is located on an Intel SBC 86/12 board. This board, along with four others are housed in an Intel SBC 86/12 system chassis which provides eight card slots, power supply and ventilation. Cards within the chassis can communicate via the multibus motherboard. An SBC 86/12 provides dual-port RAM which can be accessed by both the on-and-off-board processors. Missile position data resulting for the solution of the missile equations of motion are transferred to the PIP via the multibus for further processing and output. Data status bits are also read and written across the multibus as required.

Target motion is provided as described in the section on Miniature Modelboard. It is programmed via a stepper motor controller into which the desired target maneuver is input from a suitable menu item located in program memory of the PIP. Identification of the selected maneuver is posted within dual-port memory and therefore may be read by the DFS in order to make possible appropriate target position calculations as required by the missile equations of motion.

The DFS also provides control signals to the sound generator for side-thruster pops, ground explosion and target hits. It also provides signals for weight loss in response to trigger pull.

Photodiode Array Processor

Line scan data from the 100 x 100 photodiode array are initially stored in a set of ping-pong memories on a Reticon RSB 6020 board housed within the system chassis and attached to the multibus. Data are alternately read into ping or pong memory under control of a clock located within the Reticon RS 520. Data within the memory units gives the location of light level transitions and indicates whether it is a light-dark or dark-light transition. The stored data also indicate when the last scan line is read.

After initialization, a last-line flag is output across the multibus to the DFS which causes the DRAGON XF program to begin the transfer of data from each line of the next 100 x 100 photodiode array frame. The data read-out is then halted by the next occurrence of the last-line flag. The 100 x 100 frame data are ignored during the next frame data analysis. New frame data are thus provided every other frame.

The frame rate of the Reticon camera is 100 frames per second so new IR-spot position data are provided 50 times a second or with a 20 millisecond period. Occurrence of the last-line flag acts as the master system clock with all data processing starting with its assertion.

Computer Graphics and Video Subsystem

The DRAGON computer graphic visual presentation is prepared by the Personnel Interface Processor. In addition to this processor a computer graphics board, a phase-locked-loop sync board, and an EIA composite sync generator is used. Figure 4 shows the complete graphics and the video subsystem.

Computer generated graphics provide two major functions:

1. Real-time video graphics are generated for the gunner sight. These graphics include a simulated missile which includes thruster firings, smoke obscuration during initial launch and a final explosion.

2. Real-time graphics are generated for the instructor which indicate both vertical and horizontal gunner aiming errors. Also, for follow up analysis, graphics may be presented for gunner aiming error versus time and missile position versus time.

Gunner's sight computer graphics are generated on a 256 x 256 x 4 graphics board. Sixteen levels of gray scale provide for a full range of visual intensity which allows for smoke generation which varies from fully transparent to completely opaque. The computer generated graphics are passed directly to the gunner's sight through a one and a quarter inch closed circuit television (CCTV) monitor. The optical arrangement is shown in Figure 5. The television screen appears at infinity along with the viewed scene through the 6x scope. The CCTV is mounted inside the DRAGON IR tracker housing and electronics for the CCTV are located where the IR tracker electronics were located at the bottom of the tracking unit.

The instructor console graphics subsystem is composed of two units, a television representation of the gunner's sight picture and a graphical plot of gunner aiming error versus time and/or gunner aiming error versus missile position.

The television representation of the gunner's sight is accomplished by mixing the gunner's sight TV camera, which is boresighted to the 6x gunner sight, with the video graphics presented to the gunner's sight. The composite picture presents to the instructor an image of the gunner's sight which includes the target, missile, smoke, crosshairs and final explosion.

The graphical plot of the gunner aiming error (GAE) versus time for both horizontal and vertical error are presented in real-time during the missile flight. The graphs indicate the actual gunner aiming error during the flight as well as the limits for a 95% probability of hit performance. The guidance rocket thruster firings are shown when they are fired as well as a final actual count of the thrusters fired versus the ideal number of thrusters that would have been fired for a given target distance with perfect aim. At the end of a flight displayed results show the miss distance, in feet, where the missile passed the target. If the missile strikes the ground before passing the target, a message is displayed stating "ground impact" as well as the remaining distance to the target when grounded. If a hit is scored a hit message is displayed to mark the event.

After a missile flight a reprise of the flight may be called. A horizontal reprise replays the horizontal GAE and the horizontal missile position versus time. Likewise the vertical reprise replays the vertical GAE and the vertical missile position versus time. The reprises indicate all the hit/miss summaries of the first real-time plot.

Any of the computer graphic plots may be made into a hard-copy printout. The hard-copy may include the gunner's name or other pertinent data as desired by the instructor.

Computer Generated Sound System

Simulation of sounds produced during an actual DRAGON missile firing is accomplished by interfacing an Intel 8748 microcomputer to a General Instruments AY-3-8910 Programmable Sound Generator (PSD). Data necessary for the PSG to reproduce sounds is acquired from the permanent memory of the microcomputer. During missile flight time the DFS processor simply selects the sound to be made and communicates its choice to the microcomputer. This approach allows the processor to handle sound-making decisions with minimum time taken from its primary functions.

The choice of sounds available to the DFS processor are:

1. Gyro start-up
2. Missile launch explosions
3. Rocket thruster motor firing
4. Target missed explosions
5. Target hit explosions.

The General Instruments Programmable Sound Generator (PSG) is a 40 pin, eight bit device with microprocessor compatibility. The device features three independent analog channels each with access to its own tone generator. A 16 control register array communicates to the microcomputer through an eight bit bi-directional port. Four lines are allotted for bus control logic (read and write). Each tone generator looks to two registers within the array for a 12 bit tone period. A range of frequencies covering the full eight octaves of the equal tempered chromatic scale is available.

Psuedo-random noise may be mixed to any or all channels from a noise generator with basic frequencies of 4 KHz to 125 KHz. Two modes of output control are available for each channel. The fixed level amplitude mode selects an amplitude specified in the array by the microcomputer. For use in this system the variable amplitude mode is selected, forcing an envelope generator to control the shape and cycle of all outputs. Controlling the envelope generator is a 16 bit tone period within the array allowing for frequency ranges of 12 Hz to 7812.5 Hz and a five bit shape/cycle control register. Three D/A converters supply 0 to 1 volt signals to the output channels.

To accurately represent the flight of a DRAGON missile as it moves down-range two sound phenomena must be simulated:

1. Time delay due to the difference in the speeds of light and sound, and

2. Logarithmic sound amplitude decay due to distance sound must travel through air.

Software developed for the microcomputer closely approximates these conditions within a 1000 meter range.

As shown in Figure 6, the outputs of the PSGs are input to circuits which function to control the amplitude of the sound. These circuits consist of operational amplifiers with closed loop gains under direct control of the microcomputer. The DRAGON Flight Simulator processor initiates a timer within the microcomputer upon request of a launch explosion. Thereafter, each request for a sound by the processor causes the microcomputer to inspect the timer. Assuming the missile travels at an average speed of 280 feet per second the microcomputer is able to approximate the distance covered and set the appropriate gain. For rocket thruster firings, the microcomputer selects one of thirteen levels of amplitude, decreasing logarithmically from a gain of ten to one over a time span of 11 seconds corresponding to a distance of 1000 meters.

Time delay associated with distance covered by the missile is accomplished upon inspection of the timer for each requested sound after launch. Before signals are passed to the PSG to create a sound, software completes a sequence of three delays. The first delay represents the real-time between requests from the DFS processor. This timeout occurs only when two or more requests are made before the first request is serviced by passing signals to the PSG. The real-time between any two requests represents distance traveled by the missile and is decoded into the second time delay as determined by the time required for sound waves to travel this distance. The incremental time delays are accumulated in the microcomputers data memory. The third time delay before a sound is made is the cumulative total of all the second time delays that have already been decoded. The complete algorithm produces a series of logarithmically decaying, time delayed, sound waves that approximate the actual conditions within a 1000 meter range.

Miniature Target Board

Because most anti-armor devices use high power telescopes to view the targets, a miniature model was chosen. The target model has an IRED located at the center of the target mass. The model is moved using a stepper motor. The stepper motor controller is a stand-alone intelligent controller that is independent of the host computer, the Personnel Interface Processor, except for loading the scenario. The stepper motor controller uses a high level language for control of the stepper motors direction, position, speed and acceleration. Scaled to the real world the tank location is known to 0.9 inches.

Weight Loss and Recoil Mechanism

Launch effects of the DRAGON simulator are a very important facet of the training mission. Two of the launch transients which must be overcome by the DRAGON gunner are the weight loss due to the missile leaving the launch tube and the recoil of the launcher due to slight uncompensated differences in the pressures at launch. Weapon launch effects of weight loss and recoil are simulated via mechanical attachments to the DRAGON bipod.

The recoil mechanism is a sliding platten upon which the DRAGON bipod and gunner's feet are supported. The platten is covered with a rubber and steel hybrid material that allows the gunner to firmly plant the bipod legs in position and stabilize the launcher using his boots to press against the bipod supports. At launch the platten is given an impulse from a pneumatic solenoid thus imparting a sensation of recoil to the launcher.

The weight loss simulation is accomplished by a weight mass that is attached to the bipod via a pivot and pneumatic cylinder. When the DRAGON simulator is armed for launch, the pneumatic cylinder is energized which in turn raises the weight and places an additional equivalent weight of the DRAGON missile on the shoulder of the DRAGON gunner through mechanical leverage. When the simulated missile is launched, the pneumatic cylinder is relaxed, thus releasing the weight and effectively removing the equivalent missile weight from the gunner's shoulder.

CONCLUSION

This simulator has undergone preliminary evaluation by a United States Marine Corps Fleet Project Team of experienced DRAGON gunners. All gunners were favorably impressed with its realism and teaching attributes. Testing of the device is planned for the fall of 1981 by both the United States Marine Corps and the United States Army. Results of these tests will be reported at the conference.

The authors wish to gratefully acknowledge the support of both the Marine Corps and United States Army, PM TRADE on this program. We specifically wish to thank Major Don Head, USMC and A. J. Boudreaux - PM TRADE for their valuable suggestions and help.

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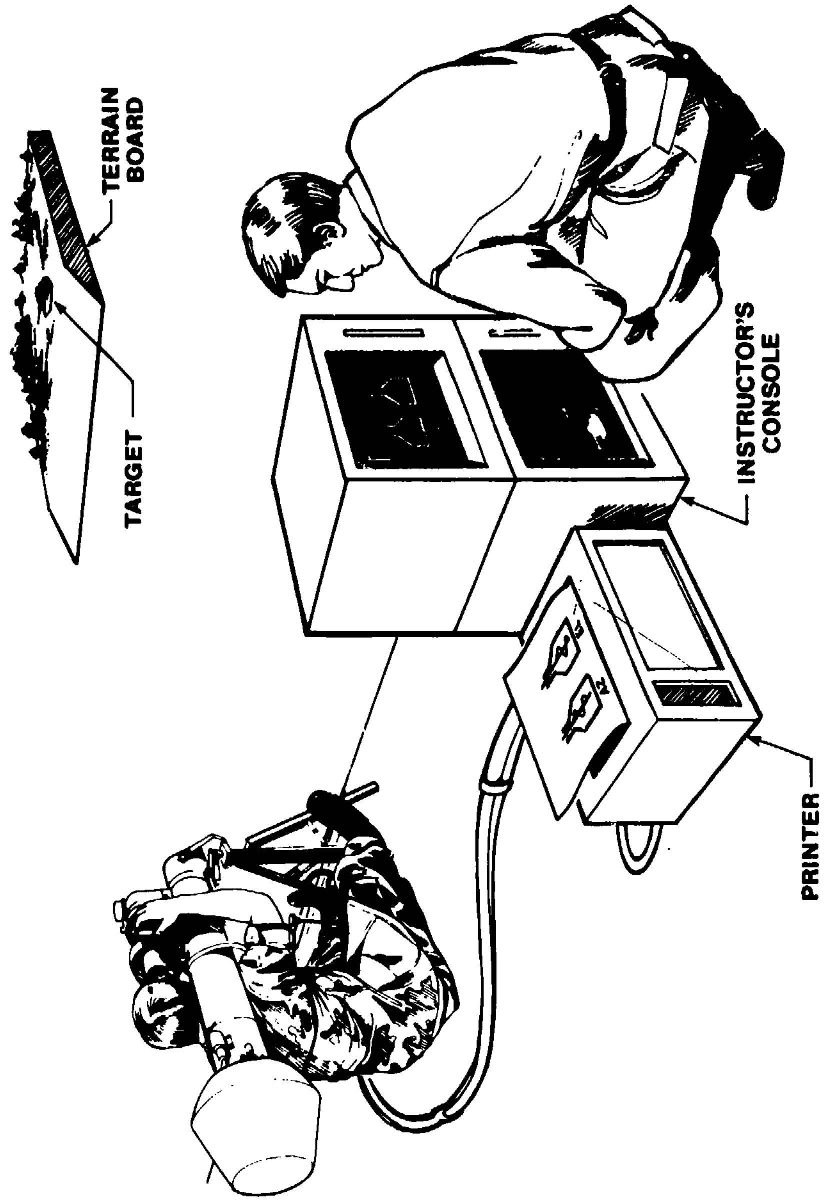

ARTIST CONCEPT
DRAGON TRAINER

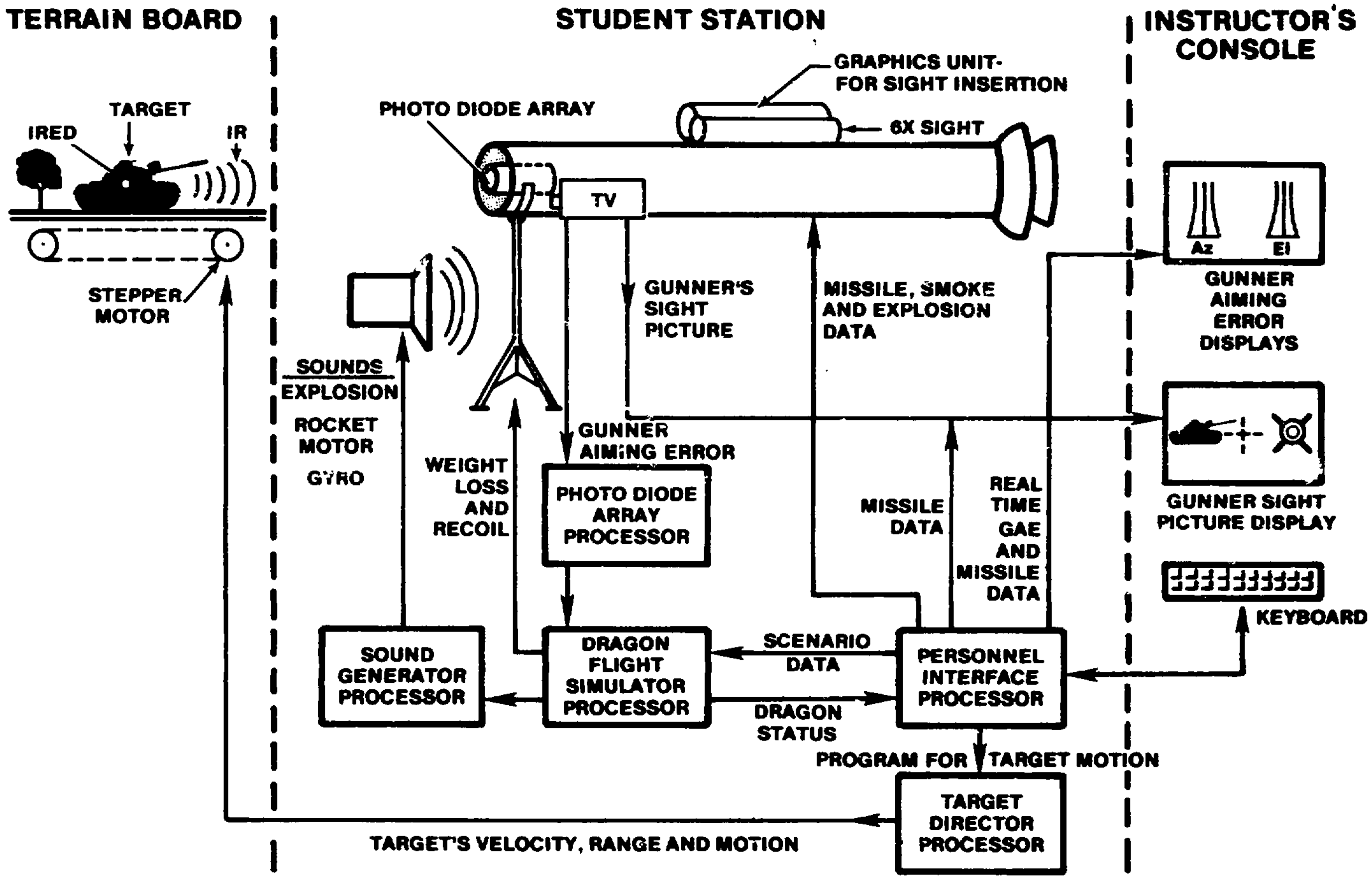

FIGURE 1. SYSTEM BLOCK DIAGRAM

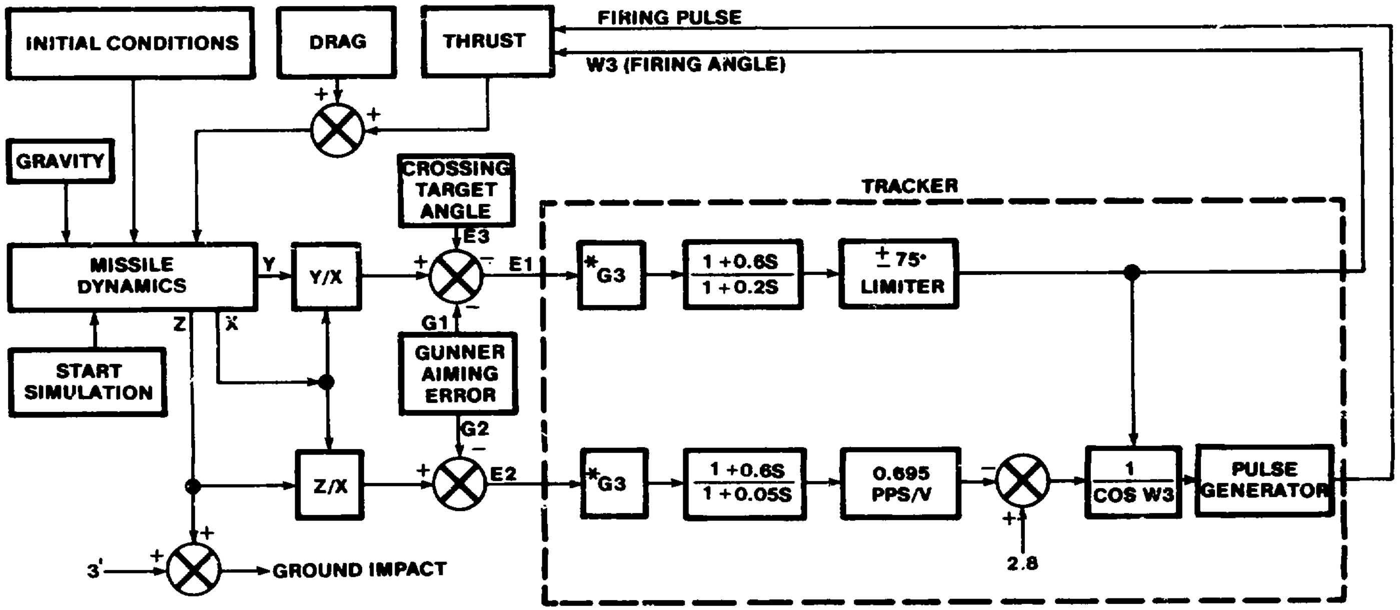

FIGURE 2. SIMULATION BLOCK DIAGRAM

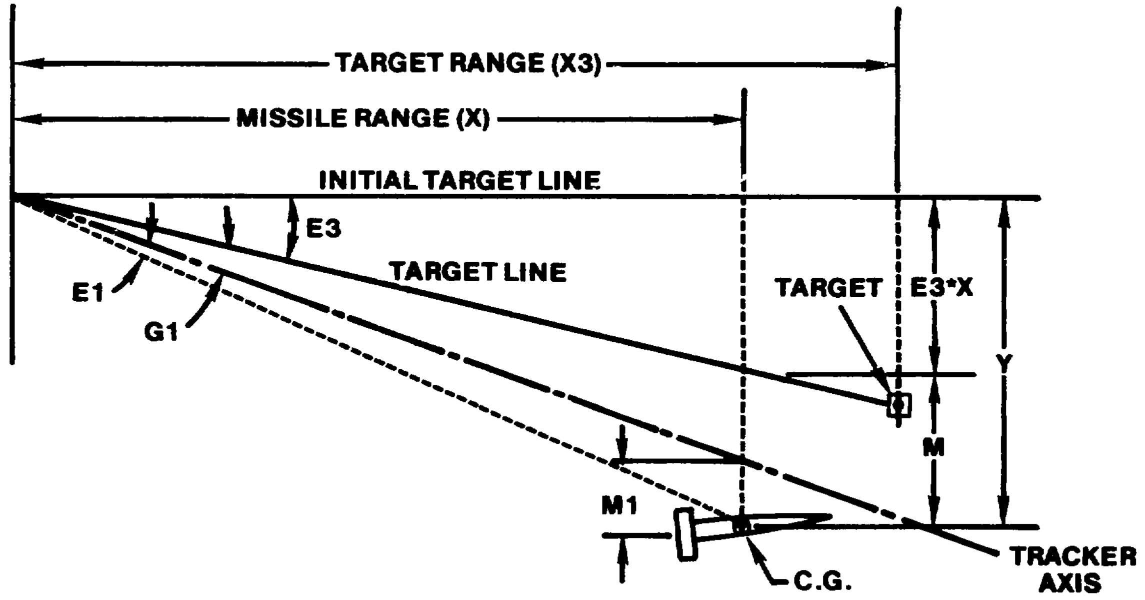

FIGURE 3. HORIZONTAL PLANE GEOMETRY

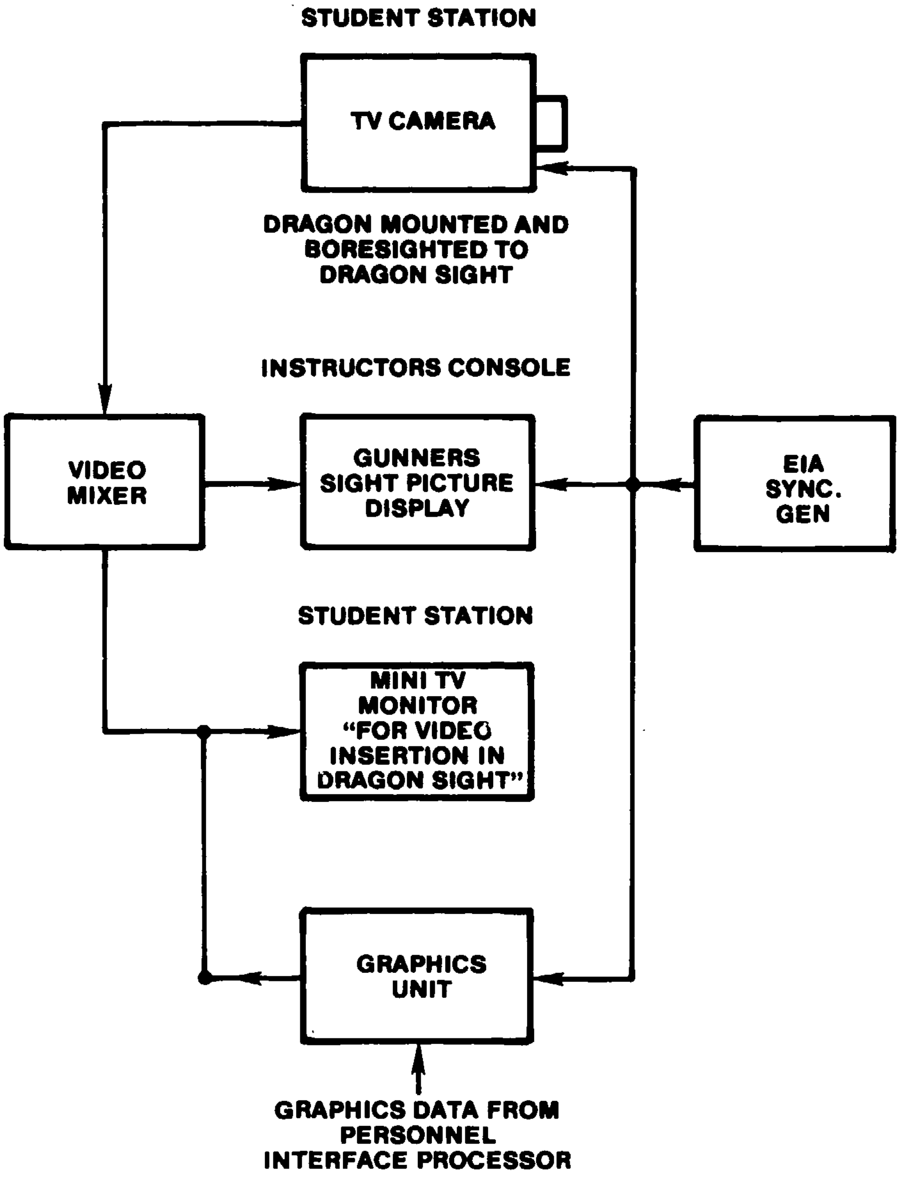

FIGURE 4. COMPUTER GRAPHICS AND VIDEO SUBSYSTEM

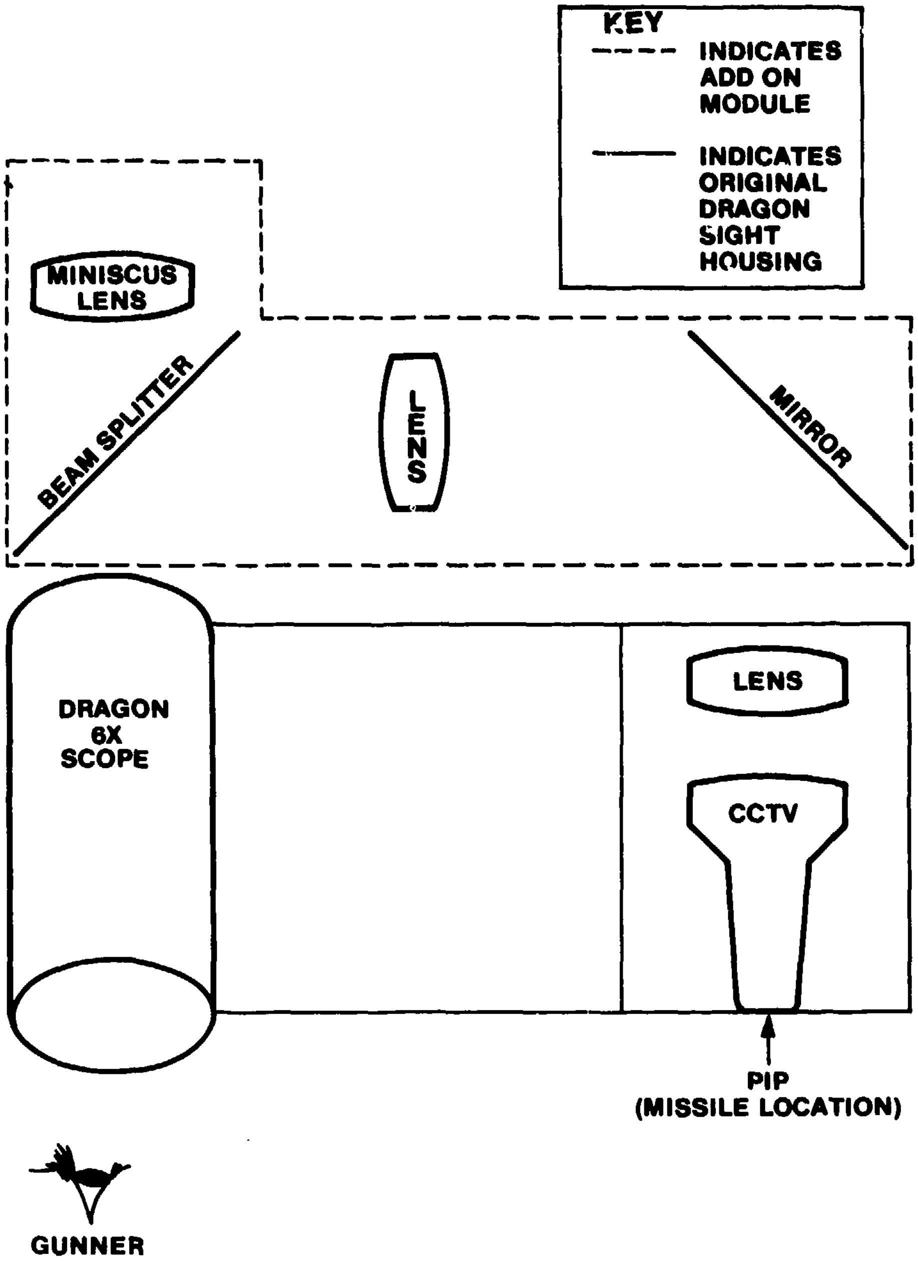

FIGURE 5. DRAGON GUNNER'S SIGHT SYSTEM

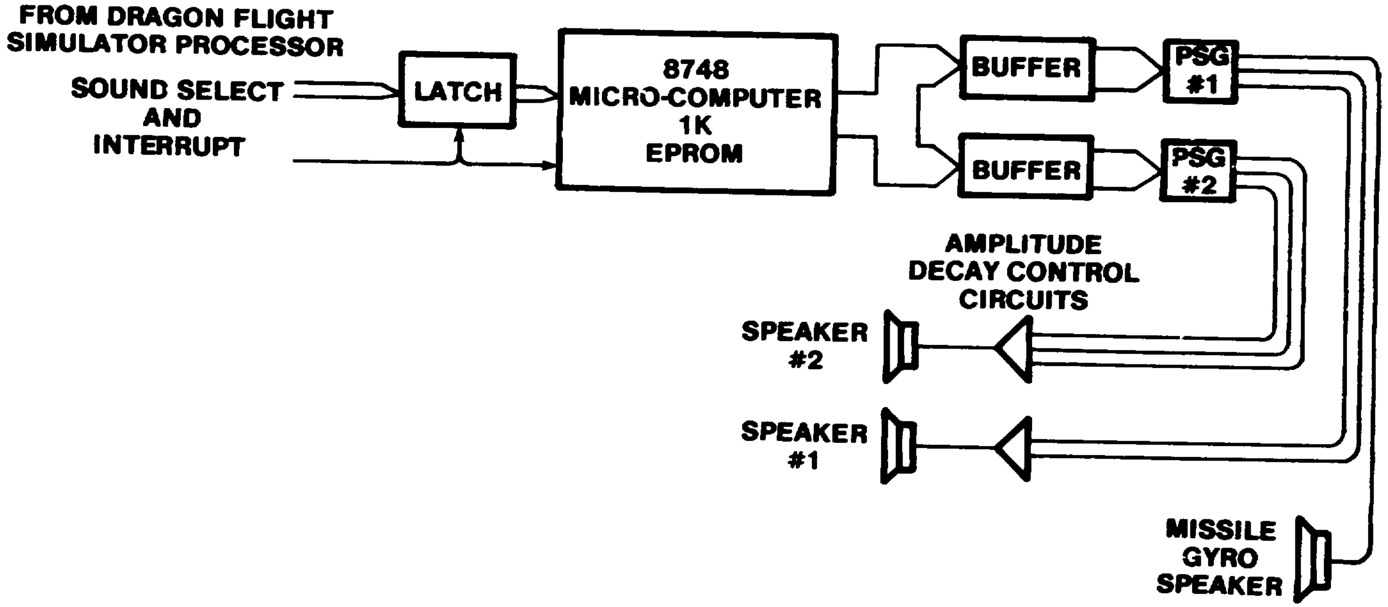

FIGURE 6. SOUND GENERATOR HARDWARE LAYOUT

PHANTOM RANGE - AN EW TRAINING SYSTEM

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ABSTRACT

Confronting NATO tactical air is a spectrum of Warsaw Pact defenses including SAMs, AAA, and airborne interceptors plus jamming of communications, fire control radars, and navigation equipment. Aircrews faced with this array, trying to perform their primary mission, must be trained to cope with the total anticipated task-loading and at the same time become neither casualties nor disoriented such that they fail to achieve their mission objective. Current training on large EW ranges is considered inadequate due to the limited accessibility and the infrequency with which aircrews can experience such training. The Phantom Range, an onboard, computer-generated threat simulator, can be programmed to provide threats at given geographic locations, independent of ground emitters, with appropriate envelopes modified by actual existing terrain. It allows the aircrew to defeat the threat by exercising proper procedures, or be "killed" if their actions are inappropriate. The whole scenario is recorded for ground debriefing.

INTRODUCTION

Phantom Range is an onboard, computer-generated threat simulation system that enables aircrews to interact with defensive scenarios during actual combat training missions and perfect their techniques in exercising appropriate defeat procedures independent of ground emitters (Figure 1). The system offers the capability to incorporate scenarios of varying complexity, in terms of varying locations, numbers, and kinds of threats. It provides real-time feedback of success or failure in accomplishing the proper procedures in a timely manner. Finally, it records encounters so that the aircrew can debrief, observing the actual displays that were seen during each engagement.

THREAT

Readiness of tactical air forces combines the availability of weapons systems, ordnance, and logistics support; the inherent capability of the weapons system itself; and most important, the ability of the aircrews to cope with all of the composite stresses of a combat situation and still function effectively to perform their primary offensive missions (Figure 2). This last, considering the anticipated threat, is a momentous task.

The threat consists of a very dense and effective array of surface-to-air weapons (SAMs and AAA), airborne interceptors, and electronic countermeasures (Figure 3). Communications jamming not only impairs command and control, it also serves as an annoyance and a distraction to aircrews. Jamming of forward-looking radars inhibits the ability to use this system for terrain avoidance or following. And of course jamming of navigation systems, or even worse, sending of false signals, makes radio navigation systems unreliable or erroneous. Together, these add significantly to the task-loading of crews -- many in single-seat fighters -- crews who are already heavily stressed just to navigate, maintain flight integrity, and accurately deliver their ordnance.

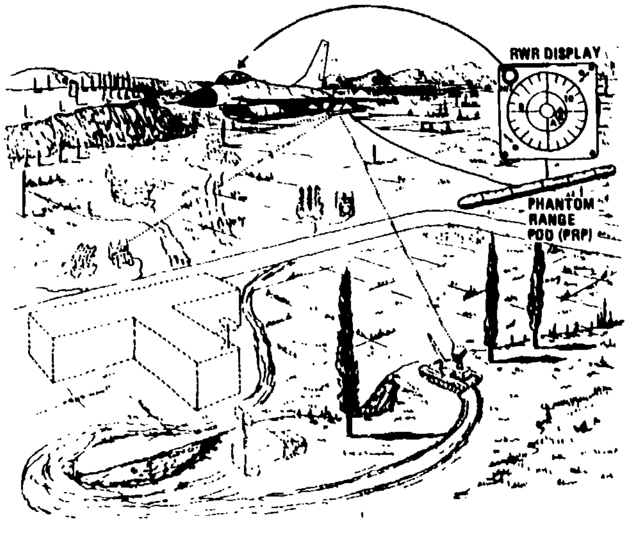


FIGURE 1. PHANTOM RANGE

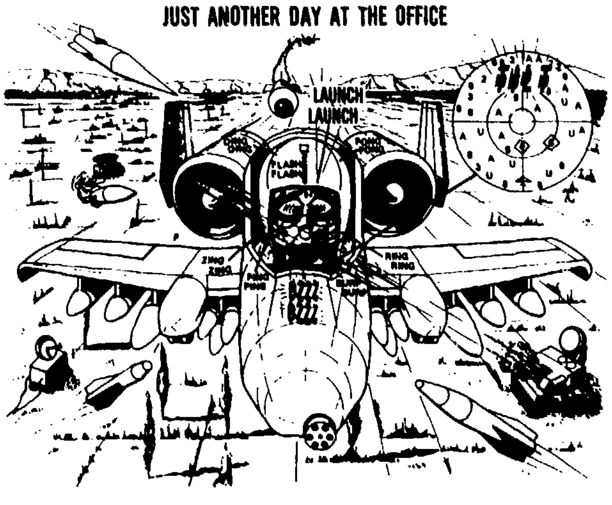


FIGURE 2. THE COMPOSITE STRESSES OF A COMBAT SITUATION

SURFACE TO AIR MISSILES - DENSE, IN-DEPTH, NETTED

AAA - RADAR CONTROLLED, ACCURATE

AIR INTERCEPTORS - INTEGRATED DEFENSE (LESS THREAT TO LOW FLYERS)

COMMUNICATIONS JAMMING - INTERFERES WITH FLIGHT INTEGRITY AND CONTROL, DISTRACTING

AI/FLR/NAVIGATION JAMMING - INCREASED PILOT WORKLOAD AND VULNERABILITY

RESULT: DEGRADED NATO AIR EFFECTIVENESS
LOST AIRCRAFT/AIRCREWS
DISORIENTATION AND MISSION ABORT

FIGURE 3. THREAT

READINESS OBJECTIVE

To achieve the requisite readiness, aircrews must learn to accommodate all of the stresses and distractions and still perform effectively. They must be able to do the following:

- Navigate by dead reckoning only
- Reorient themselves and still reach their targets after performing defensive maneuvers that have driven them off their planned route
- Maintain flight integrity. Flight leaders must be able to direct the flight even though radio communications is unfeasible.
- Learn to respond to threats in a timely, correct manner so as to minimize loss potential
- Concentrate on employing their weapon systems while responding to defensive threats and ignoring distractions.

In summary, they must become completely acclimated to the conditions of the defensive scenario such that they can continue to function effectively in carrying out their primary mission.

TRAINING REQUIREMENTS

To achieve the above, the training program must provide realistic scenarios, crew interaction, and continuation training (Figure 4).

Realistic Scenarios

These scenarios should incorporate as near real conditions as feasible. Needless to say, as in any training situation, the environment should initially be somewhat simplistic: for example, one-on-one. Then, as proficiency grows, the scenarios should become increasingly complex until the aircrews are able to cope with a maze of defensive threats and distractions and still achieve their primary objective. Surprise (encounter with unanticipated threats) should be inherent in such a scenario. Implicit in providing realism should be the effect of terrain. Since terrain masking must be considered one of the most effective ways of evading or defeating a threat, aircrews should be trained to use terrain, taking it into account during mission preparation and instinctively including it in reactive options during flight.

- REALISTIC SCENARIO
  - INTEGRATED OFFENSIVE/DEFENSIVE
  - VARYING DENSITY
- CREW INTERACTION
  - RECOGNIZE, ASSESS, ACT
  - REAL-TIME FEEDBACK
  - NO NEGATIVE TRAINING
- CONTINUATION TRAINING
  - FREQUENT
  - COUPLED TO COMBAT TRAINING MISSIONS

FIGURE 4. TRAINING REQUIREMENTS

Crew Interaction

Crews must be able to exercise prescribed doctrine, be it maneuvers or employment of onboard countermeasures systems, so as to defeat threats. When actions are correct and timely, crews must receive feedback in terms of negation of the threat. When inappropriate, they should receive indications of failure, such as becoming simulated casualties. And most important, they should not receive negative training. They should not experience success if they ignore or react incorrectly. Conversely, they should not continue to be subjected to a threat if they follow the correct procedure.

While it is true that in real life exercise of proper procedures may not always guarantee success, it is most important that the training system not instill in aircrews such subjective scepticism that they not try. For example, if a simple emitter were put on a route and it were to activate the aircraft radar warning system, and if the aircrew were then unable to defeat it by employing their countermeasures in conjunction with prescribed maneuvers, they might eventually learn to simply ignore it. Since following prescribed procedures would add to the difficulty of concentrating on their navigation under such conditions but would do nothing to increase their perceived safety, they would be tempted to do the wrong thing.

To acclimate crews properly, they should have to interact with defensive scenarios every time they fly combat training missions so as to be psychologically prepared each time they start planning a combat sortie.

Continuation Training

Since learning procedures that must be implemented almost as an instinctive reaction requires constant iteration and practice, it is most important that the prescribed readiness criteria entail frequent, continual training of this sort. No one would suggest that a Navy pilot could shoot 10 carrier landings in a 2-week period, once a year, and still be proficient 9 months later -- not unless he were practicing the equivalent on a continuing basis throughout that period.

Since most units do not have access to major hardware ranges on a continuing basis, routine local training today, particularly for tactical air forces stationed in Europe and the Far East, does not permit integrated offensive/defensive training as described above.

PHANTOM RANGE

The Phantom Range, which provides for the desired training on a continuing basis at local installations, consists primarily of a pod -- Phantom Range Pod (PRP) -- carried on a fighter aircraft standard wing pylon (Figure 5). Ground support hardware for the system consists of a Mission Planning and Debriefing Station (MPDS) and a Flightline Support Unit (FSU).

PRP

Inside the PRP (a 6-ft-long by 8-in-diameter pod) is a navigation system consisting of a Loran receiver and a strapdown inertial unit (Figure 6). This navigation system is capable of locating the aircraft position at all times, even during and after hard maneuvers.

The PRP also contains a minicomputer within whose memory is stored the geographic location of various simulated threats and the lethal envelopes modified by actual terrain surrounding those locations (Figure 7). Additionally, in memory are stored threat defeat procedures, be they maneuvers or switch positions of countermeasures equipment.

When the aircraft penetrates the lethal envelope as discerned by the Loran (Figure 8), the computer, having computed azimuth and range, commands the radar warning system to display the proper video signal on the radar warning indicator. It also lights the appropriate lights on the control panel and sends the proper audio signal through the intercom system. If communications jamming is desired, noise can be generated by the audio generator, which is used to construct synthetic radar warning audio signals and which can be injected concurrently into the intercom. (While the system as currently conceived does not provide jamming of the aircraft radar or navigation system, this capability could be added if desired.)

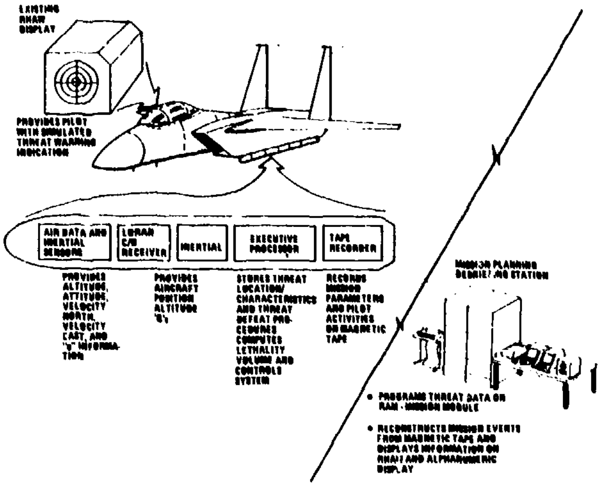


FIGURE 5. PHANTOM RANGE APPROACH

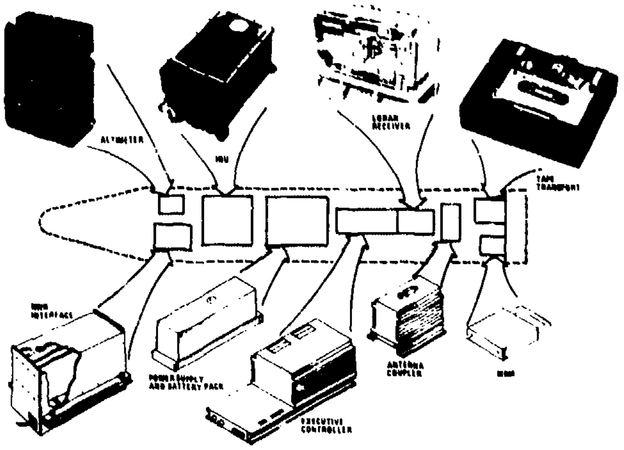


FIGURE 7. FUNCTIONAL SUBASSEMBLIES IN THE PR

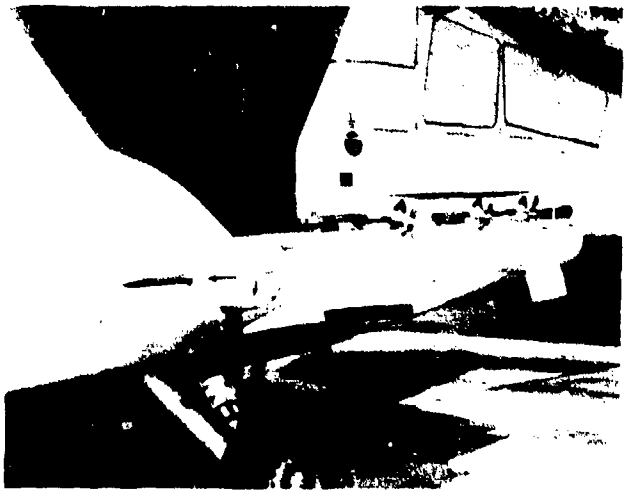


FIGURE 6. PRP - A DERIVATIVE OF TRIPOD

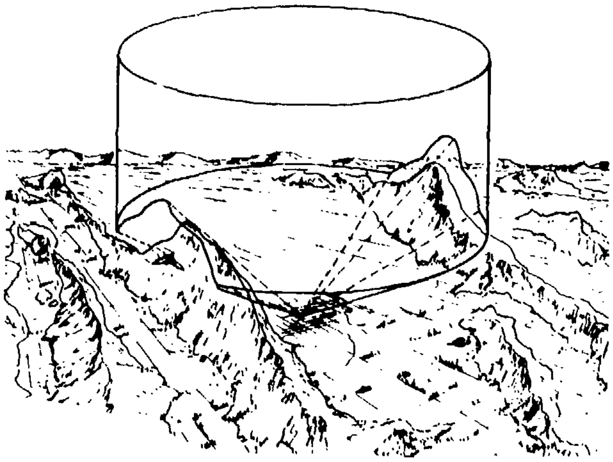


FIGURE 8. THREAT ENVELOPE

The computer also infers a launch after a nominal period subsequent to track radar lock-on. Depending on distance from launch site to aircraft, missile fly-out time is computed, and if the threat has not been defeated within that time, the video flashes and a buzzer sounds in the intercom to indicate the aircraft has been hit. After 1 sec, the system resumes normal operation so that the exercise can continue.

Finally, all visual and audio cues are recorded, as are significant aircraft and relevant aircrew threat defeat actions. These can then be inserted in the MPDS for crew debriefing.

MPDS

The Mission Planning Debriefing Station (Figure 9) has two functions: 1) preparing a RAM mission module for insertion into and control of the PRP during flight and 2) reconstructing the mission for debriefing.

For mission preparation, the MPDS, consisting of a minicomputer and input/output devices, receives generic threat data: i.e., lethal and audio characteristics, envelopes, geographic positions of each threat, significant terrain features surrounding each threat, and prescribed threat defeat procedures. These are inputted by EPROM in the case of generic threat data or threat defeat procedures, and either by EPROM or manually in the case of position location and terrain. Thus, if positions of several threats are to be changed, the operator need only delete the original locations and surrounding terrain and insert new locations of such threats and the terrain surrounding the new locations. An alphanumeric display is used to call up information from the computer and display to the operator results of his normal input. A strip printer provides hardcopy of relevant data, such as threat locations.

Once the computer has received inputs, it prepares the mission module so that it contains the appropriate threat and threat defeat data. Then the mission module is removed from the MPDS and inserted into the PRP on the flightline.

For the debriefing portion, a digital tape is removed from the PRP and inserted into the MPDS. Data on the tape are compressed for flight activities unrelated to the EW portion of the mission, while relevant data are sampled every 1 sec. The displays (the Radar Warning Scope and Control Panel plus a speaker for audio) are activated as they were in flight, while other significant parameters are shown on the alphanumeric display (Figure 10).

FSU

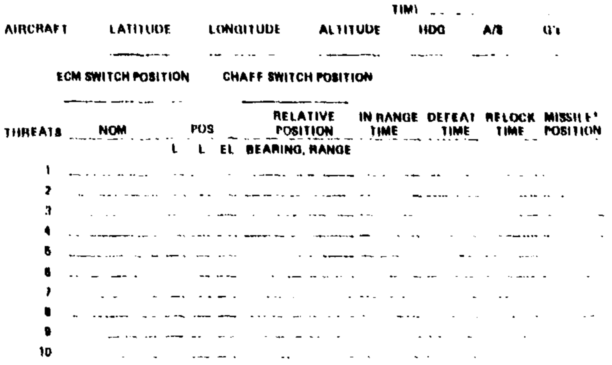
The Flightline Support Unit (Figure 11) serves to preflight the PRP, initialize the Loran, check the input of the mission module, and provide a go, no-go check. It also serves to diagnose and isolate faults or malfunctions to the Line-Replaceable-Unit level.

The FSU consists of a microprocessor, an alphanumeric display, and a keyboard for operator control.

PRP/Aircraft Interface

The PRP uses aircraft wiring currently existing at wing stations capable of carrying a jamming pod (Figure 12). It mounts on a standard stores pylon.

Electrical power (28 Vdc) existing at this station is used to power the PRP, with the PRP



*RANGE FROM AIRCRAFT
(*) MEANS KILL-TIME

FIGURE 10. PHANTOM RANGE DISPLAY INFORMATION

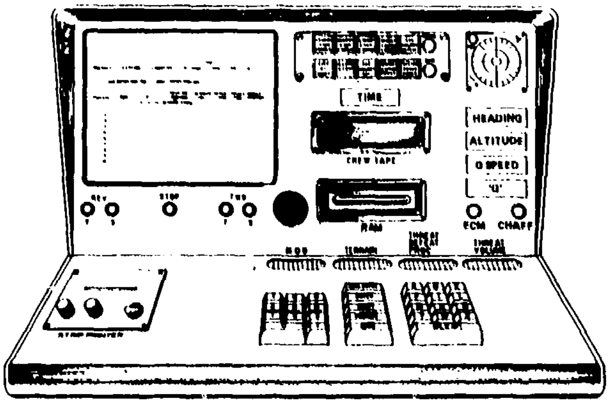


FIGURE 9. MISSION PLANNING DEBRIEFING STATION

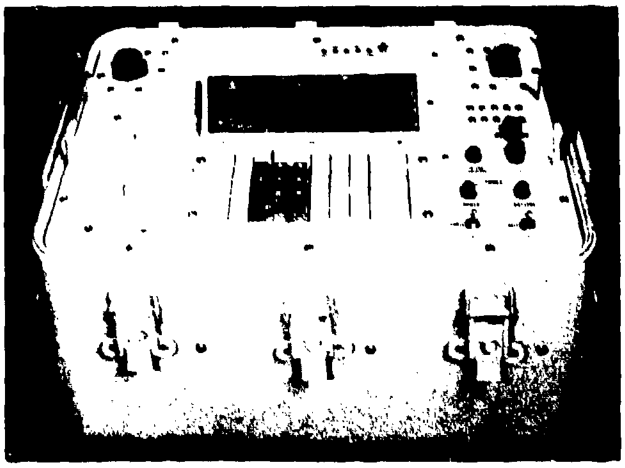


FIGURE 11. FLIGHTLINE SUPPORT UNIT

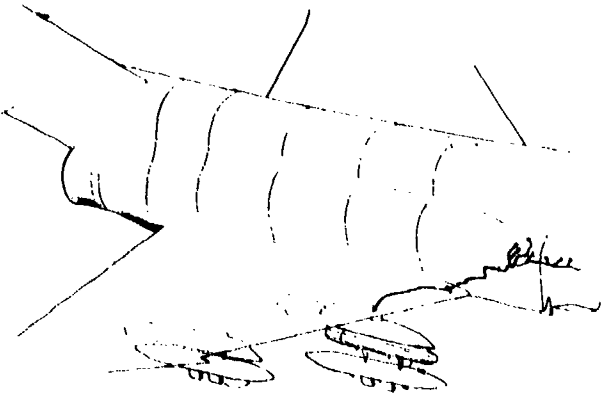


FIGURE 12. F-4E ECM CABLE HARNESS

operating any time power is available at the pylon. (A small rechargeable battery in the PRP maintains volatile memory when aircraft power is off or if there is a momentary interrupt.)

Commands for the video displays are sent through the radar warning system, which in turn generates the appropriate symbology and lights (Figure 13). Audio is generated synthetically since no actual PRF is available. The audio is then carried to the cockpit over existing wires and inserted into the intercom system (ICS) by means of a small jumper cable (Figure 14). The synthetic audio generator also creates noise representative of communications jamming and inserts this into the ICS in a similar manner.

By use of such an interface, the operational radar warning system can function normally, displaying real threats detected by the receiver simultaneously with Phantom Range threats. Thus the aircraft remains operationally ready at all times.

Finally, pilot action discrete signals, such as chaff deploy and jammer switch positions, are monitored at the pylon and introduced into the processor. These, together with aircraft maneuvers, provide the basis for determining whether the aircrew has performed the proper threat defeat procedures within an allowable time.

TRAINING UTILITY

The Phantom Range would be located at wing level with 10 to 12 PRPs, 2 MPDSs, and 2 FSUs per wing. Mission modules would be prepared locating threats along locally accessible, low-level routes used as ingress corridors to ordnance delivery ranges or for photo-reconnaissance missions. A number of such modules of varying complexity would be prepared ranging from one threat at a time and no communications jamming to a thicket of up to 10 threats displayed simultaneously and heavy communications jamming. As aircrews become more proficient, they would fly more and more complex scenarios until they are able to cope with each situation that would have been accurately prebriefed by intelligence and planned for by the mission leader.

At this point, threat locations could be altered such that the information received in the intelligence briefing would become more and more unreliable and threats would pop up where least expected. The ultimate condition would be for the aircrew to fly a mission in which all threats appear at locations other than those briefed or where no expected location information was provided prior to flight.

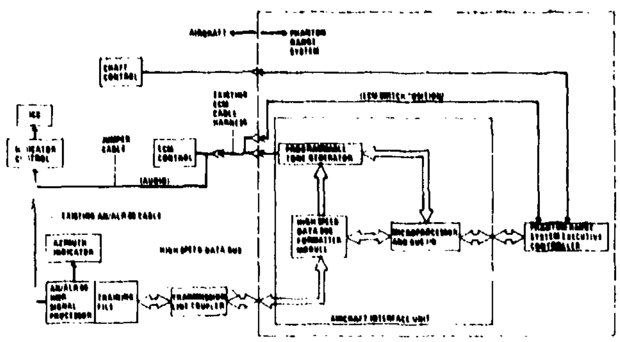


FIGURE 13. ACTUAL RWR EQUIPMENT DRIVEN BY THE PHANTOM RANGE EQUIPMENT

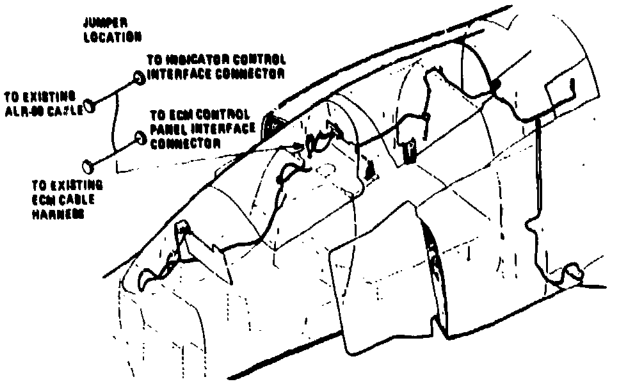


FIGURE 14. JUMPER CABLE PROVIDING AUDIO INTERFACE

Aircrews would be forced to take hard evasive action, deviating from and reacquiring planned routes, while at the same time finding and turning switches on and off as appropriate. (Jammers would be turned off as soon as a lock was broken so as not to allow the simulated threat to reacquire through an implicit home-on-jam feature.)

Once aircrews had achieved and were able to maintain requisite proficiency, they would be prepared to engage in periodic Red Flag exercises where ground personnel operating realistic threat emulators would be able to interact with the aircraft, fire simulated smoke rockets, and provide the ultimate in realism.

CONCLUSIONS

The Phantom Range permits continuous training in all normal tactical air force flying areas, independent of ranges or ground emitters; it permits the aircraft to remain operationally ready at all times; it provides realistic, increasingly complex scenarios; it enables the aircrews to interact on a real-time basis in flight; and it furnishes the capability for reconstruction during debriefing.

By means of frequent local training using Phantom Range, aircrews can be exercised in all phases of mission planning, flight operations and tactics, and detailed debriefing so as to maintain the desired state of proficiency at all times. They can learn to react instinctively to near-real-world conditions of high stress loads and surprise. Should war occur, they would not have to endure the losses associated with on-the-job training during the first 10 combat missions, as experienced in Vietnam.

BIOGRAPHICAL SKETCH

Mr. Morton Eldridge, Director of Marketing, originator of Phantom Range, Teledyne Brown Engineering Company.

Served in USN and USAF, the latter as a fighter pilot. Eighteen years with McDonnell Douglas engineering and marketing, five years at Teledyne Brown Engineering. BSEE, BS Aero E, LLB (JD), University of Michigan; MBA, St. Louis University.

WARGAME-BASED TRAINING SYSTEMS

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ABSTRACT

This paper introduces a candidate model for development of wargame-based training systems and describes the application of that concept during development of the Naval Tactical Game (NAVTAG) Training System. A wargame-based training system combines the inherent educational advantages of simulation and gaming with the best features of more formal or conventional methods of instruction.

Research indicates that gaming simulation has the potential to afford significant advantages over conventional classroom methods of training. This appears to be particularly true for complex skills such as goal-oriented decision-making. Wargames can be made more effective by using an integrated development approach based upon the systems approach to instructional development, and the addition of a complete set of courseware.

Some key features, or characteristics, of wargame-based training systems are that they:

- Utilize an Instructional Systems Development Approach
- Provide a Complete Wargame Training Package
- Are Usable in Game or Nongame Modes
- Are Scenario-Independent
- Provide Realistic Threat Portrayal
- Provide Basic and Advanced Modes
- Are Easily Modified

Other design features include a reasonable level of complexity, realism and playability; and a requirement for a minimum number of support personnel.

Wargame-based training systems are a unique approach to the special challenges of tactical decision-making training. The concept is applicable to all services and can easily be expanded to accommodate the introduction of new technologies, weapons systems and tactics.

The authors illustrate how the design and development of a wargame-based training system is accomplished by reference to NAVTAG (Naval Tactical Game). NAVTAG will be used aboard ship, probably in the wardroom, to afford officers an opportunity to enhance through practice (or to learn, then practice) skills associated with tactics and tactical decision-making. The NAVTAG Training System is intended to complement other methods of tactical and team training, but will not attempt to simulate the physical environment or provide a basis for team training.

INTRODUCTION

Tactical training was an early casualty of the restrictive budgets and decreased operational tempo of this past decade. As valuable operational training time declined, the initial tendency was to compensate through increased use of real-time simulation techniques for team and subteam training; with tactical training an adjunct to other types of training. In the face of accelerating technological advances and introduction of new systems, tactical training itself has become more complex and, therefore, increasingly more expensive. Wargaming has been recognized as one way in which to complement and enhance the overall value of tactical decision-making training. In fact, wargames have been used for training, in a variety of forms, for a long time.

Published literature contains many articles in the area of instructional systems development and the use of simulation and games for training purposes. There is, however, very little in the literature on the development of wargames to be used for training. Recent developments and growing interest in the use of wargames for tactical training applications have underscored the need for a model for development of wargames and related instructional materials. This paper presents a candidate model for development and implementation of wargame-based training systems, within the general framework of the systems approach to development of instruction. For our purposes here, a wargame-based training system is defined as an instructional system which has a wargame as an integral part. The wargame may be used as instructional media requiring direct interface with students, or as support for a simulation exercise, based on indirect interface with students.

BACKGROUND

Wargames combine the elements of both simulation and games in a military context. Simulations involve the imitation of real-life systems or operations through the use of a variety of techniques including terrain boards, computers and other aids. Games involve some element or level of competition among individuals for the purpose of achieving certain pre-specified goals. Wargames bring together the two concepts of simulation and games in applications that include operational planning, analysis, evaluation, and training. Wargames used for training can be of several basic types, including manual wargames and computer-assisted or automated wargames. (1)

Conflict simulations have long been used to prepare for combat. One of the better-known accounts of the use of wargames is that of Japanese preparations for the Battle of Midway. In this elaborate game, Japanese naval officers playing the role of Americans launched an attack on the Japanese carrier force, inflicting devastating losses. When two of the Japanese carriers were sunk, Admiral Ugaki objected to the umpires' ruling, and the carriers were declared safe. In effect, the two carriers were "refloated." The game then went on to indicate the victory at Midway that senior Japanese officers felt was inevitable. During the real battle, the Japanese carrier force was struck almost precisely as indicated by the earlier wargame, but with even more disastrous results for the Japanese, as all four carriers were lost. (2)

The development of computers has added another dimension to the design and use of wargames. Our Defense and State Departments make extensive use of computer wargames to plan and analyze policy decisions and options. Foreign policy crises have also been gamed by civilian and military planners. A recent example of this application of wargaming was the use of gaming by both military and political planners prior to the Isreali raid on Entebbe. Today manual and automated wargames are in use by all the services. The cost/benefit advantages of games for training are becoming increasingly apparent as instructional designers become more familiar with the medium and its applications; often in what might be considered as new or nontraditional settings.

TRAINING WITH WARGAMES

An understanding of some of the characteristic features of wargames is important to an understanding of their use for training.

Wargames put players in situations that model real world systems or portions of systems. The intention is not to completely duplicate reality, but to provide experiences which are transferable to an actual operational problem. The important point is that wargames are intentionally not totally realistic, at least in terms of physical realism. Just as we would not want to rely upon a wargame to specifically predict the outcome of future conflicts (primarily because of the number of variables modeled and the assumptions made), we also would not want our wargame player-students to assume that their performance in a game, and a specific outcome, are totally transferable to the real world. Therefore, an understanding of the artificialities imposed by the wargame is essential to successful transfer from the game to the real-world operational setting.

Wargames may involve only one player or they may involve groups of many players. The players strive to achieve certain goals through their participation. At the same time, players are constrained by the scenario and operating procedures. Successful play sometimes involves agreement to abide by conditions which may not exist in the real world. For example, time may be expanded or compressed during play of the game. In addition, players may be assigned roles in the game which do not necessarily conform to those assumed in real life. Regardless of other characteristics, most wargames include some method to record events, decisions and results; and to determine winners.

In the past, wargames often have been viewed as valuable analytical tools, but lacking in sufficient effectiveness for serious training applications. It is the authors' contention that this view is not supported by recent experience with the use of wargames by the various services.

WARGAME-SPECIFIC ISSUES

Although answering questions about the effectiveness of wargaming as an instructional medium is outside the scope of this paper, a brief discussion of the advantages and limitations of wargames may help to set the context for the discussion of the development of wargame-based training systems that follows.

Wargames used for training exhibit advantages that may be considered in two broad categories: (1) enhancement of the learning environment; and (2) improvements in instructional management.

Instructional wargames provide opportunities for students to experience, in a controlled environment, the consequences of decisions which may be encountered in an operational setting. A wargame can provide the valuable experiences of learning through participation that otherwise could be obtained only through real-time, full-scale simulations, field exercises, or actual combat operations. Wargames can help avoid/reduce the costs and difficulties often associated with full-scale simulations, exercises and operations, while providing much of the training value of the more expensive alternatives.

Proponents of games or wargames for instruction point to advantages of increased student motivation. Actually, little is known about the motivational power of games beyond the indications that the elements of chance, competition and excitement tend to stimulate learning. (3) There is little disagreement that, at a minimum, these elements stimulate participation and, therefore, can enhance the opportunities and potential for learning.

Because wargames establish situations that evolve with student interactions, they seem to be an effective way to teach the structure and operation of systems. (4) Decision-making skills can be strengthened through opportunities to see the results of a series of decisions unfold. The availability of such results in the form of near real-time feedback is an advantage of wargaming that does not always exist in other instructional media; even including field exercises.

In addition to the potential for enhancements to the learning environment, the use of wargames for instructional purposes has physical and logistic support advantages for instructional management. Wargames can be designed to be both exportable and transportable. In fact, the entire instructional system package can be made relatively small and light-weight for ease of transportation in the field or aboard ship. Small packaging also can ease maintenance and repair support requirements.

In certain applications, wargaming can be more cost-effective than other media. The potential to bring the instructional package to the individual, and to require minimal instructor resources, are examples of the cost benefits of wargames.

Wargaming complements other forms of decision-making or tactical training. A wargame can provide opportunities to review tactical experiences or to prepare for future exercises. Areas of individual weakness in prerequisite knowledge can be easily identified in a wargame environment. Wargames may also be tailored to specific needs; such as time available for training. Thus, wargames can provide for regular proficiency and refresher training for tactical decision-makers; working easily around other demands on an individual's or group's time.

Although there are numerous advantages, there are also limitations to the use of wargames for training. Research indicates that instructional simulations are successful, but not necessarily superior to, more conventional techniques for teaching facts or bodies of knowledge. (5) Simulation requirements also can be expensive and, therefore, cost-prohibitive in certain applications.

Wargames can also be time-consuming and difficult to learn how to play. While this limitation has in large measure been overcome by computer automation, automation has its own limitations. For instance, computer automation is expensive and can introduce additional artificialities and obstacles to transfer of training.

Unless a wargame is carefully constructed and monitored as part of an instructional system, it may have a tendency to lead student players to develop unrealistic attitudes toward the real world operational environment or their own abilities. Of related concern is the fact that the outcomes of models incorporated in a wargame rarely can be fully validated. Empirical validation of models through a "preponderance of evidence" is perhaps the best means available to validate wargame models.

In addition to the potential for development of unrealistic attitudes, or expectations, there exists with wargames the potential that students will use the game to reinforce existing biases. The student thus may bring to the game a "favorite" solution, regardless of the nature of the problem or may tend to view all problems as being essentially identical. (6) Kapper has noted that "the most blatant abuse (of wargames) today...is advocacy." (7) This includes the use of wargames to "sell" programs where vested interests are at stake, or to denigrate programs over which there is a disagreement or uncertainty. An example of this could be the justification of a new tactical doctrine through the "results" of the wargame.

The possibility that these limitations and potential disadvantages will have negative impacts on training can be lessened through a systems approach to development of wargame-based training. systems.

IMPORTANCE OF A SYSTEMS APPROACH

The development of instructional systems has long been recognized as a complex process. Systems engineering accounts for and demands a reasoned transition from precise needs statements, to validation of problem environment and situation, through identification of all alternative solution candidates and optimal selection, implementation and continuing refinement. The instructional systems development procedures followed by the services are, in fact, the application of systems engineering principles to the problems of training systems development. The application of these procedures represents the transition from art to quasi-science in the development of instructional systems. When the problems of the unique characteristics and varied implementation philosophies of wargame-based training systems were confronted, it was logical that the instructional systems development model be utilized as the basis for development of a tailored model.

One of the challenges in the adaptation of the instructional systems development model is that the media selection process often has been obviated by decisions which preceded analysis of the training needs. Validation of the results of wargame exercises present yet another challenge. This situation is further exacerbated by the paucity of real data to validate model and strategy effectiveness. For these reasons, considerable effort has gone into ensuring significant subject matter expert inputs and reviews during the development process. Further, because of the additional impact of new weapons/sensors technology, much more emphasis has been placed on the evaluation and management phases after implementation of the wargame-based training system. The known complexity and problems in the development of cost/training effective and efficient instructional systems, when coupled with the unique problems and characteristics of wargaming, underscore the requirement that the technology of instructional systems development be adapted to produce an operational model for development of wargame-based training systems.

The authors have developed a candidate model for development of wargame-based training systems. This model includes appropriate parts of the model for the systems approach to development of training materials. As currently configured, there are 12 steps in the model, as discussed in the following section.

DEVELOPMENT OF WARGAME-BASED TRAINING SYSTEMS

Figure 1 illustrates the 12 steps in the development of wargame-based training systems. Although the model is portrayed in a linear fashion, it is not a requirement that each step be conducted sequentially. Some activities may be accomplished concurrently, or even out of sequence.

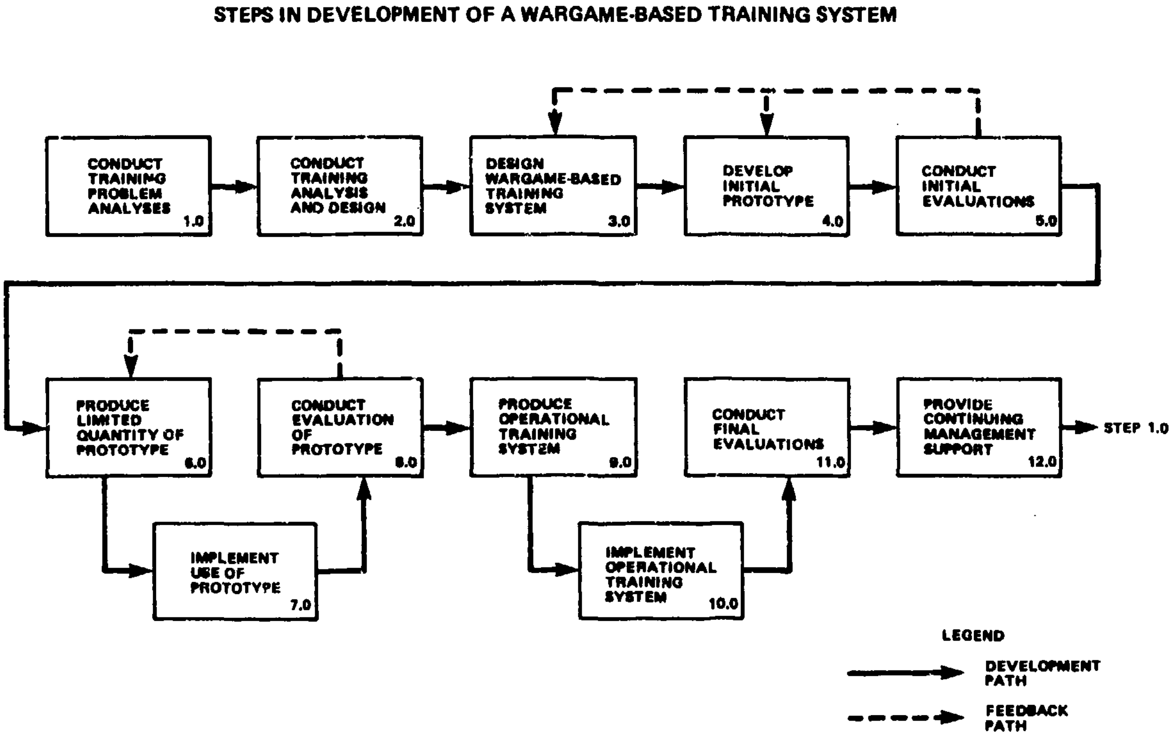

Figure 1. Steps in Development of a Wargame-Based Training System

Discussion of the model will focus on the activities to be accomplished during each step, and the products which will result from those activities. Where the model closely follows the instructional systems development model, little information will be presented, as this information is available elsewhere. Instead, unique activities and/or products of this model will be described in some detail. Considerations for development of automated systems are also presented.

Step 1.0 involves the analysis of the training problem, and is similar to the first two steps outlined in MIL-T-29053B (Military Specification: Requirements for Training System Development). The primary products of this step are a Problem Analysis Report and a Training System Development Plan, which together specify the approach required for development and implementation of the training system.

Step 2.0, training analysis and design, involves the analysis activities included in Phases I and II of the instructional systems development model.

The primary products of Steps 1.0 and 2.0, then, should be a list of tasks selected for training and a list of hierarchial, or sequenced learning objectives. These become primary inputs to Step 3.0, design of the wargame-based training system.

Although not unique to the development of this type of training system, it is important for the reader to recognize that, given the exigencies of operating in the "real-world," it is possible that some decisions - including media selection - may be used in place of original research. If the activities required in Steps 1.0 and 2.0 have been completed (or the need for such activities obviated by decisions imposed on the use of the model) the development of a wargame-based training system may begin with Step 3.0. A considerable stress, however, will be placed on the development process (and on the developers of the system), since the results of the decision, or lack of sufficient analysis, can create problems later in the process.

Step 3.0 - Design Wargame-Based Training System

The activities that take place during Step 3.0 are illustrated in Figure 2. Activities 3.1 and 3.2 involve the specification of learning activities (emphasizing the type and methods of feedback to be provided to students) and specification of the instructional management plan. Through these activities, the instructional developer should look to verify the selection and appropriateness of the wargame medium and to determine how the instructional system is to be packaged and implemented.

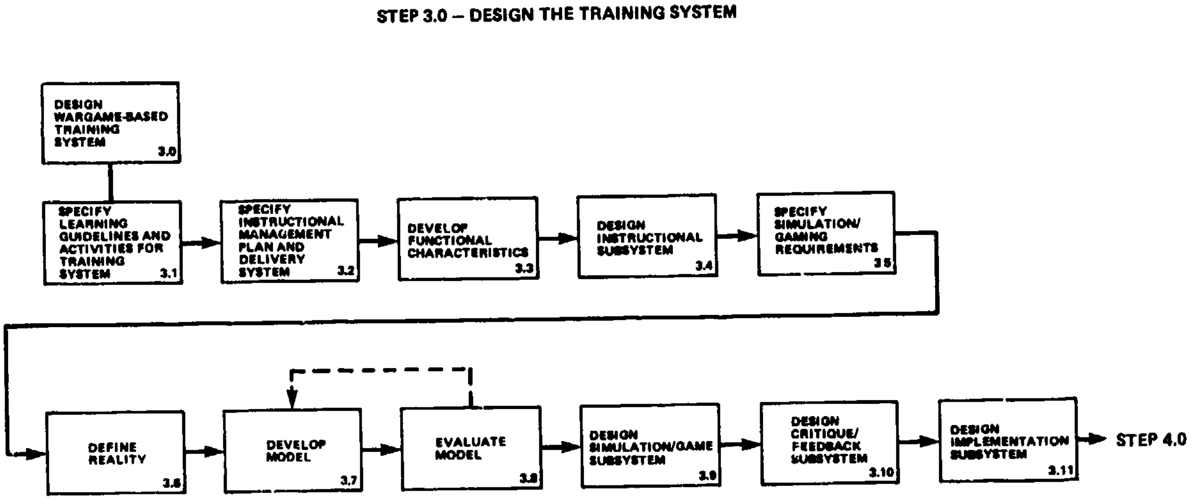

Figure 2. Step 3.0 - Design the Wargame-Based Training System.

Activity 3.3 focuses on the wargame, itself. The functional characteristics of the wargame (and the total system) should reflect the results of many decisions, all made in the context of the learning objectives. Some of these decisions include resolution of these issues:

- Is the game to be used for practice only, or will it be used as an instructional delivery device?
- Should the game be manual, computer-assisted or fully automated?
- Should the wargame be free-play or scripted?
- Should the wargame be one-sided or two-sided?
- Should the game be in the open or closed mode?

The game's functional characteristics, instructional management plan and learning objectives will serve as the primary inputs to the design of the training system. The remaining steps involve the design of various subsystems of the training systems. The subsystems of a wargame-based training system, illustrated in Figure 3, include:

- Instructional Subsystem
- Simulation/Game Subsystem
- Critique/Feedback Subsystem
- Implementation Subsystem

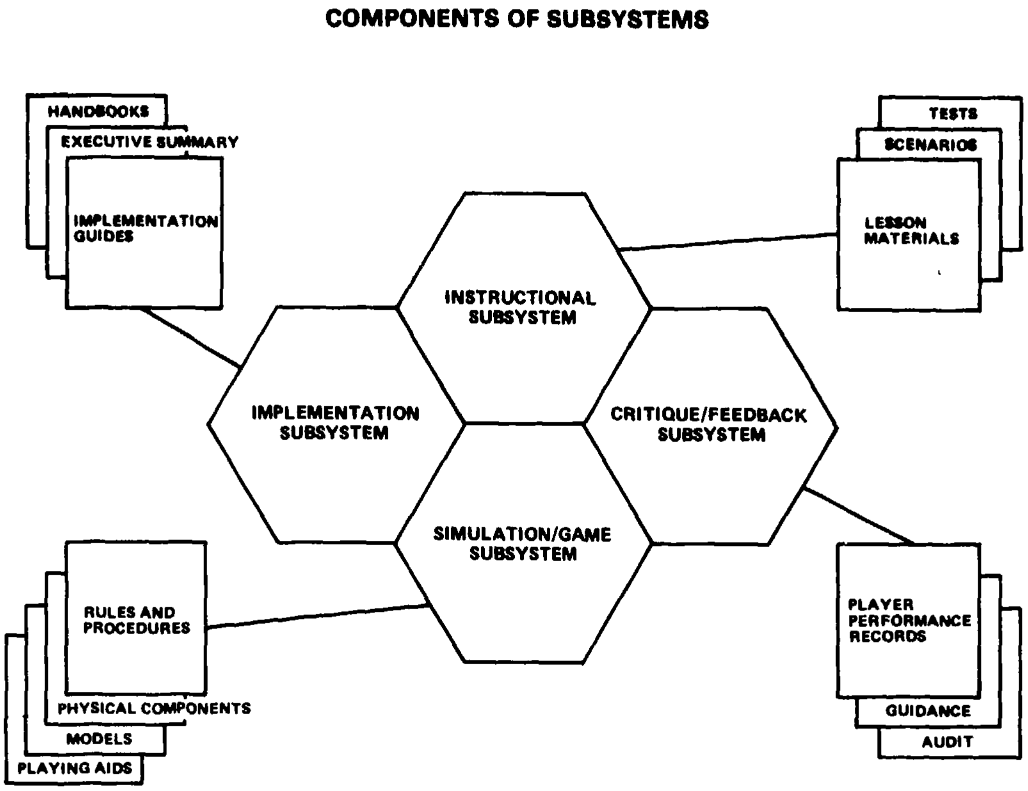

Figure 3. Wargame-Based Training Subsystems and Components

Activity 3.4, design of the Instructional Subsystem, results in the curriculum outline, lesson plan and scenario requirements, and design criteria for the Implementation Subsystem.

The specification of the simulation/gaming requirements (Activity 3.5) results in design criteria for the wargame, using as primary inputs the wargame functional characteristics and the planned curriculum outline.

Prior to completion of the design of the Simulation/Game Subsystem, the model requires development of various models of reality. This development requires a definition of reality in the form of a conceptual model (Activity 3.6), the development and documentation of an operational model (Activity 3.7) and the evaluation of the model, in terms of completeness, content validity, level of specificity, and fidelity (Activity 3.8). Once again, throughout the activities culminating in the Simulation/Game Subsystem design, there should be constant reference to the goal of the system as evidenced by the learning objectives and other products of earlier activities. In addition, it is essential that these activities result in detailed documentation for the model, including a bibliography and list of references and a record of the decision processes involved in model development (i.e., assumptions and rationale).

The Critique/Feedback Subsystem is primarily concerned with student and game performance monitoring and evaluation. The design of the Critique/Feedback Subsystem should provide preliminary answers to such questions as: How will the instructor/controller use the game and instructional materials to best instructional advantage? What should be the methods of recording critical events, decisions and outcomes?

The Implementation Subsystem design should provide for complete implementation guidance for instructors, controllers and players. The design, therefore, should include development of a list of tasks selected for training and a set of learning objectives for those positions.

Step 4.0 - Develop Initial Prototype

This step is illustrated in Figure 4. The subsystem designs from 3.0 provide the primary inputs to the development activities in Step 4.0.

STEP 4.0 – DEVELOP THE INITIAL PROTOTYPE

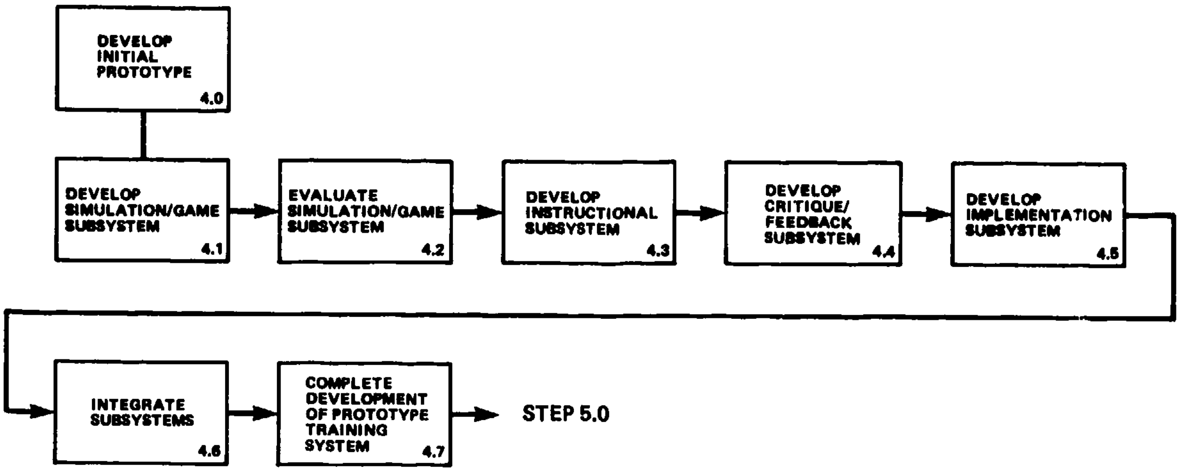

Figure 4. Step 4.0 - Develop the Initial Prototype

The Simulation/Game Subsystem development should result in development of the game rules and procedures and physical components. Model hardware and software, as required, will also be developed during this activity. Before completion of development of the Instructional Subsystem, Activity 4.3, the Simulation/Game Subsystem should be evaluated in relation to the design criteria of workability, playability, validity and fidelity. The Simulation/Game Subsystem evaluation report will provide valuable input to the development of the Instructional Subsystem; particularly in the development of system training capabilities and limitations.

In addition to the lesson plans, scenarios, and training capabilities and limitations, the Instructional Subsystem should provide a matrix, or cross-index, of learning objectives and lesson plans.

The development of the Critique/Feedback Subsystem in Activity 4.4 will result in the instructions and procedures necessary to evaluate student performance. Because the instructors and controllers, as well as players, will be principal users of the Critique/Feedback Subsystems, the development of this subsystem can be expected to impact the development of learning objectives for these positions and, therefore, the design and development of the Implementation Subsystem.

The Implementation Subsystem developed through Activity 4.5 will consist of instructor's guides, controller's guides, player's guides and the executive guide or executive summary.

Upon completion of initial subsystems development, the subsystems must be integrated into an initial prototype training system. Integration activity should point to additional changes required in the initial prototype subsystems and components prior to commencement of initial prototype evaluation in Step 5.0.

Step 5.0 - Conduct Initial Evaluations

The primary purpose of Step 5.0 is the overall effectiveness of the initial prototype system prior to a decision to produce limited quantities of the prototype. These evaluations can best be arranged in three phases: (1) in-house evaluations; (2) appraisal by subject matter experts; and (3) one or more sets of external evaluations.

The initial evaluations should be directed toward answering questions such as:

- Are the lesson materials and game mutually supportive of the prescribed learning objective?

- Do the instructor, controller and player guides provide sufficient guidance for game play, player performance evaluation and critique?
- Is the game reliable in that the simulation model yields consistent results?
- Does the system exhibit the degree of fidelity intended (i.e., are the simulations realistic and reflective of the real world)?
- Is the system playable in a physical sense? Are the procedures easily understood and does the system meet prescribed criteria for such considerations as readability, time to play, and physical characteristics? Is the game/simulation interesting?
- Does the system have validity in terms of reasonableness, realism, and comprehensiveness? Is the appropriate mix of simulation, automation, activity and player interaction provided?

In house evaluation should be an extension of the iterative processes of design, develop, test and revise begun in earlier steps. A design review checklist should be developed for use in this activity, which can, and should, begin prior to completion of the initial prototype system.

Subject-matter expert appraisal can be accomplished with the assistance of the Fleet Project Team, Reserve Training Units, Tactical Training Groups, or similar activities, as appropriate. It will be necessary to carefully plan and schedule this activity, as well as to provide a complete package of data collection materials and appraisal guidance.

The third activity in this step requires one or more series of external evaluations. Actually, "external evaluation" is a misnomer in that these activities involve implementation of the system using representative members of the target population. An intensive data collection effort is required, focusing on each aspect of the training system. Depending upon the results of the first external evaluation, a second or even third evaluation may be required.

Step 6.0 involves production of limited numbers of the prototype system. The initial activity is the development of a production strategy, to include identification of government and contractor-furnished material requirements and a production plan. Subsequent activities require the preparation of procurement packages and tasking for cognizant government activities. The remaining activities in this step involve contract management and completion of the prototype. Step 6.0 is an adaptation of the "fly before buy concept" employed with success in other areas.

The prototype training system is implemented in Step 7.0. The first activity is to develop an implementation plan that will establish the schedule and procedures, and assign responsibilities for prototype implementation. Prior to distribution of the prototype systems, one or more courses of instruction will be required for those personnel assigned as instructors/controllers.

A second evaluation step (step 8.0) should follow distribution of the prototype games to selected units. This evaluation should be conducted by unbiased sample groups from the target population. The primary purpose here is to evaluate the training system in its intended setting and without interferences on the part of the system developers. Final modifications to the training system may be required, based on analysis of the utilization data.

Steps 9.0 and 10.0 of the development model involve production and implementation of the operational training system. Step 11.0 provides for "final" evaluation over the long-term following full-scale implementation. This evaluation can, and should be conducted using a variety of information sources, including regular feedback, periodic sampling of users, questionnaires and personal observations. A specific goal of the ongoing evaluation activities should be to ensure that the system game, scenarios and courseware continue to accurately reflect real-world operational capabilities and doctrine.

Step 12.0 involves the various well-established activities associated with providing continuing management support/services to the users of the training system.

DEVELOPMENT OF DATA PROCESSING REQUIREMENTS

As mentioned earlier, the design of a wargame-based training system may require use of a digital computer. Use of the computer is generally specified for many reasons: to speed up play; to allow for utilization of more sophisticated models; to permit storage and use of much more data; to provide for more complex interaction with the player; to allow for easier employment of stochastic models; for ease of gathering statistical and analytical data; and/or to eliminate the need for many human player/decision-makers.

Automated wargames fall into three general categories of increasing difficulty and implementational sophistication: Computer Assisted, Interactive and Computerized wargames. In each of these categories, the data processing (DP) requirements that must be addressed are: processing, fast memory, input, output, software language, and operating system. This section will address a method for developing an accurate needs estimate for a generic wargame-based training system's data processing requirements. It is assumed that once an accurate data processing needs estimate has been developed, implementation of these requirements will be accomplished in the generally accepted fashion for computerized training devices (or training devices with embedded computers), and according to the established procedures for such devices, Military Standard for Trainer System Software Development, MIL-STD-1644 (TD) 7 March 1979.

Proper development of the device data processing requirements requires integrated analysis performed in a linear, staged fashion of increasing effort and sophistication. The authors have developed a nine step model defining the data processing requirements effort (See Figure 5). This process will answer the critical questions in the seven data processing areas detailed above.

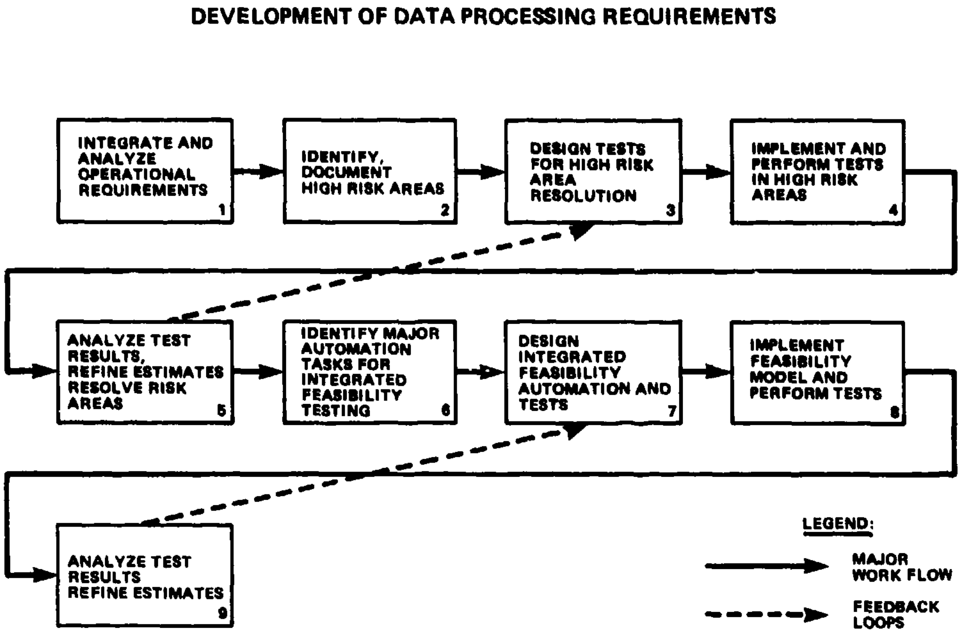

Figure 5. Development of Data Processing Requirements

In the processor area, analysis and tests are conducted which integrate size and weight limitations with model complexities to determine the required speed of computation. These tests must necessarily also address the issue of language, operating system, and mass and fast memory. These processes will define, for example, whether a micro-, mini- or main-frame computer is required. The issues of higher order language vs. machine language and standard off-the-shelf vs. a tailored operating system will also be addressed. The wargame model complexity, supporting data requirements, number and sophistication of participants and environment will be analyzed to provide inputs to the mass and fast memory requirements. Options available for player/participant inputs include typewriter keyboard, joysticks, light pens, trackballs, resistance pots, push buttons/switches, graphics, tablets and voice recognition. The capabilities must be matched against the wargame input requirements and user skills. Typical output characteristics include printer/hardcopy and cathode ray tube units; their speed of operation, number of lines and characters per line, graphics resolutions (line drawing or raster), colors and the number of words/phrases for voice output. Output requirements address the system's need for communication of instructions, computation and interaction results, and situation reports/plots to the players and controllers. Data access speeds and transfer rates within the processor and to its various peripheral devices are important concerns for processor timing, mass and fast memory selection, and input/output operations.

Referring again to Figure 5, the first step in the development of the wargame-based training system data processing requirements is integration and analysis of the device operational requirements. This activity will result in a list of automation tasks and an initial DP needs estimate. For NAVTAG, this process resulted in preliminary selection of a micro-computer using a high order language in an off-the-shelf operating system environment.

In Step 2, the list of automation tasks is reviewed in the context of the initial DP needs estimate to identify the high risk areas for the chosen approach. The list of high risk areas for the NAVTAG device included the capability of a microcomputer to store, position update and legibly geographically plot the positions of an adequate number of platforms within reasonable time and memory limitations, and the capability of microcomputer peripheral storage devices to store all of the required information.

The third step of the development effort designs tests which will aid in resolution of the high-risk issues. A representative micro-computer and disk storage system was selected to implement test programs for NAVTAG. Software design specifications were developed which addressed the storage, position update and geographical plotting of a variable number of platforms. In general, this step results in test specifications designed to generate the timing, storage and graphics data necessary to adequately lower the initial risk level for the identified tasks.

In the fourth step, the test specifications from the previous step are implemented in software and performed on the representative hardware. The timing, storage and graphics data and results generated by the test are captured and documented. These data are analyzed and used to refine the initial estimates of the DP requirements in the fifth step. The outputs from this stage are the interim DP needs estimate and the documentation of the resolution of the high-risk issues. It is at this stage that high-risk automation tasks can be dropped, modified or used to justify more capable equipment/software, depending upon their priority and complexity. Analysis of the results of the NAVTAG high-risk area software demonstrated that reasonable, effective and low-cost solutions existed for these issues.

With the high-risk automation issues resolved, the sixth step addresses the identification of the major automation tasks that require integrated feasibility testing. In this step, the interrelationship and dependencies of the major tasks and the special input/output requirements are analyzed. This study produces a list of those critical links and input/output functions that require feasibility testing to more completely define the system DP requirements. For the NAVTAG training system, major automation tasks were movement, electronics, weapons utilization and damage assessment. The feasibility issues concerned the interrelationship of these varied tasks through the rules of the manual game and the common database required. Of concern was the computer reaction and computation times for the varied tasks, and the form and format of communications with the system user(s).

The design of a limited, yet integrated feasibility automation and test plan is accomplished in the seventh step. The tests are constructed to validate the interim DP requirements and to evaluate the feasibility of the critical linkage and communication concepts contained in the system design. The automation tests and design for the NAVTAG feasibility model were developed in an iterative fashion between computer scientists, training and education specialists and a naval subject matter expert. This approach assured validity of design prior to feasibility model implementation. It was decided to model two ships for surface interactions only because of time and cost considerations. The game, however, still contained all of the major automation tasks to be tested.

The eighth step is the implementation of the feasibility model designed in the previous step, and utilization of that model to accomplish the limited testing specified. The output of this step is the feasibility model and documentation of the success of the tests, including data on the performance and acceptability of the critical automation tasks, linkages and communication strategies. It is interesting to note that, in spite of considerable subject matter expert input in development of the NAVTAG feasibility model, significant rework was required after the initial implementation. Redesign was necessary to achieve correct terminology usage; to assure straightforward and complete presentation of the results of computer activities, and background data and options available to the user. The requirement for this redesign pointed to the need for a model for development of wargame-based training systems.

The ninth and final step includes analysis of the feasibility model test results and documentation. This analysis refines and completes the estimate of the wargame-based training system's DP requirements. This step also results in the identification of interrelationships and system overall integration and communication (input/output) requirements. The analysis of the NAVTAG feasibility model produced many significant results that dramatically aided in procurement of the pre-production prototype. It was at this stage that the need for use of a compilable higher order language, instead of an interpreted language; and the need for an 80 column (rather than a 40 column) display was demonstrated. Other important results included an accurate data base, fast memory and source code estimates. This information proved to be of great use during the competition prior to award of the contract.

Utilization of this procedure to define the wargame-based training system data processing requirements produces a low-risk, low cost system, while maintaining the desired level of performance. This process saves money and lowers risk through studied efforts to improve the device through early identification of high-risk areas and refinement of DP requirements; based on hardware evaluations and software development and testing. A further benefit is that the amount and complexity of the device's final source code can be much more accurately estimated.

CONCLUSIONS

This paper has presented a candidate model for the development of wargame-based training systems. This model is evolutionary; its application to real world situations has been limited. It is undergoing revisions as it is currently being used and evaluated for future applications.

The model was developed based upon the broader principles exemplified by the instructional system development model and the large body of research already completed on instructional games and simulations. The experiences of both the Army and Navy in developing wargames for training during the past ten years was also a significant factor.

The need for a detailed development model for wargame-based training systems was recognized by the authors after they jointly became involved with the development of the Naval Tactical Game (NAVTAG). It was also considered to be of benefit to the various services and to industry because of the increased interest in the use of wargames for training and the numerous potential applications for such systems throughout the Department of Defense.

The need for regular proficiency training for tactical decision-making has long been recognized. Wargames are one way of providing combat leaders with experience in the operational impact of their decisions. When properly developed and implemented, wargames can provide valuable training to tactical commanders in all the services. However, it is important that the reader understand the authors do not offer wargame-based training systems as a panacea for all tactical training problems. Applications of this model (or appropriate variations) will increase the probability that such instruction will be both cost and training effective/efficient. The use of the instructional systems development model as a basis for this model allows for simultaneous optimization of both the wargame and the instructional system.

Variations of this model are being used as the basis for development of a number of wargame-based training systems at the Naval Training Equipment Center. The success achieved through application of the model to date has been excellent, with the Naval Tactical Game (NAVTAG) most notable. Specific examples of the application of this model to NAVTAG development program have been included in this paper, where appropriate, to further explain and demonstrate the intent of this model. Notable benefits to that program from use of this model have been reported. A subsequent effort will address the application of a variation of this model, including each of the twelve steps to the development of a manual wargame-based training system for the USMC.

Consideration should also be given to utilizing the model presented in this paper for defining the data processing requirements whenever computers are used as part of the training system.

As noted earlier, this paper does not attempt to define all the advantages and disadvantages for using wargame-based training systems, nor to describe in any great detail the media selection process which would result in identification of the need for a wargame-based system. It is the authors' opinion that the criticality of the duties of our tactical decision-makers, in all services, requires that any and all reasonably effective approaches be pursued, and that no one solution be offered as a panacea to the problems of training those combat leaders. The fact that wargames - or wargame-based training systems - can be used to provide a partial solution to those needs is well recognized. The model presented herein provides one possible framework for achieving those goals in a cost/training effective and efficient manner. The validity of this model will be tested in the cauldron of real world application during the coming year, and the results reported in a subsequent paper.

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A UNIQUE RADAR WARNING EQUIPMENT TRAINER CONCEPT
BASED ON DIGITAL STIMULATION

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ABSTRACT

Prior techniques in EW training equipment designs have used either the approach of signal injection into operational EW equipment or the approach of software real-time modeling of the EW equipment and environment. The analog injection approach preserves the signal processing characteristics and anomalies of the EW equipment, but is costly and difficult to maintain and keep calibrated. The software model approach is easily maintained and offers excellent simulation repeatability, but the realism is limited to the degree in which the math model simulates the equipment and environment. The new approach presented in this paper offers the realism advantages of the signal injection approach plus the repeatability and maintainability of the software modeling approach. Instead of injecting analog RF signals or video level signals into the operational EW equipment analog to digital (A/D) signal converter, the new approach bypasses the A/D converter and injects digitally formatted signals directly into the EW processor data collection buffer. This approach uses general purpose digital computer equipment to generate the real-time digital pulse data and uses the operational EW equipment to process the data. All the processing characteristics and anomalies are preserved in the EW equipment, and the repeatability and maintainability of digital versus analog signal generators are provided.

INTRODUCTION

This paper describes a new and unique trainer design concept for a simulator to be used in training pilots and electronic warfare (EW) officers in the use of radar warning system (RWS). Past approaches have either employed RF level stimulation, video level stimulation, or software simulation of the RWS. However, with the state-of-the-art trend toward digital RWS and digital signal processing, a new avenue has been opened up, digital stimulation. As used in the text of this paper, digital stimulation is defined as the injection of digitized radar data into the direct memory access (DMA) buffers of an operational RWS. This new design incorporates the operational signal processor with its complex software, threat library, I/O units, displays and control boxes. The operational equipment analog to digital signal converter is replaced by an interface to a general purpose simulation computer. The simulation computer generates digital words which the RWS signal converter would have generated under the same operating conditions. All RWS response times, reactions to ambiguous threats, and simulation of most system anomalies are guaranteed, since the actual on-board signal processing equipment is used.

Simulation of the EW environment and accurate modeling of the RWS antennas, receivers, and signal digitizing modules are performed in software on the general-purpose computer. Real-time line-of-sight, relative position, aircraft orientation, and emitter propagation effects are also performed by this simulation computer to provide a continuous stream of information to the RWS computer and signal processing software.

As in most training devices, monitoring and control of the simulated threat environment, RWS and training exercises are provided by an instructor's console interfacing with the simulation computer.

Whether designed for application as a task training device or integrated into operational flight or weapon system trainers, this digital stimulation concept should provide the foundation for low cost, realistic, reliable and easily maintainable EW training devices.

REQUIREMENTS

Performance Requirements

A radar warning system trainer (RWST) must meet a number of performance requirements to be an effective training device. It must be able to reproduce (on a real-time basis) all the visual and audio cues that the actual system produces in the same conditions of flight and threat environments. All character movements or strobes on displays, lighted legends, audio tones and beeps, and system reaction to control switches must function as if the operational equipment were actively being used. Realism, accuracy, and repeatability of the cues are important to the trainee. However, the degree of realism should not extend beyond the threshold of cue discernment for most pilots for the system to be properly cost-effective.

The specific performance requirements of an RWST can be divided into several categories, as follows:

- Airborne Equipment Simulation
All displays, controls and audio tones associated with the RWS during both normal and failure modes of operation must be realistically simulated, including signal processing anomalies such as delay times, false alarming, misidentifications and DF wander.

- EW Environment Simulation
Radar threat models need to be simulated with those characteristics which influence the response of the RWS, such as pulse repetition intervals, transmitting frequency, scan modulation, correlation of missile guidance uplinks, and pulse synchronization with other threats.

- RWS and Environment Interaction
Emitter mode switching as a function of range from the aircraft, and the reaction of emitters to electronic countermeasures (ECM) must be taken into account, along with the measurement of pilot reaction times to engage the proper ECM or make proper evasive aircraft maneuvers to minimize the probability of kill.

The development of on-board equipment simulation requires an understanding of the elements of an airborne radar system. Figure 1 shows the physical components of the AN/ALR-67, a typical airborne system built by ATI. Figure 2 presents a highly simplified block diagram of a

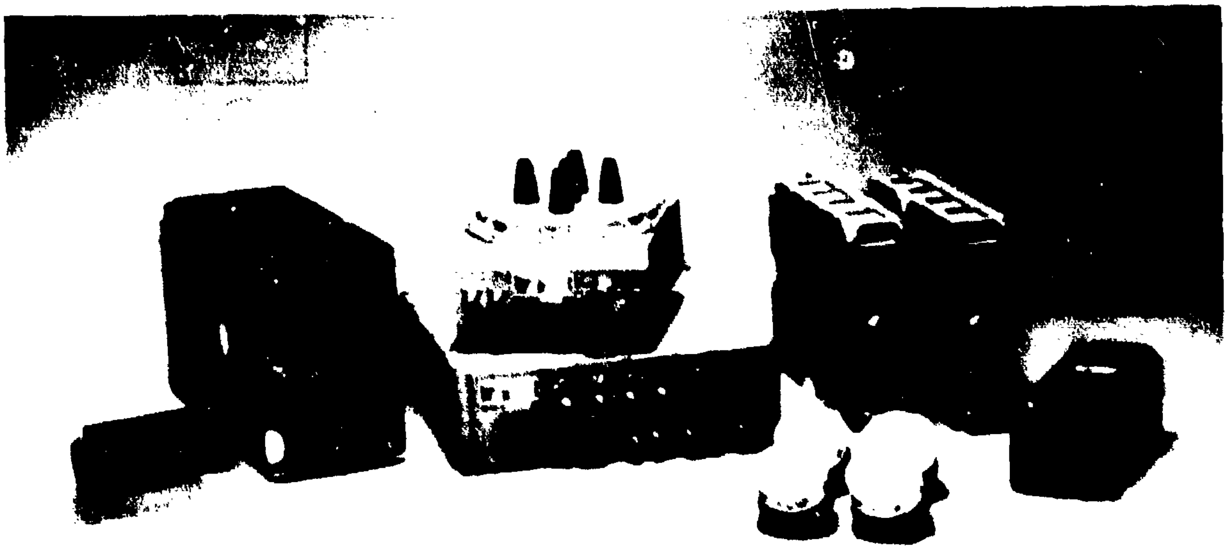

Figure 1. Components of the AN/ALR-67 Radar Warning System

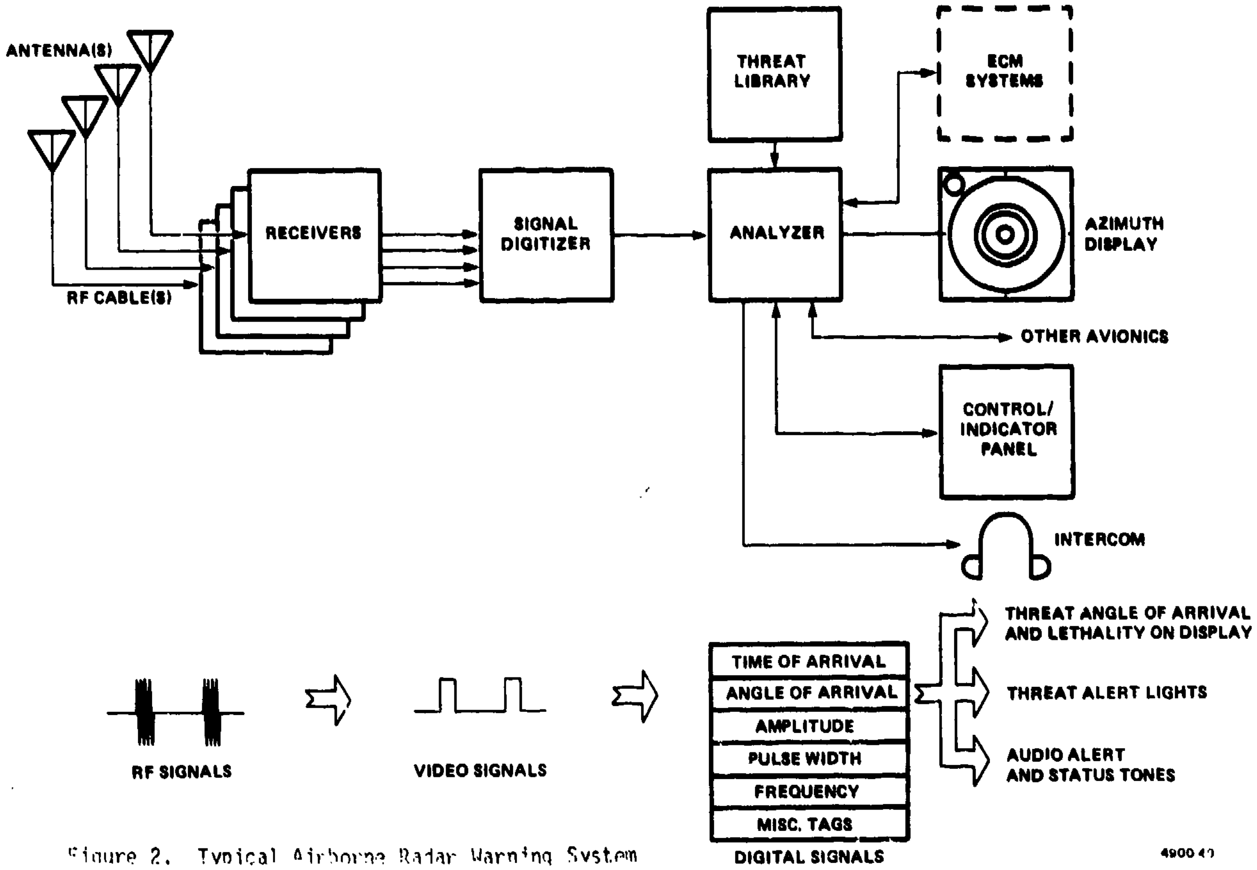

Figure 2. Typical Airborne Radar Warning System

representative airborne RWS consisting of directional antennas, RF cables, radar receivers, a signal digitizer, a signal analyzer, a threat library, a control/indicator panel, an azimuth display, and audio output. An ECM system may be a part of, or directly interfaced with, the RWS.

Free-space radar signals are picked up by the antennas, sent through RF cables to receivers, and converted by video amplifiers into voltage level signals. The signals are then digitized into a set of data words containing time of arrival, angle of arrival, amplitude, pulse width, transmitting frequency or band, and various tags or flags. The digital pulses are deinterleaved and processed by the analyzer to determine pulse repetition intervals (PRI), amplitude modulation characteristics, and other signal signatures. These processed signals are then compared to the signatures of known threats in order to make an identification and assign the appropriate display symbol. The azimuth display and control/indicator panel are driven by the analyzer to display to the pilot the presence of the detected threat, signal angle of arrival, relative threat lethality, and system status. Figure 3 shows a typical azimuth display from a modern RWS system. In some systems, audio identification, alert, and warning tones are also produced.

Whether the elements of such a system are simulated or stimulated, certain characteristics must be preserved if the pilot is to be given realistic cues. As a minimum, the following factors must be taken into account to achieve realistic system performance:

- Antennas - Three-dimensional reception gain pattern as a function of elevation and azimuth incident angles and signal carrier frequency; movement dynamics; and masking of the aircraft

- RF Cables - Signal power loss as a function of cable length and signal frequency

- Receivers - Milliwatt input to millivolt output transfer characteristics for video amplifier; triplexer or quadruplexer filter skirts; characteristics of local oscillators or mixers

- Signal Digitizer - Millivolt input to digital word output transfer functions, including effects of signal walkthroughs and dead times between pulses

- Analyzer - Signal processing algorithms, time delays, reaction to missing pulses and pulse walkthrough effects; threat ambiguity resolutions; reaction to pilot mode selection

- Threat Library - Specific threat parameter limits

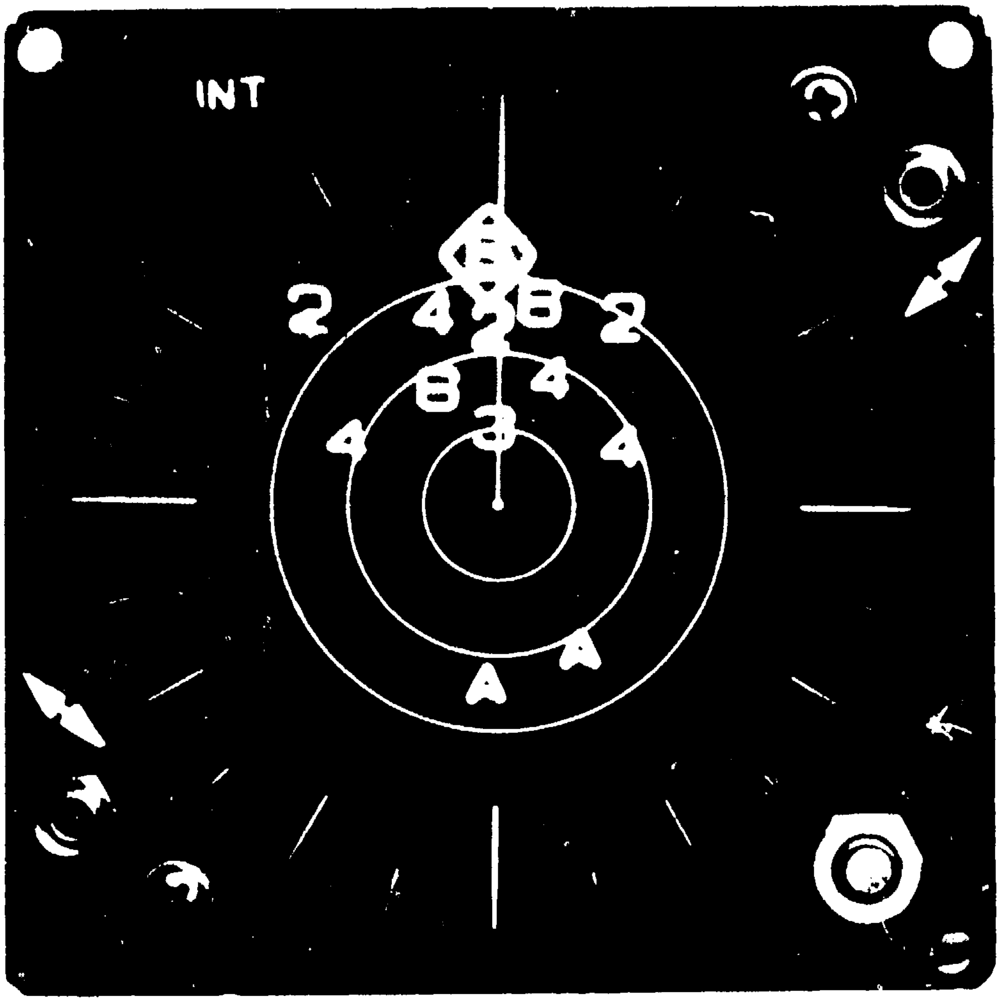

Figure 3. Typical RWS Azimuth Display

- Displays and Controls - Refresh rates, update rates, symbology, intensity effects, synchronization of display symbols with lighted legends and audio tones

The requirements for equipment simulation also apply to threat environment simulation. All possible modes of a threat emitter that may emanate from a pilot's warning equipment must be simulated to provide a sufficient level of realism. Some of the threat environment characteristics that must be considered are:

- Radiating Beam Patterns - Beam shape, and radiated power as function of modes of operation

- Scan Pattern - Searching and tracking scan patterns such as circular, conical and raster scans

- Pulse Modulation - High and low pulse repetition frequency modes; staggered, jittered and pulse frequency modulation

- Frequency Modulation - Band switching and frequency hopping effects

- Guidance Signals - Realistic pattern and correlations

Simulation of the RWS/environment interaction may vary widely. A simple model would require that each threat have programmable modes of operation as a function of range to the aircraft, including line-of-sight and space loss propagation effects. A more sophisticated model would program threat emitters to change modes of operation and interact with other emitters as a function of passive and active ECM employed by the pilot of the simulated aircraft. It should also be noted that whatever the degree of interactive simulation required for an RWST, the effects may need to be coordinated with other training or simulation systems. For example, the number of threats, location, orientation and modes of operation must be coordinated with simulated visual and radar land mass systems, when such systems are part of a trainer.

Instruction Control Requirements

To be an effective training tool, an RWST must possess certain on-line and off-line instructor control features. The required on-line features include:

- A tactical situation display (TSD) showing the current position of all threats in the environment along with the RWS aircraft position and heading
- Means of monitoring and controlling the location and modes of operation of each simulated threat
- Real-time duplication of displays and audio tones sensed by the trainee.
- Means of injecting and deleting simulated RWS equipment malfunctions
- Mission record and playback control functions, along with situational freeze and reset controls

A part from the on-line instructor control features which provide the general training exercise and simulated mission monitoring and control functions, there is the category of off-line instructor control features. The creation of training scenarios is the primary off-line function. Prior to training exercises, the instructor must be able to conveniently build, modify, or select simulated threat environments. This requires an interactive threat data base editing capability as well as mass storage facilities to hold and reload previously constructed scenarios.

Interface Requirements

The RWST may need to interface with a number of the following external systems:

- Host simulator instructor's console
- Auxiliary control terminals
- Host simulator computer system
- Earth effects simulator
- ECM subsystems
- Other detection subsystems
- Weapons subsystems
- Special test facilities

In addition to the instructor's console, which is generally an inherent part of the RWST (as was described in the previous section), there may be an integrated tactical instructor's control station associated with the host flight or weapon system trainer. In such applications, the RWST must work in a fully integrated mode with other systems, sharing a common threat environment data base and set of instructor control functions. A trainee can optimize his mission effectiveness only when his RWS proficiency is mastered in coordination with other on-board systems in a variety of tactical situations.

In addition to the regular instructor consoles, some RWSTs may have special auxiliary control terminals to permit maneuvering and control of special emitters (e.g., airborne interceptors) in real time to simulate realistic dynamic engagement scenarios.

Another important interface is with the flight simulation computer. RWST training is generally performed in conjunction with flight training to allow the trainee to perform simultaneous vehicle control along with EW engagement. The host simulator computer must provide periodic information to the RWST indicating host vehicle position, speed, heading, altitude, attitude (e.g., pitch, roll, and yaw of aircraft) and other pertinent vehicle effects. In turn, the RWST will provide to the host vehicle system simulator inputs that might affect subsystems within the host vehicle simulator (e.g., acoustic signals to the operator, sound effects, status of threats as they would affect radars in the vehicle).

If the host vehicle simulator has a visual display to provide the trainee realistic images simulating the operational environment, it is extremely important that the EW engagement stays synchronized with the appropriate images. For example, to simulate the destruction of emitter sites, it is necessary to coordinate the visual images with loss of signal on the RWS display and possibly loss of target on the host simulator's radar landmass display.

The earth effects simulator provides inputs to the EW simulator on terrain or environmental factors which will establish whether emitters are hidden and whether their respective signals may have delays, attenuation, distortion, and/or multiple reflections.

If ECM effects are to be included, the deployment of ECM by the trainee must be sensed and the likely effects of emitter track loss or mode changes must be superimposed on the threat scenario. In addition, the effects of chaff on the RWS must also be imposed onto the RWST simulation.

The RWST must also be designed to permit special test subsystems to be hooked up to provide for various checkout and maintenance operations. Such test subsystems might be used to verify the operational readiness of the trainer, and to aid in isolation and repair of failed trainer components.

Other Requirements

Because such trainers are expensive and generally not built in large quantities, a replacement system or replacement parts cannot easily be found. These systems must be designed for high availability. This calls for high reliability and ease of maintenance: in essence, a long MTBF and/or low MTTR.

By its nature, the design of the RWS trainer calls for a system configuration that is flexible, readily modifiable, and highly adaptable. From the onset, the design should be geared for change. This is true for several reasons:

- Many of the functions to be simulated cannot be accurately defined during the design phase (e.g., RWS detection characteristics as affected by aircraft installation and ECM factors). These functions should remain variable until sufficient experience is gained in flying one or more aircraft in a typical experimental range.

- The threat environment and/or the software elements of the operational RWS system are likely to change with time, and the system performance will need to change accordingly.

- The EW system may be configured within a number of different type host vehicles or interfaced with changing equipments (e.g., different jammers or weapons) over the lifetime of the system, requiring the design of subsystem interface as well as the operational characteristics of the system to vary with time.

For these and other reasons, it is necessary that the trainer operation be easily adaptable to meet broad and changing requirements.

This adaptability factor brings up a special additional problem: configuration management. Provision must be made in the design/development/adaptation cycle for setting up and maintaining adequate knowledge, control and documentation on the configuration of each version of the trainer that is built and separately installed.

Since proper training requires realistic threat data, the EW trainer also requires special security measures and controlled access of the classified data to authorized individuals.

As for other systems, cost is a major consideration in the design. In general, increasing the realism of simulation (representing the threat environment, propagation and reflection effects, effects on the signal of aircraft motion and body shadowing, and the different anomalies; all of which may occur to the detection process in real life) calls for more computer power, more sophisticated algorithms, and much specialized hardware.

The trade-off in performance gained for added cost of realism is a major requirement in the practical design approach to RWSTs.

PREVIOUS DESIGN APPROACHES

A number of design approaches have been used to simulate radar warning equipment and threat environments, ranging from various methods of signal injection into operational RWS hardware to total software modeling of the operational hardware. The former approach has been called "stimulation" and the latter, "simulation." Having designed equipment using both of these approaches, Applied Technology is intimately familiar with the corresponding advantages and disadvantages. Applied Technology has developed two software RWSTs currently in use with operational flight trainers, for both the Canadian Air Force and another NATO country.

Signal injection, or stimulation, can be at either the radio frequency (RF) or video (as converted by the receiver) levels. In the RF approach, the RF signals are injected into the operational receivers (see figure 2). The advantage of this approach is that most of the operational equipment is used without modification. If a part fails in the trainer, it is possible to replace it with aircraft parts. This approach also provides for many of the subtle mixing and walkthrough requirements of signals which, if not met, could seriously affect the displays and audio cues from a warning system.

The disadvantages of the RF level stimulation approach are numerous. It is difficult and costly to obtain a good dynamic power range, pulse width, and rise time characteristics and be able to mix several independent signal sources. Extensive calibration procedures are required to prevent degraded performance. Individual RF sources are costly and have a poor MTBF. A central computer system is needed to control the individual emitter sources and compute the antenna gain pattern effects on the RF injected signals.

The video signal stimulation approach models the receiver and antenna transfer characteristics and squirts video level signals into an analyzer or signal digitizer (see figure 2). The advantage of this technique is that it also uses operational equipment. Thus, if threat library or operational analyzers are changed on the aircraft, they can be installed in the trainer with little or no reprogramming requirements. Signal mixing and walkthrough can be realistically established.

The disadvantages of this approach are similar to those of RF level stimulation, but are not so extensive. Banks of pulse and scan generators must be mixed in a very accurate manner to ensure proper walkthrough characteristics. The video sources must be calibrated to ensure proper power range and angle-of-arrival simulation. However, they have a much better MTBF and do not drift out of calibration as fast as the RF sources. Like the RF stimulation approach, a computer system is needed to program and control the video sources. The antenna gain patterns, cable losses and receiver transfer characteristics must be modeled into the stimulated signals to provide proper realism.

The software simulation approach has the primary advantage of a low recurring cost for multiple training devices, plus a very good MTBF. Use of general-purpose computers to model the entire RWS in software (with the exception of the displays and control panel in the cockpits) provides other significant advantages. The ability to readily program and reprogram any desired operational condition and/or anomaly makes this approach very flexible. Reproducing the same indications for record/playback purposes is easily achievable in digital computer-based systems. Simulating equipment failures or common malfunctions is also easy in the software simulation approach.

The main disadvantages of this approach lie in two areas. First, there is the difficulty in assuring that the software model can realistically reproduce the time responses, false alarms, DF wander, signal modifications and other anomalies associated with the operational equipment. Second, changing any part of the operational hardware in the aircraft would require a reprogramming effort in the RWST.

SELECTED APPROACH

The selected approach , which is currently under development at Applied Technology, is outlined in figure 4 and described in the following paragraphs. The block diagram represents the functional make-up of the system in its integrated mode of operation (i.e., in conjunction with flight or weapons system training). The stand-alone mode of system operation will be briefly described later.

During the integrated mode of operation, there is a real-time input providing the host vehicle's current position and attitude as it is being flown through a simulated gaming area. The position and attitude data could also be derived from a prerecorded simulated flight.

The "signal selection model" using this information accesses the "emitter model" to determine which emitters would be candidates at this point in space for the RWS to detect, process, and present on the trainee's display. The emitter model is essentially a large data base which contains information on location, mode of operation, and operational characteristics of all emitters to be included in the training scenario. In addition to earth-referenced position information, the emitter model indicates when the emitter is active and the radar mode in which it is operating. The scan and beam patterns of the emitters as a function of time, plus transmission characteristics such as pulse repetition intervals, radiated power and frequency are also identified. If the emitters are mobile, as are aircraft interceptors (AI), there will be special control consoles for maneuvering them during simulation. In any event, the instructor will be able to monitor and modify the status and mode of any emitter during the training session.

Using factors such as the relative position of the emitters with respect to the location of the trainee's vehicle, and the emitter's current status, the "signal selection model" determines which emitters are visible to the RWS, their effective received power, and their relative angle with respect to the host vehicle's course. All dynamic emitter selection is made available to the instructor's console in the form of a tactical situation display.

The "propagation effects model," for every signal, computes what effective signal strength would be detected at the aircraft antennas based on space losses and the respective sending and receiving antenna lobe characteristics. Any other effects, such as moisture absorption or signal reflections, are also introduced at this point.

The "aircraft dynamics model" modifies the received signal characteristics based on the current attitude of the simulated aircraft. A six-degree-of-freedom model is used to compute the relative incident angles of all incoming signals with respect to the receiving antennas. The output of this model goes into the "antenna receiver model," and can be sent to other subsystems.

The "antenna/receiver model" simulates the antenna gain patterns as a function of relative incident angles received from the "aircraft dynamics model." The emitter transmitting frequency also influences the antenna gains. Aircraft masking effects are included in the antenna model, as well. The transfer function associated with the RWS receivers are a part of this model, and include such effects as crystal video pulse compression, pulse shadowing effects and recovery times.

The "effects generator" includes the transfer functions inherent in the parameter digitizing units of the radar warning system. Various effects can be input on a statistical and/or operator-controlled basis to simulate missing signals, spurious signals, failures or other special effects. The "effects generator" also intercepts control signal inputs from the trainee (i.e., RWS control panel switches) and modifies system operation accordingly. The output of the "effects generator" is real-time, digitized data words representing the radar signal data which the RWS signal digitizer would send into the RWS signal processor. The "effects generator" injects, at the appropriate rate, the digitized emitter parameters for the RWS software to process in a manner closely resembling the processing normally performed in the RWS. The signal processing software uses the real threat library to identify, classify, and prioritize the receiver inputs. It then generates and updates the display at the trainee's station. The same display is also presented at the instructor's console so he can monitor and evaluate the trainee's performance. Audio as well as visual displays are appropriately generated and kept refreshed.

In a training system which has an inherent ECM capability and/or is concerned with ECM effects, an "ECM effects model" can provide input to the "effects generator" to model the reaction to on-board or off-board ECM by individual emitters (e.g., lose track, change frequency) and by the RWS (e.g., noise, lookthrough control signals, support requests). Thus, reactions due to on-board and off-board ECM equipment can be accommodated.

As seen in figure 4, the instructor's control station can control the modeling in a number of areas such as emitter status and position, special propagation effects to be included, special effects to be incorporated such as equipment failures, and ECM effects to be considered on the emitters.

Though not explicitly shown on the diagram, a number of signal and data flows are routed back to the instructor: namely, the audio and visual displays to the trainee as well as identification of trainee action. Furthermore, the system provides for recording and playback of the threat environment, displays to the operator, and operator actions which take place during a training exercise.

In addition to the integrated mode of operation within a flight trainer, there are two stand-alone modes of operation. In one mode, the RWST can be used as a classroom trainer where an instructor can demonstrate most modes of RWS operation against various threat scenarios. Using previous recordings as demonstration aids, the instructor can play back threat scenario, aircraft position and attitude, and

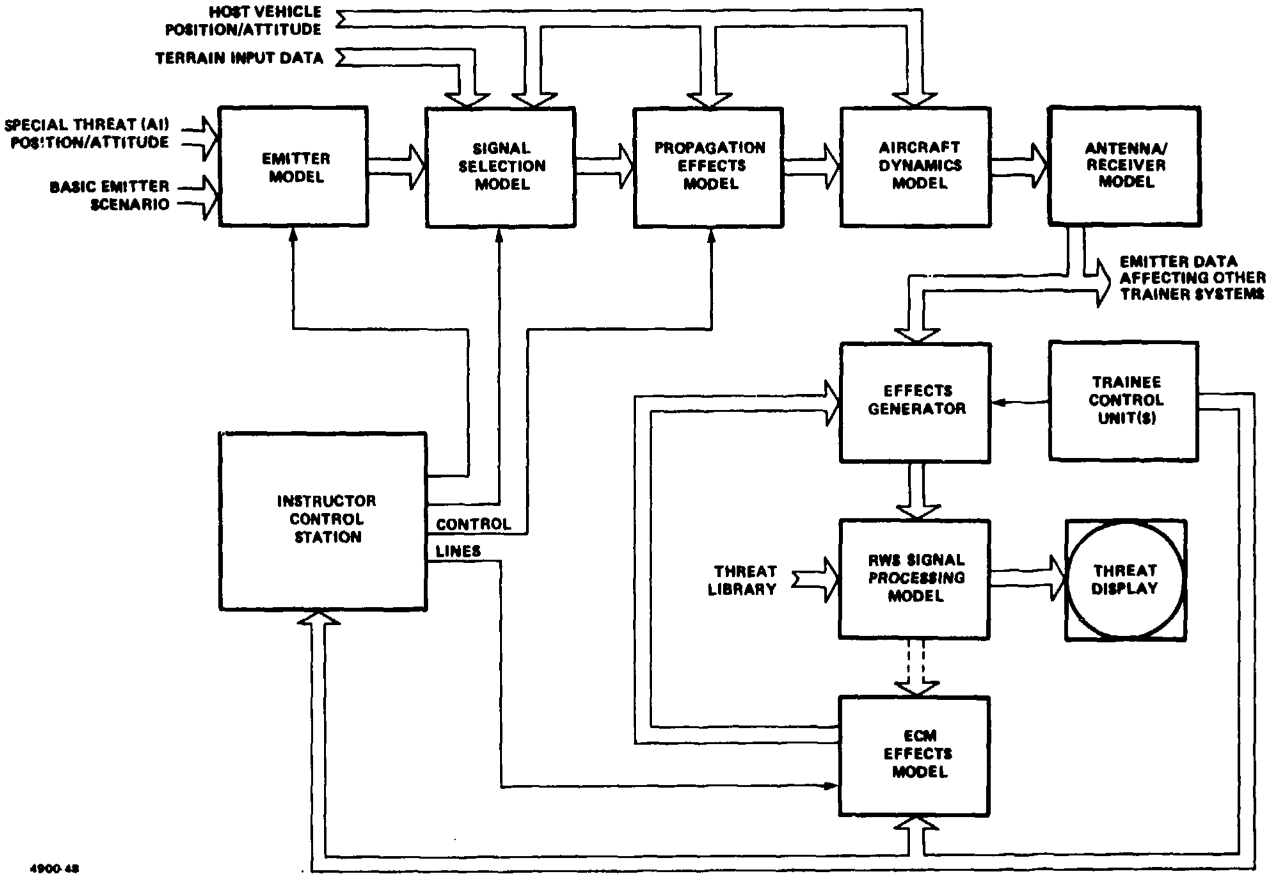

Figure 4. Digital Stimulation Functional Block Diagram

RWS control switch positions. The recorded data would be retrieved from the mass storage device and input to the "RWS signal processing model" to provide the real-time playback function.

The second stand-alone mode of RWST operation concerns itself with the preparation of training scenarios and reprogramming of simulated equipment or special effects. The purpose of the emitter model scenario preparation is to allow the placement of emitters and basic changes to their performance characteristics prior to actual dynamic flight training. Having reprogramming capability allows for changes in the operational aircraft which have an effect on the RWS, to be incorporated into the RWST.

DESIGN CONFIGURATION

Figure 5 represents the design configuration being developed at ATI. The design incorporates a general purpose "Master Computer" and a special-purpose high-speed "simulation processor."

The following functions are contained in the "master computer:"

- Emitter model
- Signal selection model
- Propagation effects model
- Aircraft dynamics model
- Instructor control function
- Interface to flight simulation computer, radar land mass simulator, and visual display system computer
- Off-line threat scenario generation

The "simulation processor" includes the following functions:

- Antenna/receiver modeling
- Effects generator
- Real-time interface to the RWS
- ECM effects

In addition to the above simulation functions, trainer system built-in test features are included into the design to ensure daily operational readiness and rapid fault isolation in the event of an equipment failure.

CONCLUSIONS

This new digital stimulation approach to RWST simulation is under development at ATI. Detailed analysis is being performed in the area of data storage and throughput requirements for various threat scenarios, threat parameters, signal densities and jamming lookthrough timings. At present, the digital stimulation approach is quite viable and offers several advantages over prior approaches. Table 1 shows a comparison of the digital stimulation approach versus prior approaches.

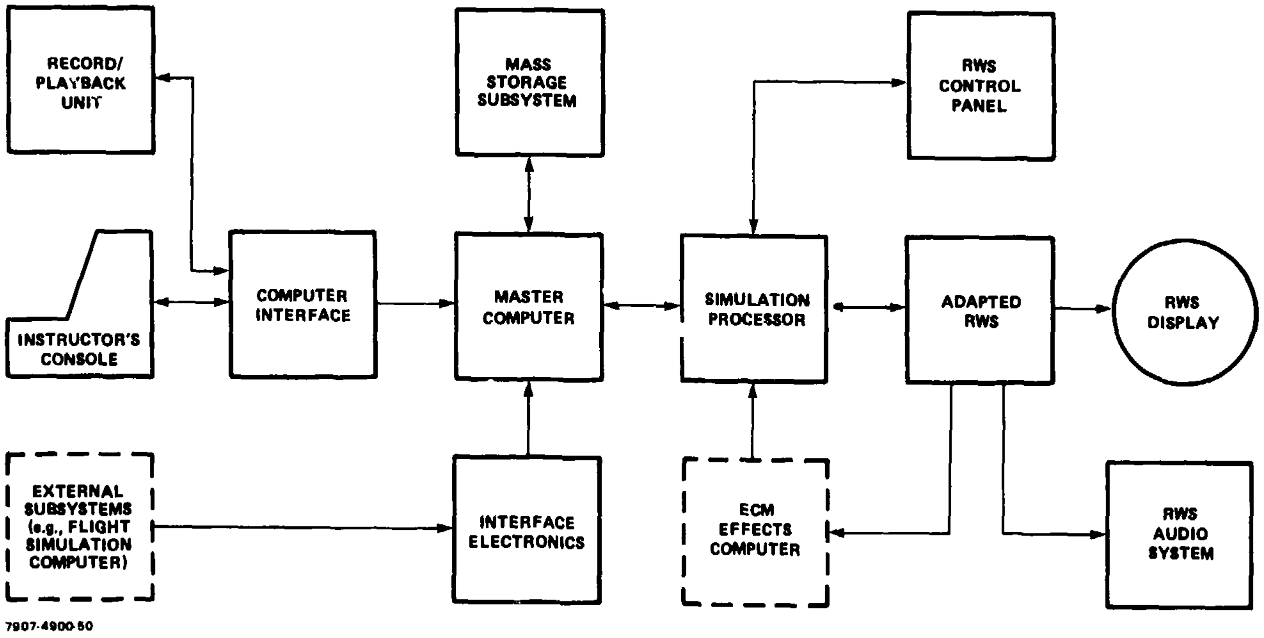

Figure 5. RWST Block Diagram

Table 1. Comparison of Alternative Approaches

Comparison Item	RF Stimulation	Video Stimulation	Digital Stimulation	Total Software Simulation
Difficulty to realistically simulate all operating conditions including RWS anomalies	Highest	High	Moderate	High
Difficulty of attaining exact reproducibility of a given training scenario	Highest	High	Low	Lowest
Update difficulty for changes in				
- RWS antennas	Moderate	Moderate	Moderate	Moderate
- RWS receivers	Lowest	Moderate	Moderate	Moderate
- RWS digitizer	Low	Low	Higher	Higher
- RWS analyzer	Low	Low	Low	Highest
- RWS emitter library	Low	Low	Low	Highest
- ECM equipments	Highest	High	Low	Low
- Threat model	Highest	High	Moderate	Lowest
Difficulty in simulating RWS malfunctions	Highest	High	Low	Lowest
Failure rate	Highest	High	Low	Lowest
Need for daily calibration	Highest	Moderate	Low	Low
Need for special support equipment	Highest	High	Low	Low
Added cost for multiple trainee station simulator	Highest	High	Low	Lowest
Cost of expanding threat environment	Highest	High	Low	Low
Time to repair	Highest	High	Low	Low
Spare requirements	Highest	Moderate	Low	Lowest
EMI problems	Highest	High	Low	Low
Facility requirements	Highest	High	Low	Low
Level of training required to operate and maintain	Highest	High	Low	Low
Non-recurring cost (excluding software development)	High	Moderate	Low	Moderate
Software development cost	Moderate	Moderate	High	Highest
Recurring cost (procurement)	Highest	High	Low	Lowest
Life cycle cost	Highest	High	Low	Low
Cost per degree of realism	High	Moderate	Lowest	Moderate

The RF stimulation approach has an advantage in the ability to update future changes in the operational hardware with minimal effort and effect on training schedules. On the other hand, the RF stimulation approach requires more special-purpose hardware than the other approaches. This results in logistics, reliability and maintainability problems, and will generally lead to a high life cycle cost.

The advantages of the video stimulation approach with regards to RWS equipment updates are similar to the RF stimulation approach; however, future changes to the RWS receiver would require reprogramming. The required hardware for video stimulation is significantly less than for RF stimulation, thus improving the reliability, maintainability and life cycle costs.

The software simulation approach uses the least amount of specialized hardware, and essentially consists of off-the-shelf general-purpose computer components. Better reliability and hardware maintainability, along with a low life cycle cost, are the biggest advantages of this approach. However, the software simulation approach has higher software development costs and imposes additional time delays and costs to accommodate RWS equipment updates.

The digital stimulation approach shares most of the advantages of the video stimulation approach and the software simulation approach, and practically none of the disadvantages. Updates to most of the RWS components can be made with minimal effort and delay to training operations. Being computer based, the peculiar reliability and maintainability problems associated with RF generators, pulse and scan generators are minimized.

In summary, this new concept in RWS simulation shows excellent promise. The goal of highly realistic simulation at a low life cycle cost, with a flexible hardware/software configuration and development schedule, is achievable. In addition, the trend in operational EW and avionics equipment has been progressing from analog-to-digital processing. In the world of trainers and simulators, the trend has gone from analog-to-digital computers. There is no reason to believe that RWS simulators should not follow this trend.

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LOW COST WEATHER RADAR SIMULATION

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ABSTRACT

There has been a growing interest in the use of Airborne Weather Radar simulation from both military and commercial operators of transport aircraft. This interest, in part, stems from the need to train aircrews to fly through weather conditions, which at one time would have been given a "wide berth", without sacrificing safety margins. This change in requirement has arisen due to escalating fuel costs.

To date, the cost of full radar simulation has restricted its use to the more sophisticated aircraft simulators. The Link-Miles Division of Singer has developed a low cost or simple Weather Radar Simulator for use on transport aircraft simulators. This paper describes the simulation techniques adopted and shows how recent advances in semi-conductor technology have been incorporated to produce a system capable of being fully integrated into an aircraft simulator.

INTRODUCTION

The evaluation of the picture as it appears on the display of a weather radar indicator is a skill that increases with experience. The information the picture yields when interpreted correctly can mean a significant reduction in operating costs, and of even greater importance make a major contribution to flight safety. Discrimination between safe and potentially turbulent areas in cloud formations early enough during a flight can avoid unnecessary "dog-legging" with the inherent advantages in maintainability schedules and fuel saving.

In a situation where a complete detour is impractical the penetration of weather patterns may be required. Using a radar simulator, cloud pattern penetration techniques can be mastered in the safety of the training complex. Also the weather situations displayed are under instructor control, which means both tropical or temperate zone weather systems modified by seasonal variations can be presented at the "flick of a switch". It is this flexibility coupled with the safety and fuel saving aspect which renders this system a useful tool in aircrew training.

Despite the obvious advantages offered by weather radar simulation, in general this facility has not been fitted to transport aircraft simulators in the past. This is mainly attributed to the relatively high capital outlay of such a system. However, recent advances in semi-conductor and micro-computer technology has presented designers with the opportunity to develop systems which would have been impractical or prohibitively expensive a few years ago. Two such areas in which this has been apparent are in the microprocessor and semi-conductor memory fields.

This paper will show how these technological advances have been exploited to produce a microprocessor based low cost system.

APPROACH

A flexible approach was adopted in the design of the weather radar simulator so that its use would not be restricted to a specific type of aircraft or radar system. A stand-alone configuration was considered as this would facilitate installation to existing aircraft simulators with a minimum of modification. Thus the simulator would store all cloud information and perform those tasks normally accomplished by the radar receiver/transmitter and antenna sub-systems.

Whilst most radar systems use performance characteristics to ARINC 564, the simulator would not be restricted to these. Indeed the design described is based on an EKCO E290 Radar System which does not conform to ARINC 564 characteristics.

DESCRIPTION OF DESIGN

The weather radar simulator, a block diagram of which is illustrated in Figure 1, is intended for use with an aircraft simulator which is assumed to be controlled by a computer, referred to here as the

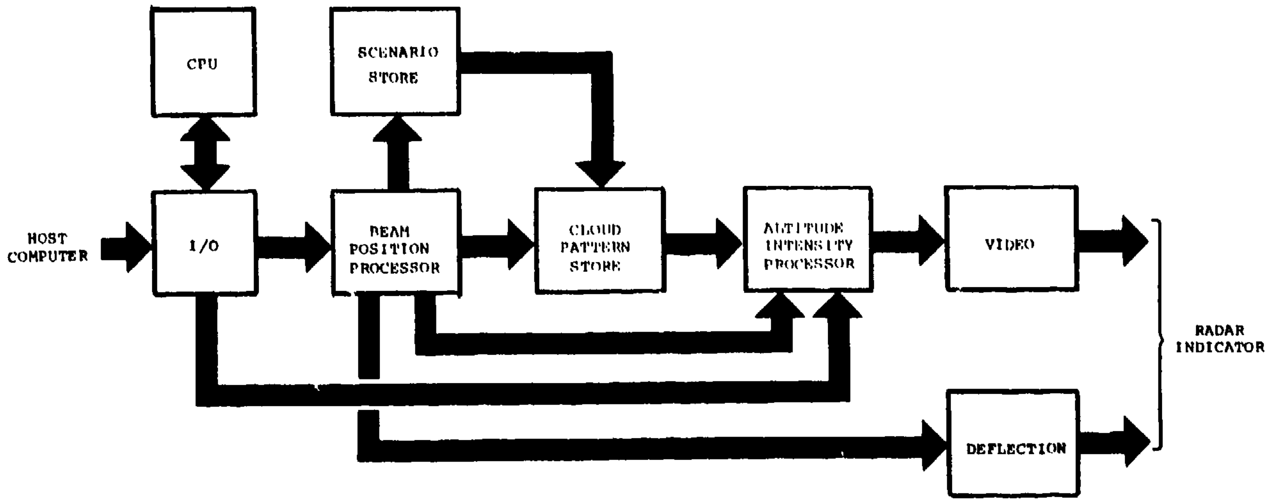

FIGURE 1. BLOCK DIAGRAM - LOW COST WEATHER RADAR SIMULATOR

"host computer" and serves to produce a simulated radar signal for display on a standard weather radar indicator mounted in the cockpit of the aircraft simulator.

Input/Output

The interfacing between the host computer and the weather radar simulator is achieved via an input/output section. Aircraft location parameters and also control data, such as radar status information, are fed from the host computer via a parallel data path. The data are received and distributed via output ports to other sections of the weather radar simulator under control of a 16 bit microprocessor. The microprocessor supervises the input of each data word and performs a software parity check to verify data validity. It then controls distribution of the data to the relevant output port of the input/output section. It also includes provision for manipulation of the incoming data so as to modify the aircraft position information to give the impression of a dynamic weather system.

Thus, although the embodiment described employs a store with data representing fixed cloud formations, cloud movement can be simulated by applying a progressive shift to the input aircraft position information.

Beam Position Processor

Aircraft location parameters are fed from the input/output section via an output port to the beam position processor. This section performs three main tasks:-

(a) system timing.

(b) generation of simulated antenna azimuth position data.

(c) calculation of the X-Y coordinates of points on the radar beam path.

System timing is derived from an internal crystal oscillator from which are obtained pulses at a pulse repetition frequency (PRF) of 400Hz., which is the frequency typically used in the E290 Radar.

The beam position processor generates angles, representing antenna azimuth position over a range ±90° of aircraft heading, in the form of a 12 bit data word. This is output to the video processing section, which will be described further below. Assuming, as above, a 400Hz PRF and a typical 120°/sec. scan rate, the antenna azimuth rotation between successive radar pulses is 0.3°.

Using the X-Y coordinates of the aircraft position input from the host computer, along with the simulated antenna position information generated as described above, the X-Y coordinates of the radar beam at successive positions over the range under consideration are derived. Based on the E290 Radar performance characteristics a range of 175 nautical miles is covered, and to achieve maximum resolution at short range the simulated range increments are non-linear. Thus the beam position for range values between 0 and 20 n.miles is based on a 0.25 n.miles increment, while values between 20-50 n.miles are based on a 0.5 n.miles increment and for the 50-175 n.miles a 1.00 n.miles increment is used. This produces a total of 265 range increments per scan. With a PRF of 400Hz this gives a radar beam position update rate of 9.4μS. The radar beam position is calculated for each of the 265 range increments for every 0.3° azimuth scan.

To take into account the beam width characteristics of the antenna main lobe, two other beam positions are calculated at angles ±1.75° of the boresite.

The X-Y coordinates are calculated using:-

$X = R\sin(\theta+\phi)+X_{a/c}$ n.miles

$Y = R\cos(\theta+\phi)+Y_{a/c}$ n.miles

where R = Range

θ = aircraft heading angle

ϕ = antenna pointing angle

$X_{a/c}$, $Y_{a/c}$ = X-Y coordinates of aircraft location.

Therefore, for each 9.4μS period, three values of X-Y coordinates are obtained.

Cloud Store

The X and Y beam coordinates are used to read out information from a cloud store. Basically the store contains a cloud map in which the area covered is divided into cells in which information is stored of cloud intensity, together with base and ceiling heights. The manner in which this information is stored will now be discussed in more detail. The cloud store contains three memories each with a capacity of 64K bytes provided by thirty-two 2K x 8 erasable programmable read only memories (EPROMS). The first memory, the scenario memory, stores up to 16 scenarios. Each scenario occupies a memory space of 4K x 8, representing 4096 cloud pattern locations on a 64 x 64 matrix. Each memory location contains an 8 bit data word which is a code specifying which of a predetermined number of possible cloud patterns occurs in that particular cloud pattern location. The six most significant bits of each of the X and Y coordinates from the beam position processor provide a 12 bit address to the scenario memory. The remaining 4 bits, for selection of the desired scenario, are input from an output port on the input/output section. The selection originating from the instructor's facility.

The 8 bit data format used in the scenario memory is in principle capable of selecting from up to a maximum of 256 patterns, but only 16 cloud patterns have been provided for this particular application. The cloud patterns are stored in the second and third memories. Each cloud pattern occupies a memory space of 4K x 16 and represents an area of sky 32 x 32 n.miles to a resolution of 0.5 n.miles square. Therefore, a cloud pattern consists of 4096 cloud cells on a 64 x 64 matrix. The cloud pattern memories receive

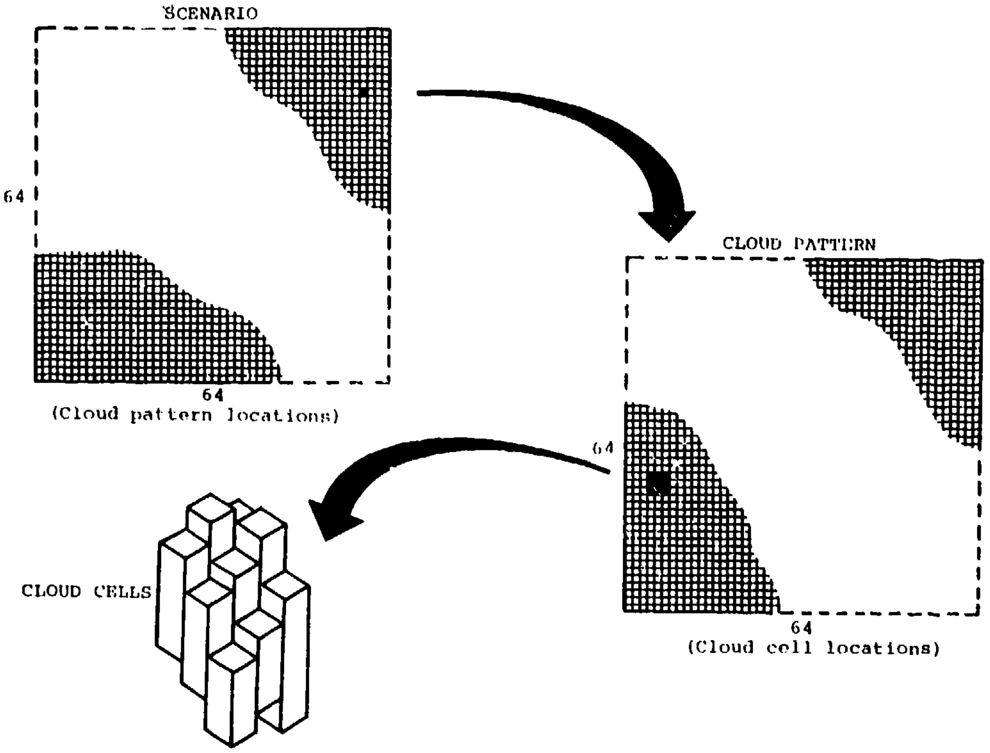

FIGURE 2. CLOUD STORE CONFIGURATION

a 12 bit address from the beam position processor (i.e. the least significant bits of the X and Y beam coordinates), and 4 bits from the scenario memory. The 16 bit data format used in the cloud pattern memory contains information on cloud cell intensity, and cloud base and ceiling heights. This data is formatted as:-

3 bits - cloud intensity (8 levels)

8 bits - ceiling height (in units of 1,000 ft.)

8 bits - base height (in units of 1,000 ft.)

1 bit - unused

This arrangement enables a three-dimensional cloud map to be formed covering an area of 2048 x 2048 n.miles x 64,000ft. A scenario is configured by coding any of the 16 cloud patterns into each of the 4096 locations in the scenario memory, as illustrated in Figure 2. It will be appreciated that the two tier memory arrangement described represents a very substantial reduction in memory requirements compared with that which would be required if a separate memory location were provided for each cell of the total area to be covered.

It will be appreciated that the cloud store arrangement described does not admit the possibility of two or more discontinuous sections of cloud within a single cloud cell. Obviously the cloud pattern memory capacity could be expanded to permit the inclusion of more than one set of intensity and height data per cell to admit the possibility of overlaying cloud formations.

Altitude and Intensity Processor

The cloud information from the cloud store is fed to the altitude and intensity processor. The first task of this section is to establish whether the radar beam height lies within the altitude range specified by the base and ceiling heights of the cloud cell under consideration.

The radar beam height is given by the aircraft height modified by the antenna tilt components. The latter is given by:-

$$Z_{tilt} = k.R\sin(\alpha) \text{ (feet)}$$

where R = range of beam (n.miles)

α = antenna tilt angle (degrees)

k = conversion constant (feet/n.miles)

Thus the altitude processor receives aircraft height information from the host computer via a output port of the input/output section, range information from the beam position processor, and antenna tilt angle as selected by the user at the radar control panel. The latter can be input directly from the control panel, or in this application via the aircraft simulator linkage, to be output eventually by the host computer. Using these data inputs the height of the instantaneous beam position is calculated. This height is compared with the base and ceiling heights of the cloud cell under consideration (from the cloud store). If the beam falls within these heights, the cloud cell intensity data from the cloud store is routed to the intensity processor.

The intensity processor serves to determine the intensity of the "paint" on the radar indicator. This can be achieved by using the standard radar equation:-

$$P_r = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4}$$

where P_r = reflective power

P_t = transmitted power

G = maximum radiation power gain

A_e = effective receiving antenna area

σ = echo range of target

R = range

However, radar equation computation is avoided by following a simplified procedure. The intensities of all the cloud cells the beam has passed through before reading the location under consideration are accumulated, and this accumulated intensity along with the range are used to address a look-up table, (e.g. a read only memory) containing empirically derived weighting factors. In this way a radar return intensity signal is obtained as an 8 bit data word. Although this involves a degree of approximation, it has been found in practice that the resultant signals are sufficiently accurate for the purpose, particularly when (as is usually the case) the raw radar returns are processed to a degree by the indicator unit before actually being displayed on the cathode tube. This is especially valid in the case of colour displays which are now replacing the older direct view storage tube (DVST) type displays.

Normally the data corresponding to the centre (boresite) position is used unless this does not encounter any cloud, in which case the intensities at either side of the main lobe are considered.

The intensity values are computed sequentially for the 265 range increments, and owing to the non-linear increments used, the resultant signal has a non-linear range/time relationship. For use with a conventional radar display unit these signals must be linearised and this is achieved by clocking the intensity value for each range increment into a read/write memory at one rate and clocking them out at another rate synchronised to the display. To maintain continuity of data flow, two memories are used which are interchanged after each radar scan. Finally, the altitude intensity processor converts the calculated 8 bit intensity word for each range increment into an analogue signal.

Video Processor

The final stage of the weather radar simulator comprises a video processor and deflection section. The video processor serves to receive the video signal from the altitude and intensity processor and to add a number of special effects required to add realism to the radar "paint", and these are mixed with the video signals. The special effects include:-

(a) spurious noise

(b) height ring

(c) ground returns

(d) H.F. spoking

(e) radome icing

The composite radar signal is amplified and output via a coaxial line to the radar indicator. In addition a pre-pulse synchronisation signal, derived from the beam position processor, is also amplified and output to the radar indicator.

The deflection section produces indicator deflection signals corresponding to the antenna pointing angle, the latter being output as a 12 bit word from the beam position processor. These are converted into signals which would normally be output by a synchro-resolver mounted on the antenna mechanism of an actual radar system.

SUMMARY

The weather radar system described was developed to meet the requirements of one particular customer. There are several enhancements which, although not taken up by that customer, can be added to this system. These include:-

(a) Storm cell growth and decay: where storm cells appear to move in relation to each other, whilst increasing and decreasing in size.

(b) Windsheer Vectors: whilst the present system is capable of operating on the entire weather map using a common windsheer vector, this enhancement will cause movement of the weather map using several windsheer vectors differing in both height and direction.

The following photographs were taken of an E290 radar indicator driven by the radar simulator. Figure 3 illustrates a squall-line ahead and just to starboard of the aircraft track. Figures 4a-4f are a sequence of six frames showing the negotiation of a complex weather system generated by the radar simulator.

ABOUT THE AUTHOR

Mr. Dennis A. Cowdrey, is a Principal Development Engineer with the Link-Miles Division of Singer (UK).

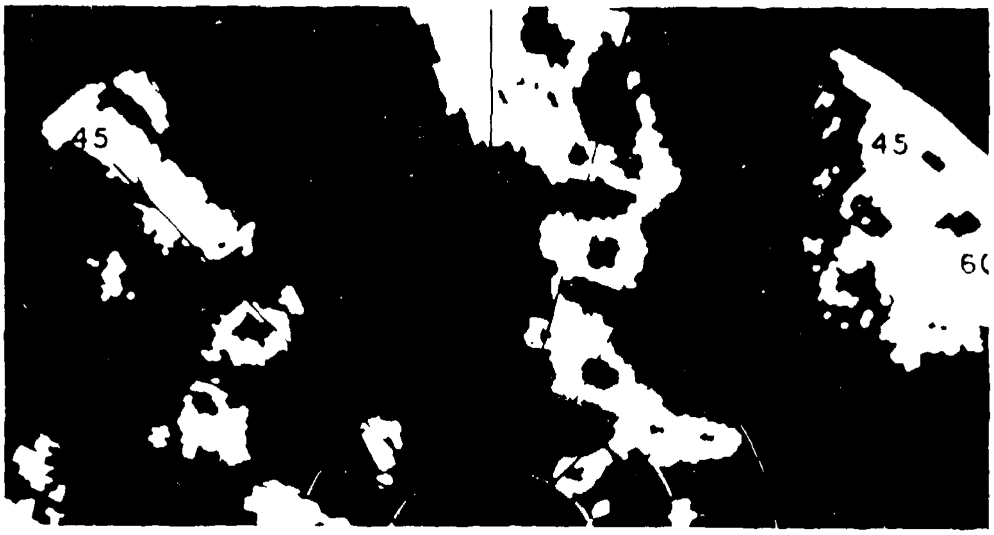

FIGURE 3.

FIGURE 4a.

FIGURE 4b.

FIGURE 4c.

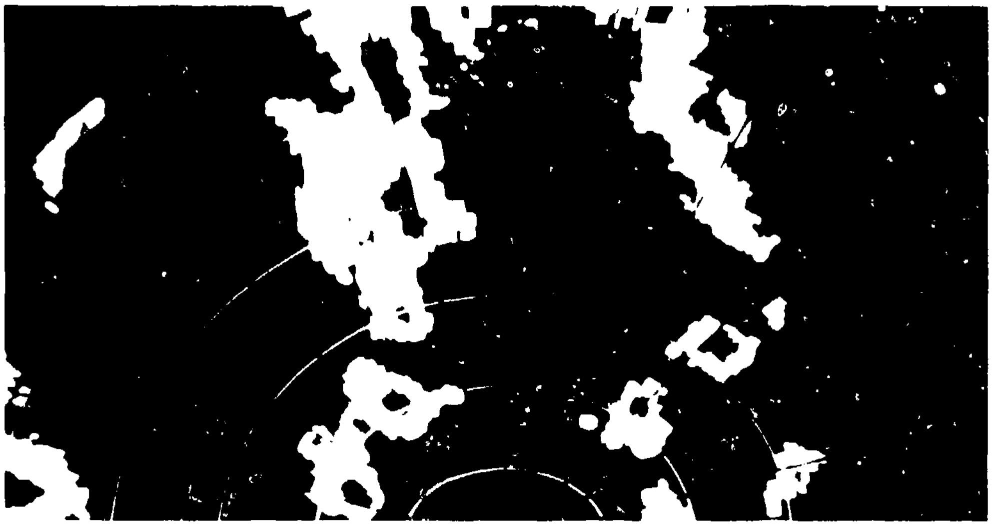

FIGURE 4d.

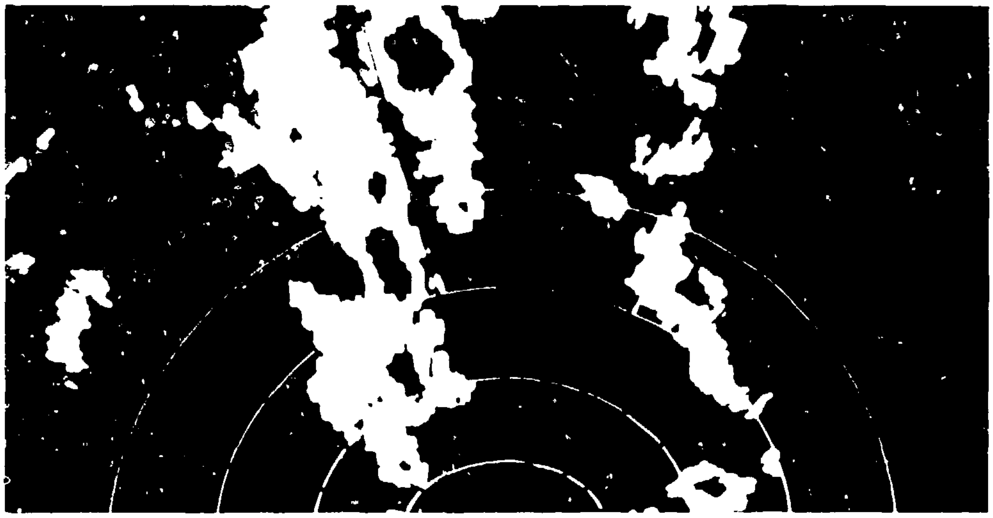

FIGURE 4e.

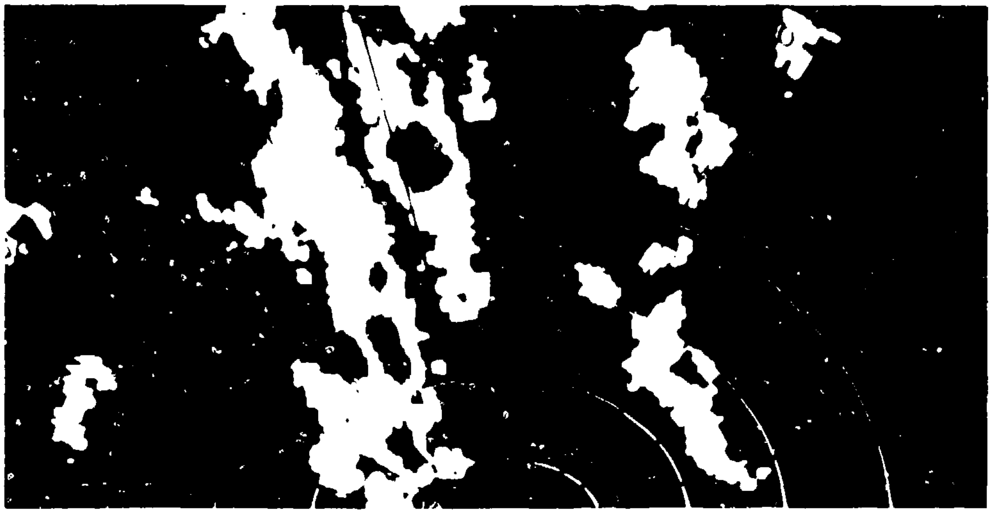

FIGURE 4f.

SIMULATION OF MODERN RADARS IN FULL TACTICS SIMULATORS

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ABSTRACT

The correct use of modern radar in flight and attack aircraft is one of the main tasks of the pilot and copilot. This means that training in radar operation and image interpretation is one of the most important training aspects in a full mission simulator. Realistic simulation of modern radars is essential to achieving the required training.

The state-of-the-art in micro-electronics, data processing, computer graphics and other relevant areas make it possible to generate all necessary radar signals in real-time using completely synthetic video generation methods. Based on digital data bases and the appropriate aircraft and radar parameters, terrain and culture profiles are generated. From these profiles, radar echoes simulating Ground Mapping Radar, Terrain Following Radar and the Radar Altimeter are synthesized. Typical radar effects such as range attenuation, shadowing, far-shore enhancement, and pulse stretching are accounted for along with the antenna, transmitter, and receiver characteristics of the actual radar in all operating modes.

The radar simulation is performed in real-time, with all computations up-dated at a rate consistent with the radar characteristics and the flight control system of the aircraft. The use of a high up-date rate allows all training missions to be performed with full freedom of manoeuvring in the simulator.

This paper describes the performance characteristics of a Digital Radar Landmass Simulation System (DRLMS), developed for the TORNADO Flight and Tactics Simulator, with an emphasis on its training role.

INTRODUCTION

The European Multi Role Combat Aircraft Tornado is equipped with one of the most modern and sophisticated Radar systems. The system has been developed by Texas Instruments. For the Tornado Operational Flight and Tactics Simulator the German Air Force and Navy as well as the Italian Air Force have decided to adopt a Digital Radar Landmass Simulation System developed by Messerschmitt-Boelkow-Blohm, Dynamics Division with certain know how inputs from General Electric, SCSD Division, Daytona Beach, Florida.
In the meantime the first two systems have been accepted by the customer.

RADAR SIMULATION OF MRCA

The primary function of the Multi Role Combat Aircraft (MRCA) Digital Radar Landmass Simulation (DRLMS) is to provide realistic simulated radar display video for the ground mapping radar (GMR) and terrain following radar (TFR). The simulated radar video is subsequently presented on the operation/maintenance station radar display and the MRCA Operational Flight and Tactics Simulator (OFTS) simulator system displays. Simulated video is also generated for presentation when either the contour mapping on-boresight (CMO) or target height finding (THF) mode of the GMR is selected. As selected by mode, the content of the simulated video includes a predetermined combination of terrain and culture returns, environmental and mission effects, jamming and noise interference, air and seaborne target skin paint returns, and beacon code video.

The format of the DRLMS simulated video output is compatible with the MRCA-OFTS interface for each of the varius operating modes of the MRCA nose ground map radar set and the terrain following radar.

Other functions of the MRCA DRLMS subsystem include the altimeter radar, the occulting of fixed site and moving platform threats, incorporation of mission and environment effects, generation of thunderstorm or chaff backscatter and data base up-dating.

Principal features of the MRCA DRLMS subsystem include European gaming areas, accurate terrain and planimetry data for each radar pulse width and on-line data storage capacity for a minimum of 5,000.000 square kilometers (1,500.000 square nautical miles).

MRCA-DRLMS

The Digital Radar Landmass Simulator (DRLMS) is a subsystem of the Multi Role Combat Aircraft (MRCA) Operational Flight and Tactics Simulator (OFTS). The DRLMS in the OFTS is shown in Figure 1.

Interface data from the MRCA-OFTS that define the current aircraft position, radar control functions and the threat, weapon, beacon and jamming requirements of the mission are supplied to the shared core memory portion of the MRCA-DRLMS computer. Interface data from MRCA-DRLMS that define the GMR-Video and TFR-Profil are supplied

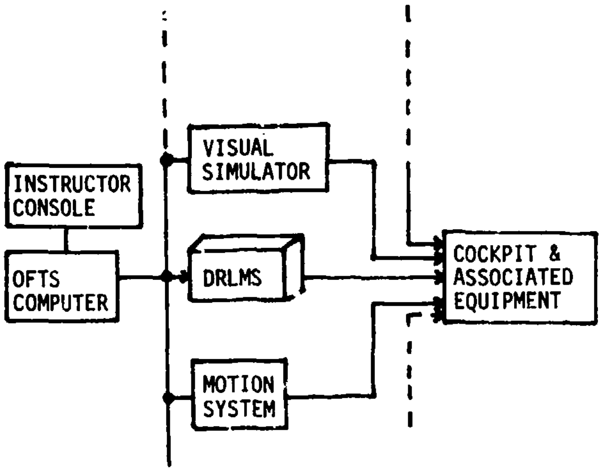


Figure 1: DRLMS in the OFTS

to the simulator cockpit, altimeter- and threat occult-data are supplied to the OFTS main computer.

The physical system configuration is shown in Figure 2. The major equipment items that comprise the MRCA-DRLMS are the DRLMS-Computer system (CPU, tape, 3 discs, terminals and printer), the DRLMS-radar processor with the power control and the operator/maintenance station (operator/maintenance console with a summagraphics digitizer tablet, graphic/alphanumeric terminal and hard copy unit).

The system function block diagram (Figure 3) is helpful for explanation of the DRLMS function. Figure 3 shows the system block diagram with the principal data flow represented by solid lines, and the basic control functions represented by broken lines.

Interface data from the MRCA-OFTS that define the current aircraft position and radar control functions are supplied to the DRLMS computer. Regions of real-time digital data are selected as a function of aircraft position and read from one of three 300 megabyte disc units.
The selected region data are stored in the DRLMS region memory. The regions stored there are for the long-, medium- and short-range data bases.
A square set of region is selected about the aircraft home region at the mission initial point for each data base.
Thereafter, the active real-time data base is updated by deleting regions out of range because of aircraft movement and by adding new regions which are presently within range of the radar. This is accomplished each time the aircraft crosses a region boundary and thereby enters a new home region. Refer to Figure 4 for typical region update geometry. In addition to the region data, the real-time data includes dynamic target and occulting data from the OFTS-computer. These data are sent by the DRLMS-computer to the moving target memory. The moving target memory is also holding weather and chaff data as established by the OFTS instructor selection.

The data base processor includes region selector, segment stripper and segment memories. Segment data are selected from the region memory by the region selector in the region controller. Radar return response data for point targets in the word format are target identity, directivity, reflectivity, and target width. Radar return response data for culture edge word contain reflectivity and edge type identity. Terrain edge words carry no reflectivity. The weather code replaces reflectivity for weather and chaff edges. For beacon, dynamic target data, a beacon code is included. For dynamic (or point) targets, the return is dependent on the cross-sectional area code.

Figure 5 illustrates the home region of the aircraft and the surrounding 8 regions that are always read by the region selector. The reminder of the regions selected grossly approximate the segment width to be stripped (Θ_{S2}).

The segment stripper tests reduce the data to that pertinent to the segment width (Θ_{S2}) for storage in the segment memories.

The data word type and X/Y position is used by the segment stripper in determining which edges and targets (points) are to be selected for each simulated antenna scan segment. All GMR and ALT edge or point words, passing the segment tests, are stored in a common active edge ping-pong memory. A separate memory is maintained for TFR or TOP data. Each unique memory segment of data contains the data for the next set of scan lines.

The data sorter provides three functions (intersection processor, intercept orderer, and priority resolver and data profile storage). The intersection processor determines points of intersection on the process sweep line. In so doing, it converts the X, Y, Z cartesian vertices received from the second memories to range (R) and Z coordinates at the process sweep line angle of the intersection processor. These converted data are ordered from near range to far range by the intercept orderer. Then, the data culture is resolved by priority number where conflicts exists for which data are to reside in a particular range process element of the process sweep line. Then resolved data are stored except for weather and chaff. These data are sent direct to the weather processor. The terrain data are processed and stored and require no priority resolution because terrain data carries no reflectance.

The power processor includes natural effects processor (NEP), weather processor (WEP), altimeter processor (ALT), terrain following radar processor (TFR) and target occulting processor (TOP). The ground range ordered terrain profile and culture profile are output from the data sorter to the natural effects processor. The natural effects processor determines the slant range and angle of incidence relative to the radar antenna (aircraft position) above the earth for each successive simulation pointing angle of the radar antenna. Using this data and transmitter power,

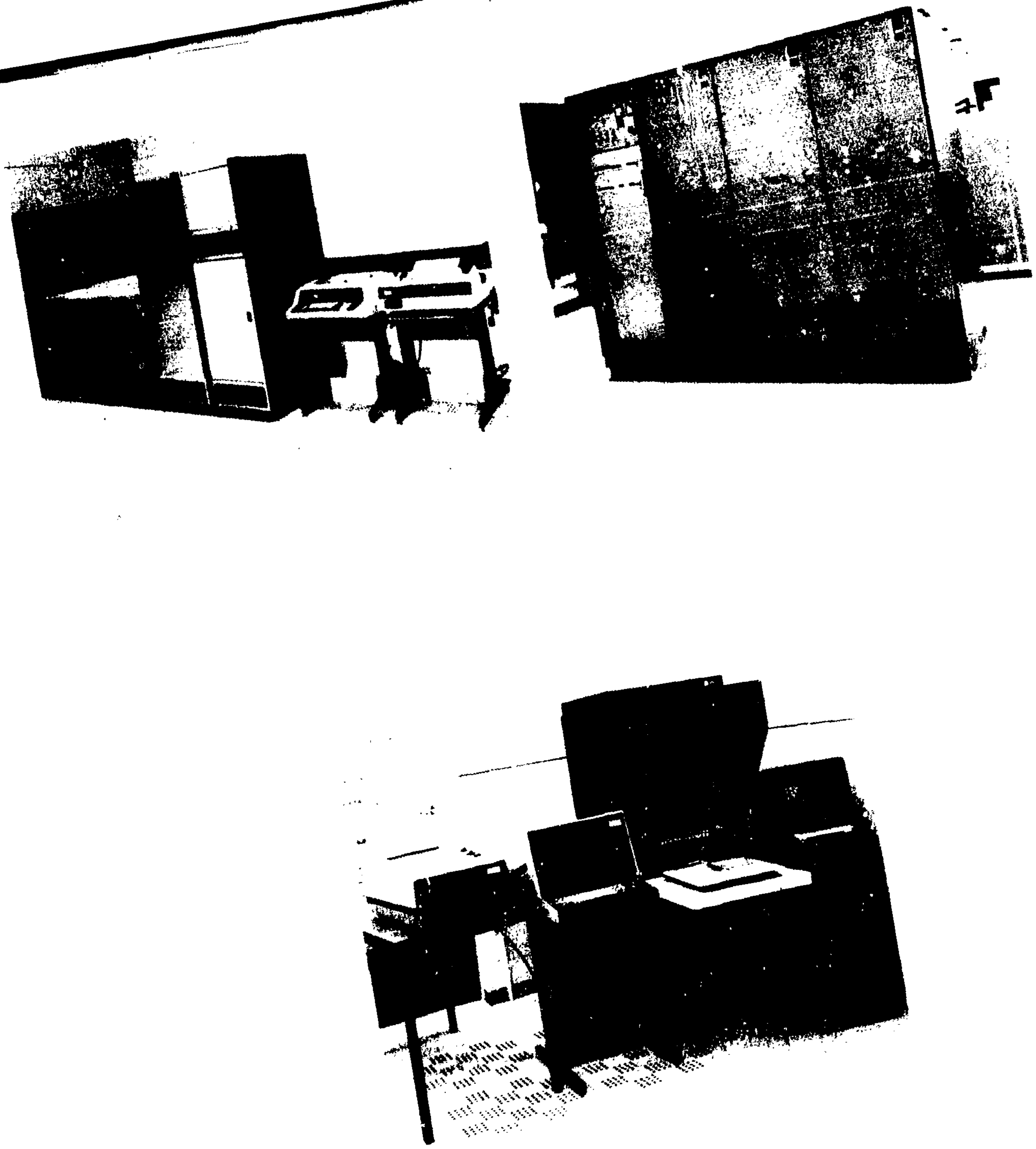


Figure 2: MRCA DRLMS System Configuration

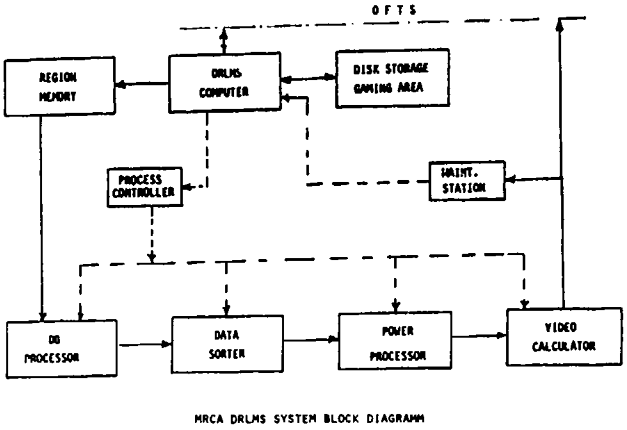
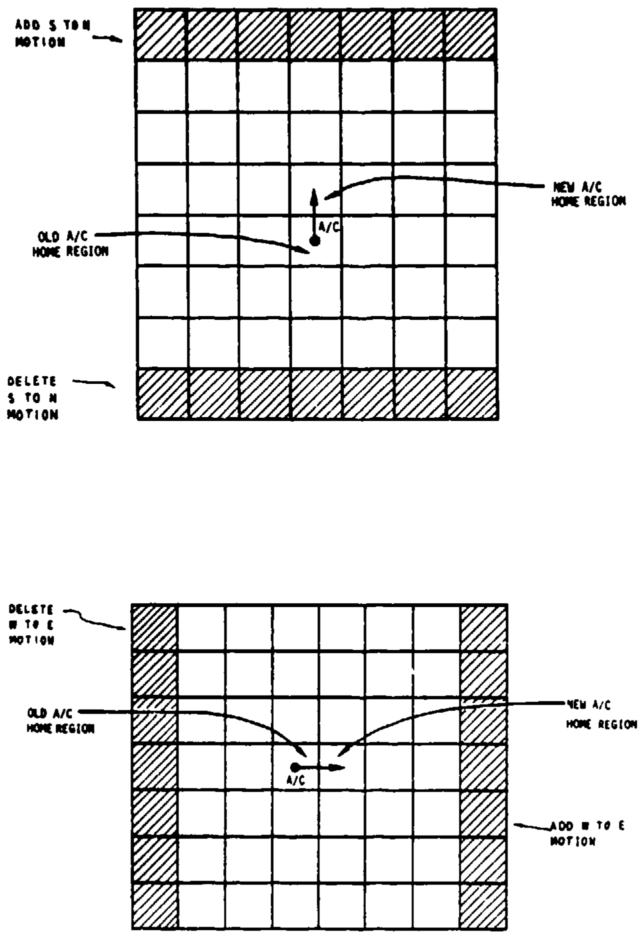


Figure 3: MRCA DRLMS System Block Diagram



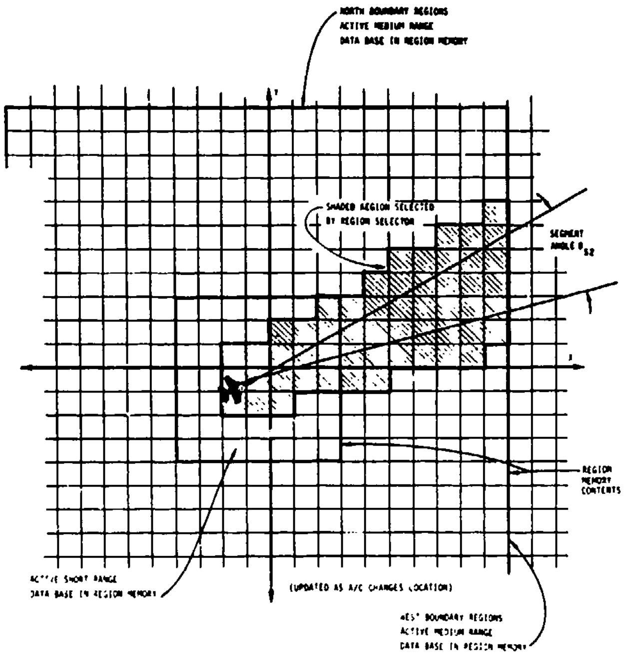


Figure 5: Region Map of Data Selected by Region Selector and Segment Stripper

Figure 4: Typical Region Up-date Geometry

antenna gain and assigned backscatter coefficients in the culture reflectance codes or weather data codes, the natural effects function determines the solution of the radar return equation. Four versions of this equation are used to provide for areal target returns, point or line targets returns, weather returns and beacon or jammer returns. Radar shadow flags and special effects such as fare-shore enhancement, and sea state are added. These returns, in decibels (dB), are sent to the radar effects processor along with the slant range (SR).

The weather/chaff processor provides weather/chaff backscatter return levels and weather atmospheric attenuation for all GMR modes, and the ALT and TFR mode cycles. The weather/chaff processor is not required for TOP functions.

For altimeter (ALT) radar simulation, the altimeter radar return, simulator portion of the natural effects processor tests are calculated return level in the 360^o altimeter antenna field of view about the aircraft and saves only those that are above the altimeter radar receiver sensitivity threshold. A further test saves the first return with the nearest slant range in the field of view. These data are output to the OFTS computer.

Terrain following radar (TFR) information selected from the medium-range active real-time data base is furnished to TFR processor by the natural effects processor (NEP). These data are subsequently slant range ordered and are accumulated for 6 consecutive TFR scan line segments to obtain an average power level for the TFR antenna field of view. Upon completing the sixth iteration of the order and accumulate process, a TFR slant range ordered profile is generated as a function of the accumulated data, that is output to the OFTS interface and the video controller portion of the video calculator.

The threat occult processor (TOP) provides 2 functions:

(1) computes the effect of jamming for up to 4 threats that are identified as being jammers and

(2) records the occult status for up to 64 threats.

The threat data includes the occult status elevation above mean sea level and threat/weapon identification number. The TOP performs the necessary calculation to determine the occult status of each threat target. These data are identified by threat target ID number from input to the moving target memory until it is returned to the DRLMS computer. The TOP provides jamming information to the GMR video channel for each GMR sweep output. Jamming simulation data are also provided for each TFR sweep.

The video calculator includes the radar effects processor (REP) and the video controller (VC). The radar effects processor (REP) receives the radar return dB levels and slant range for terrain/culture, dynamic targets, weather and chaff, and beacon from the natural effects processor (NEP). The beacon code, beacon flag, glitter flag, and CMO flag are also received from the NEP. The terrain/culture dB is slant range ordered, including airborne target dB. Weather is independently slant range ordered. The pulse width error (or pulse width integration effects), horizontal beamwidth integration, beacon, jamming, receiver noise, radar receiver characteristics, sensitivity time constant, and conversion from dB to volts are than accomplished. The output is at the operating bandwidth resolution for display output to the video controller. Jammer dB levels and jammer type identifying flags are received by radar effects from the target occulting processor.

The video controller (VC) receives the video levels in volts and in digital format from the radar processor. The video is digital-to-analog (D/A) converted and is processed to output GMR video to the OFTS. Either GMR or TFR outputs may be selected for display on the maintenance console.

Functional control of the DRLMS is directed from the process controller (PC). The process controller function contains a control oriented computer (CORC). The CORC synchronizes and directs all of the DRLMS computer/processor activities. It accepts radar parameter and aircraft data from the DRLMS computer. The OFTS computer provides dynamic control data for the radar control parameters to the DRLMS every 55 msec. This information is than distributed to the applicable functions in DRLMS, in a manner that is transparent to the OFTS system operators. The CORC is a fixed program, interrupt-driven device. Fundamental to the pipeline process timing in the DRLMS is the selected operating mode and pulse repetition frequency (PRF) of the radar. Also function of the operating mode is the effective antenna scan rate. The PRF established the time between radar sweeps and, thus, the angle between sweeps for a given PRF and scan rate.

The DRLMS computer/processor has two fundamental operating modes: On-line and off-line. Selection of the operating mode is accomplished by the operator at the DRLMS operator/maintenance station. Data base up-date and diagnostic and maintenance operations are conducted in the off-line operating mode. The diagnostic data base for these operations is stored on a dedicated portion of one of the 300-megabyte discs. Control of the DRLMS subsystem for the off-line operating mode is exercised from the operator/maintenance console.

The method of data base modelling is of critical importance in establishing the DRLMS design approach.

The digital data base is a set of numerical data that defines the terrain elevation and the radar significant features on the earth surface for a given geographical areal, which is prefered to as the gaming area. The realism possible from a radar simulator is directly dependent on the quality (or fidelity) of the digital data base, for without a valid discription of the gaming area the best of software and hardware cannot create a realistic radar image.

The data capacity of the DRLMS for the on-line data base is sufficient to store at least the data of a 5 million square kilometer gaming area. Out of a 1.996 x 1.996 nm square an arbitrarily gaming area may be choosen. MRCA DRLMS real-time radar data base boundaries are shown in Figure 6.

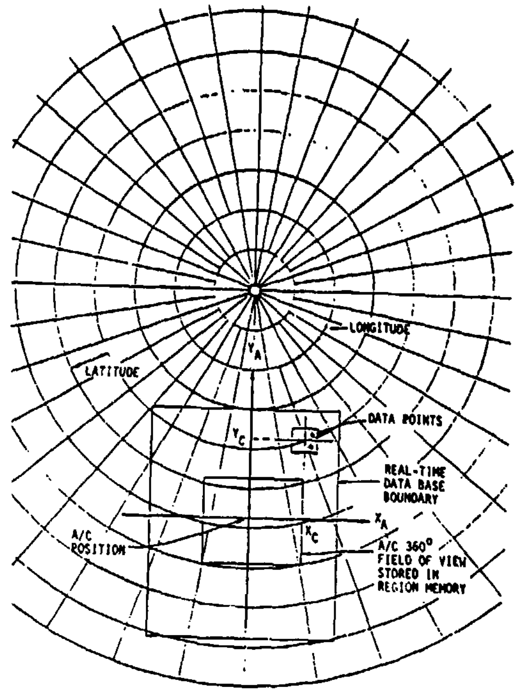


Figure 6: Aircraft 360 Degree Field-of-View in Real-Time Radar Data Base

Transformation of defence mapping agency aeronautical center (DMAAC) terrain and planimetry source data and merging of these transformed data into a single radar data base file are accomplished by the transformation program. The transformation program is fully automatic implementation of the terrain and planimetry compression technics described. Three digital data base maps (DDM) are generated, one for each level of resolution to be simulated. Each DDM defines both the terrain elevation and radar reflectivity for the entire gaming area. Radar reflectivity is defined in terms of a reflectance/texture code associated with each discrete radar point/line target and each bounded (areal) target. Target reflectivity codes, 32 for point/line targets and 32 for areal targets, are assigned by the transformation program as a function of a DMAAC feature identification codes. These feature identification codes describe all features in the planimetry file with descriptive information set characterizes the feature in terms of its surface material, e.g. matter, stone/brick,water, snow/ice, trees, rock.

The final step in generation a transformed DDB+) from the DMAAC source data is to concentrate the separately generated terrain and planimetry files into a single DDB file for each DRLMS region of the gaming area. This process consists of merging the two files to a single disc pack or tape, as required. The output of the merge process is the transformed digital data base. Figure 7 summarizes the data base data flow, processing and storage.

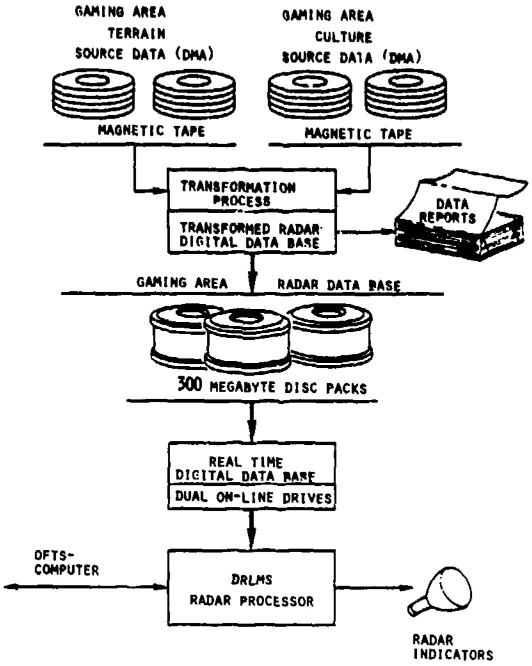


Figure 7: Radar Data Base Flow

CONCLUSION

Since the Trainings Simulator for Tornado is used as a Full Mission Simulator the system is equipped with a Computer Generated Image Visual System (CGIVS) in order to train among others weapon delivery and position up-dating by means of the head-up display. Necessary correlation of information presented by DRLMS and CGIVS is achieved by common source material used to generate the data bases. The source material is cartographic information in digital form (DMA-format). By means of a data base generation system under development for the German services CGIVS and DRLMS data bases will be created.

+) DDB - digital data base

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MID-RANGE TRAINERS: CONCEPT AND DESIGN AS APPLIED TO THE B-52 OAS/CMC PART TASK TRAINER

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ABSTRACT

Mid-range trainers are designed to provide useful training at significantly lower cost and development time than those for full-capability (full-scale) trainers. Mid-range trainers are appropriate for use prior to development of full-scale trainers and as supplements to full-scale trainers. With a mid-range trainer, trainees may, for example, practice operational procedures, become familiar with system control locations and reaction times, and learn to recognize and handle system faults. This paper describes the B-52 OAS/CMC Part Task Trainer, detailing its function as both a conversion trainer to provide the highest level of simulated training while the full-range trainer is being developed, and as a "lead in" trainer before the student moves to the full-range device. Capabilities of the Part Task Trainer are explained. Cost effective aspects of dual use are discussed. Design features to provide lower initial cost and flexibility for future modification and expansion, use of minicomputers, off-the-shelf components, and modular structure are detailed.

INTRODUCTION

Mid-range trainers provide high training value with lower cost and shorter development time then full-range trainers, such as weapons systems trainers. They can be applied effectively in situations requiring: 1) a conversion trainer, to train new or unique procedures, tasks, and functions in the interim during which the weapon system is being built or modified, or when no full-range trainer is available; and 2) an initial lead in trainer, for when the weapon system or full range trainer is in complete operation but training is required for the user to become skilled at lower-level tasks, such as becoming familiar with system controls and locations, practicing operational procedures, and performing system malfunction procedures. As conceived mid-range trainers provide maximum "hands-on" training in a well-ordered training program. In many cases, these mid-range training devices will be the "backbone" of a well ordered, highly developed training program.

TRAINING SITUATIONS

Mid-range Training devices can be effectively developed and applied in two training situations: 1) the fluid training situation, and 2) the static or established training situation.

In a fluid training situation, the training program is being developed and produced while the weapon system is in full scale development. Thus the word fluid is applied because the curriculum and training devices are undergoing change concurrently with changes in the weapon system to meet training requirements and objectives.

In this fluid training situation, the mid-range device will be used as an interim device before development of a full-range trainer such as a Weapon System Trainer. These devices would be designed to train procedures, task and functions of a new system before moving to the weapon system itself. This training concept saves aircraft hours needed for training and effectively trains lower-level training tasks. With these devices, the students or trainees will become familiar with system controls and locations, practice operational procedures and perform system malfunction training. All of this training can be performed in a simulated real-time operational environment. The mid-range trainer would represent the highest level of simulated training. It must be capable of complete lower-level training because the next level would be training in the weapon system itself. The mid-range trainer to be cost effective, must take the load of training lower level objectives away from the weapon system.

Another case for use of interim trainers would be during major weapon system modification. When a weapon system undergoes a major modification, the weapon system is usually modified before the companion full-range simulator is either brought up to date or produced. An interim device will be necessary to train new procedures and new equipment before the weapon system is used. This mid-range trainer would be used in conjunction with a highly developed conversion training program. A simulator attached to this type of training program would be a Part Task Trainer or Cockpit Procedures Trainer, a device specifically designed to train only the changes, modifications and specific tasks and functions related to the operation of the new system.

In the static training situation, the training program has both mid-range and full-range trainers. The weapon system is static in that it has been delivered and all training revolves around an established program and continuous proficiency training situations. An example of the static training situation would be the Combat Crew Training Program. In this situation the mid-range trainer would be used to train at lower levels, preparing the trainee to move to the full-range device. This one fact is important to the well ordered, established training program to provide cost effective use of the full-range device. In the simplest terms, the mid-range trainer provides cost effectiveness by allowing the training manager to use the full-range device for what it was designed for; to train higher level objectives. Mid-range trainers could be specifically designed to fit into a highly developed Combat Crew Training Program. It is conceivable that this type of device would be used as a "lead-in" for training missions in the full range trainer. If the trainee is knowledgeable in switch locations system function and operation, the full range trainer sessions can be used for real mission profiles. If problems are encountered in student performance, that student can be given extra training sessions in the mid-range device until proficiency has been attained. The WST training periods now become cost effective and can complement training in the weapon system itself. By moving through the hierachy for training devices, students become better trained and build the confidence that is necessary to perform in the weapon system.

The key to any mid-range trainer is their low cost, high training value and short development time. Use of minicomputers, off-the-shelf components and a modular design is important to reduce the initial cost of mid-range trainers and provide the flexibility necessary for future modifications and expansion of these devices.

As the next sections illustrate, the B-52 Offensive Avionics System (OAS)/Cruise Missile Carrier (CMC) Part Task Trainer (PTT) fills all the necessary requirements of the concept of mid-range trainers as part of a sophisticated training program.

INTRODUCTION TO THE B-52 OAS/CMC PART TASK TRAINER

The U.S. Air Force B-52 Bomber is receiving a major modification in the form of the Offensive Avionics System (OAS). The OAS, which is used by the B-52 radar navigator and navigator to perform navigational and offensive-weapon-delivery tasks, replaces the older ASQ-38 equipment and automates some previously manual functions.

As part of a major weapon system modification, a total aircraft simulator/trainer will be built for the OAS. This full-range trainer is scheduled to be operational in the 1983-1986 time frame, which leaves a gap between scheduled deployment of the OAS and availability of the complete trainer system. Crews using the first B-52 OAS modified aircraft will need a trainer in the interim to fill this gap. The 4235 Strategic Training Squadron (STS), Headquarters Strategic Air Command (SAC), in conjunction with Air Training Command and Technology Service Corporation of Santa Monica, CA, has been tasked to develop and build four B-52 OAS interim trainers to be used by Strategic Air Command in their OAS conversion training program.

The 4235 Strategic Training Squadron (STS) was tasked to develop the OAS conversion curriculum. Included with this tasking, was the development of a new OAS/Cruise Missile training program and curriculum for the B-52 Combat Crew Training School at Castle AFB, CA. Using the Instructional Systems Development (ISD) approach, the 4235 STS/Special Project Branch developed the training requirements for the OAS and Cruise Missile. With these training requirement in hand, a list of tasks outlined which were essential for training in a ground simulator was developed (see Figure 1). These tasks were determined with both the conversion program (fluid training situation) and the Combat Crew Training Program (static training situation) in mind. As requirements and design began to take shape it became readily apparent that an interm mid-range device was absolutely necessary to the Conversion Program and would greatly aid in Combat Crew Training.

The interim trainer will be a Part Task Trainer (PTT), one that addresses some of the tasks, procedures and conditions the crewmembers must handle with the actual weapon system (See Figure 2). Because the air crews receiving training will be highly experienced in the B-52 navigational functions, the focus of the PTT will be on procedures training; specifically, those procedures unique to the new OAS. As an example, the PTT must respond exactly as the OAS would to all commands (button pushes, switch activations, etc.), but only those features used directly in navigational and weapon-targeting procedures need be displayed in radar video.

With only the limited OAS functions included, the PTT would reduce the Conversion Training Program by two flights per crew, saving the Air Force $16,000,000. If applied in the Combat Crew Training Program the device would reduce WST periods necessary to train lower tasks and again savings would amount to approximately $400,000 a year in simulator training time. The above savings alone are significant, but when compared with the cost of the four simulators they become impressive. The entire simulator project was given $1.9 million, which breaks down to $450,000 per device including software and hardware.

Design features of the PTT hardware include mobility, so that the PTT can be moved easily

TASKS FOR THE OAS PART TASK TRAINER

GENERAL NAVIGATION TASKS

Navigation Tasks
(To perform general OAS operation)

- Destination Sequencing/Selection
- Fixpoint Sequencing/Selection
- Direct Steering
- Centerline Recovery Steering

Position Fixing Tasks
(To update aircraft position and course)

- Radar Position Fix
- Terrain Correlation Fix
- Overfly Fix

Calibration Tasks
(To calibrate navigational systems)

- High-Altitude Calibration
- Memory Point Wind Calibration
- Alternate Heading Calibration
- Low-Altitude Calibration

Rendezvous Tasks
(To perform aircraft refueling)

- Point Parallel Rendezvous
- Alternate Air Rendezvous

Special Procedures

- OAS Turn On
- OAS Shutdown

WEAPONS TASKS

(To prepare and launch/release weapons)

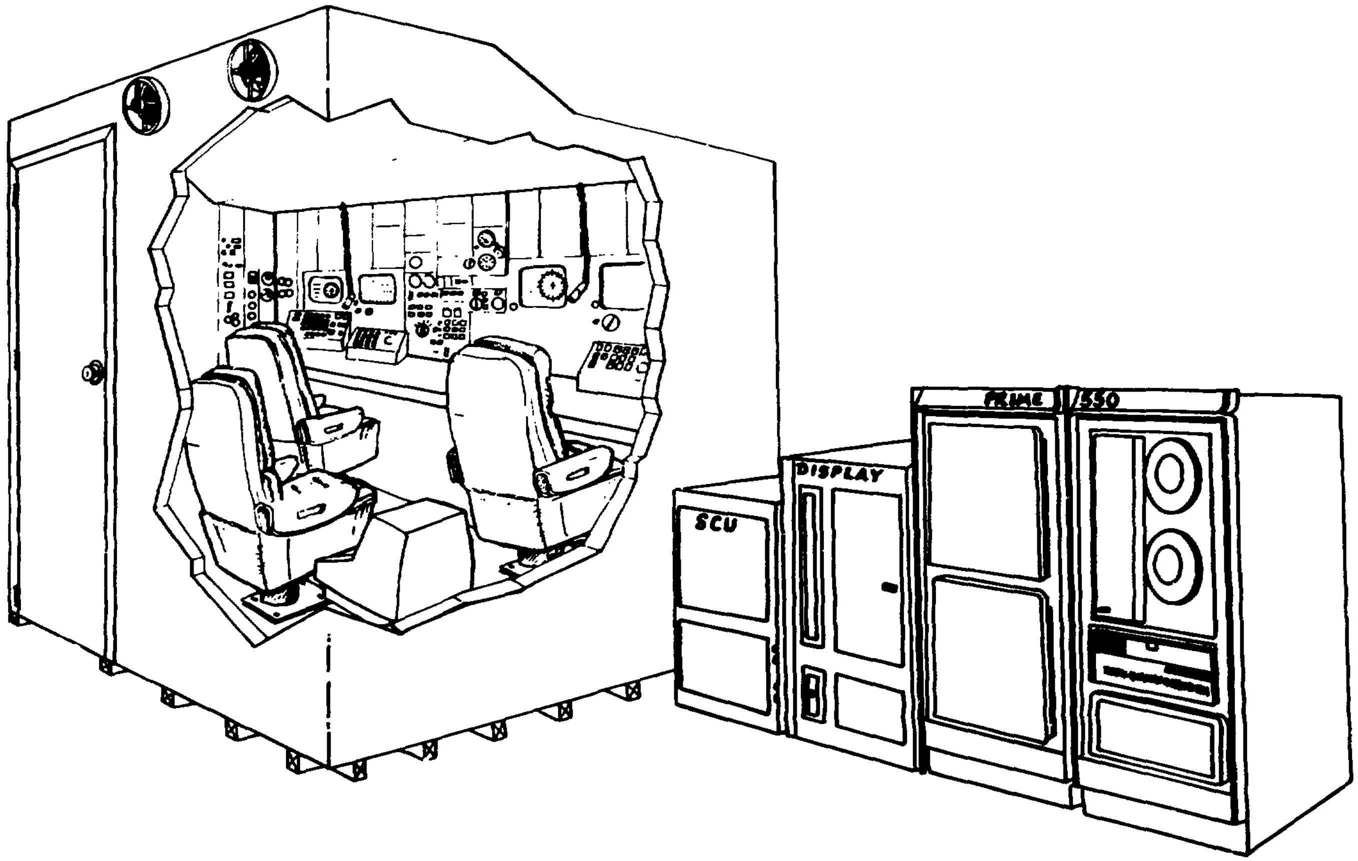
- SRAM Alignment
- ALCM Alignment
- SRAM Prearm
- ALCM Targeting
- ALCM Retargeting
- ALCM Prearm
- SRAM Ranging
- SRAM Launching
- ALCM Ranging
- ALCM Launching
- Procedure Irregularity Recovery
- Missile Jettisons
- Launcher Rotation
- Synchronous Bomb Run
- Alternate Bomb Run

MALFUNCTIONS

(To perform alternate/back up procedures when OAS components fail)

- RN Management Panel Fails
- WCP Panel Fails
- Doppler Radar Failure
- OAS Failure

Figure 1



B-52G/H OAS/CMC PART TASK TRAINER

Figure 2

from base to base to meet training schedule; and use of off-the-shelf computer components. To reduced the cost of hardware and make maintenance easy by service contract decreasing PTT down time. As to the software, it must be flexible to handle OAS design changes easily and make future expansion possible.

OAS PART-TASK TRAINER CAPABILITIES

The physical layout of the PTT (see Figure 3) comprises stations for the two crewmembers (called the radar navigator and the navigator) required to operate the OAS, as well as for an instructor. Included in the PTT is a physical mockup of the OAS identical to the OAS's layout and dimensions of panels, switches, displays, etc. The mockup comprises 16 operations panels, two of which include a keyboard and trackball (one for each crewmember). Four monochromatic display monitors provide up to 33 different display formats, including three with synthetic radar imagery. The instructor's position is equipped with a CRT console for setup and monitoring of the training sessions.

The OAS PTT automatically navigates the B-52 according to a predefined scenario flight plan. The crewmembers are able to monitor, update, and override this automatic navigation system, using the OAS equipment and a variety of OAS navigational procedures supported by the PTT. The PTT also supports OAS procedures to perform in-flight refueling; preparation and delivery of Air Launched Cruise Missiles, Short Range Attack Missiles, and Gravity Weapon Delivery; and backup procedures used when certain OAS failures occur. Takeoffs and landings are not supported by the PTT, but OAS startup and shutdown procedures are functional.

In the PTT, the instructor can select a flight plan from a set of seven canned scenarios or modify any canned scenario to generate a new flight plan. The canned scenarios are representative of actual training missions. Scenarios of up to five hours of flight time can be generated within a region of 2-million square nautical miles, covering the Western and Central United States. Sufficient navigational fixpoints and target areas are included within this region to define at least 100 different realistic

CREWSTATION
Figure 3

scenarios. Actual terrain data are used to generate synthetic radar imagery for display of these navigational fixpoints and target areas. Since radar scope identification is not a primary training requirement the synthetic radar will contain only chosen fix points, target OAP's and radar returns on flight path for navigation orientation.

The instructor also has the capability to inject faults and malfunctions at specific times in the scenario, as well as at any time during the training session. With the ability to steer the aircraft off the flight plan and to accept corrections from the OAS crewmembers for recovery, the instructor acts as the B-52 pilot. He also monitors crewmembers' actions and is able to freeze the training session at any time, to give additional instruction, and then resume the session.

OAS PART TASK TRAINER DESIGN

The PTT has been designed in modules, to facilitate modifications as the OAS itself changes and as additional OAS trainer capabilities are identified. The five modules -- independent subsystems -- of the hardware configuration are depicted in Figure 4 and described below. They illustrate the use of off the shelf equipment.

Mainframe Processing Subsystem

The Mainframe Processing Subsystem (MPS) consists of a minicomputer with disk drive, magnetic tape drive, and system console (See Figure 5). The disk is used for real-time storage and retrieval of radar imagery data; the magnetic tape is used for transfer of software and updates of terrain data.

The MPS is the central processor for the PTT. It is responsible for logical and numerical processing plus control of all other subsystems. The PTT Software runs on the MPS.

The virtual console is a CRT required for the PRIMOS Operating System. The disk drive is required for the operating system, for software and data file storage, and for real-time access to display files for synthetic radar imagery updates. The magnetic tape drive is required for

PART-TASK TRAINER SYSTEM BLOCK DIAGRAM

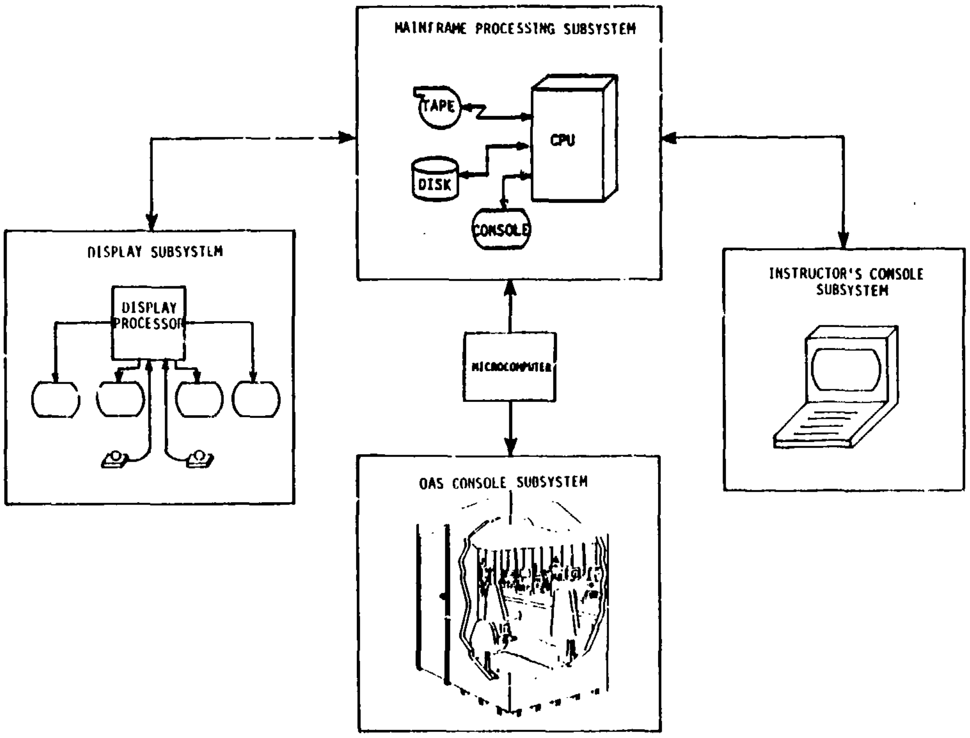


Figure 4

loading terrain files and software updates on the operational systems in the field. All peripherals are standard PRIME equipment.

All peripheral devices on the PRIME 550 CPU (disk drive, magnetic tape drive, and virtual console) have standard interfaces supported by PRIME hardware and software.

The mainframe processing subsystem capabilities are listed below for the PRIME 550 CPU.

PRIME 550 CPU

32 Bit CPU Architecture

128 Registers

512 K Byte Error Correcting Code Main Memory (expandable to 2 M Byte)

1 K Word Cache

Single/Double Precision Floating Point Arithmetic in Firmware

Up to 32 DMA Channels

16 Asynchronous Channels

Up to 63 Simultaneous Users

PERIPHERALS

PRIME Virtual Console (PT-25 CRT Terminal)

PRIME 96 M Byte Cartridge Module Device Disk Drive

PRIME 9-Track, 800 BPI, 45 IPS Tape Drive

The MPS interfaces to the Display Subsystem (DS), Instructor's Console Subsystem (ICS), and Switch Control Unit (SCU). These interfaces are described in the respective subsystem descriptions below.

Display Subsystem

The Display Subsystem (DS) is the primary output device for the navigator and radar navigator positions. The DS includes four monochromatic monitors (called multifunction displays or MFDs) mounted on the panels in the crewstation. The display processor and refresh memory interface with the mainframe processor to generate imagery, graphics and alphanumerics on the MFDs. Two trackballs are also included in the DS and are physically mounted in the

MAINFRAME PROCESSING SUBSYSTEM BLOCK DIAGRAM

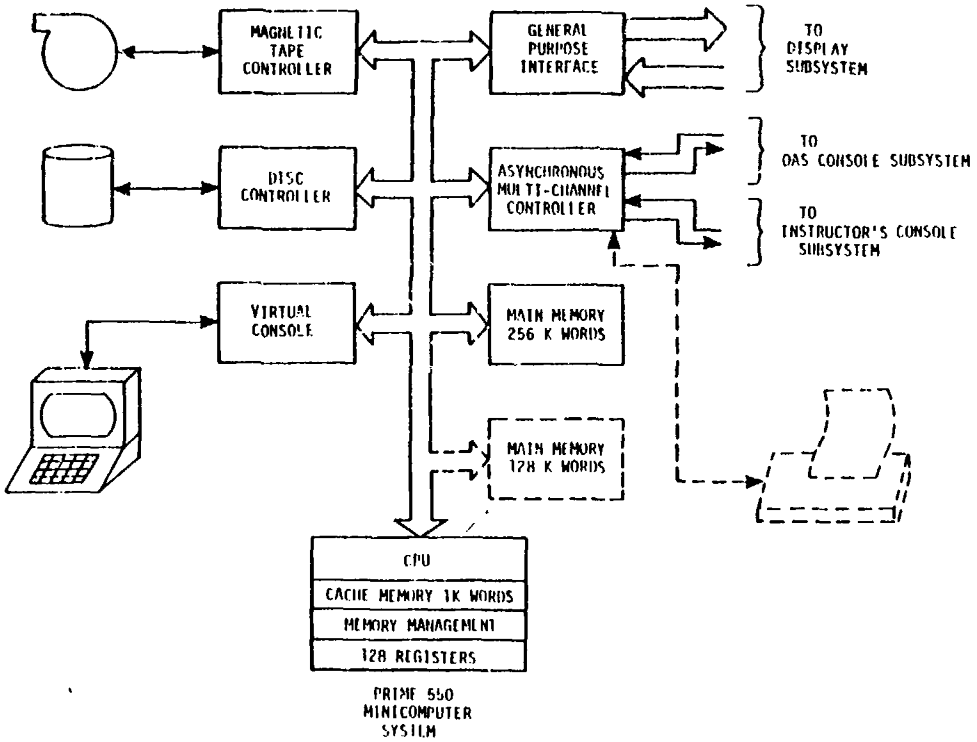


Figure 5

DISPLAY SUBSYSTEM BLOCK DIAGRAM

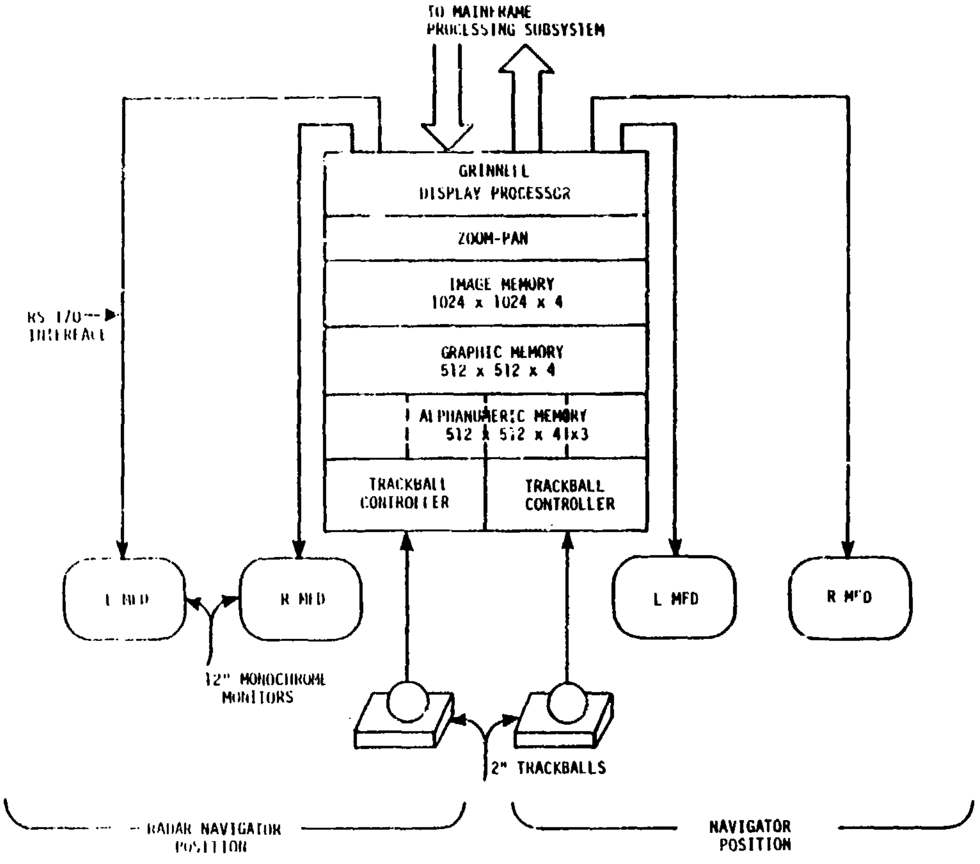


Figure 6

crewstation to allow the crewmembers to position crosshairs on the MFDs (See Figure 6).

Each crewmember has control of two MFDs and one trackball. Thirty-three different display formats may be selected for presentation on any one or combination of MFDs. Most display formats contain only alphanumeric data, but some contain alphanumeric data overlaid on radar video imagery, which at any one time may include crosshairs, ground track vector, and navigational markers (aircraft heading vector, range rings, bezel rings).

The display processor, refresh memory, and trackballs are a special-purpose system provided by Grinnell Systems Corporation for this application. The monitors are model NDC-12 provided by TSD Display Products, Inc.

The DS interfaces with the mainframe processor via two high-speed, unidirectinal 16-bit parallel interfaces with direct-memory-access (DMA) transfer capability. To accomplish 16-bit parallel data transfers, the General Purpose Interface Board provided with the PRIME computer was modified by Grinnell to interface with the display controller.

The following is a list of the Display Subsystem Capabilities:

IMAGE

One Image Shared By Up To Four Monitors

4 Bits (16 Levels) Gray Scale Image

4 Bits For Four Overlays (also shared by monitors)

1024 x 1024 Resolution (512 x 512 displayable at any one time)

ALPHANUMERICS

Independent Alphanumerics On Each Monitor

May Overlay Portions Of Image Data

Dual Intensity

Reverse Video

Underline

Blink

7 x 9 pixel characters in 8 x 12 matrix

OAS CONSOLE SUBSYSTEM CONFIGURATION

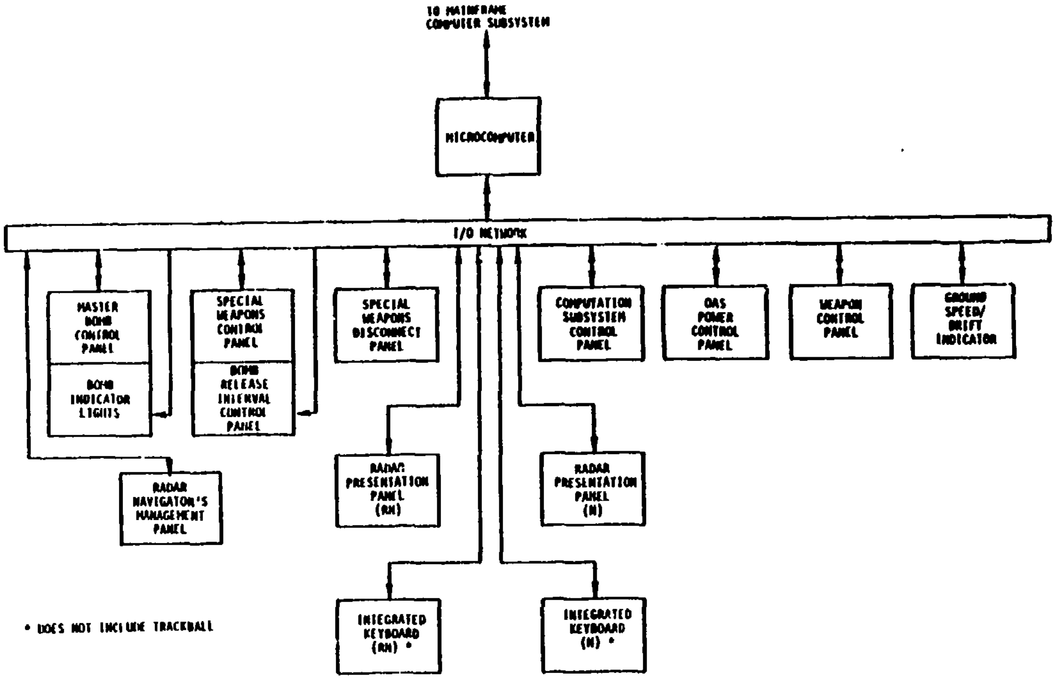


Figure 7

128 alphanumeric characters, special symbols

MONITORS

4 Monochromatic (P39 Phosphor) Monitors

6" x 9" Viewing Area (or 12" diagonal)

OAS Crewstation Subsystem

The OAS Crewstation Subsystem (see Figure 7) contains operational mockups of those OAS and weapon panels required for the specified procedures training in the PTT. This subsystem consists of the 16 panels used by the crewmembers. The panels are equipped with switches, buttons, lamps, and two keyboards. The four MFDs and two trackballs are physically located with the panels in the crewstation but are logically part of the Display Subsystem.

Switch Control Unit

The Switch Control Unit (SCU) provides an interface between the mainframe processor and the switches and lamps in the panels in the crewstation. The SCU is responsible for: 1) sensing switch activations on the panels and reporting them to the MPS, and 2) generating appropriate signals to light/extinguish lamps on the panels by request of the MPS.

The SCU block diagram is shown in Figure 7. The SCU is a CROMEMCO Z2 microcomputer with appropriate software.

The interface box (see Figure 8), which is mated with the Cromenco Z2 microcomputer to form the Switch Control Unit, is being produced at the 3300 Technical Training Wing/Technical Training Division, Keesler AFB, MS.

Instructor Console Subsystem

The Instructor's Console Subsystem (ICS) serves as a system monitor and control interface for the instructor. It provides for interchange of textual data with the Part Task Trainer control programs executing in the MPS. The following data are displayed at the Instructor's Console on an alphanumeric CRT display:

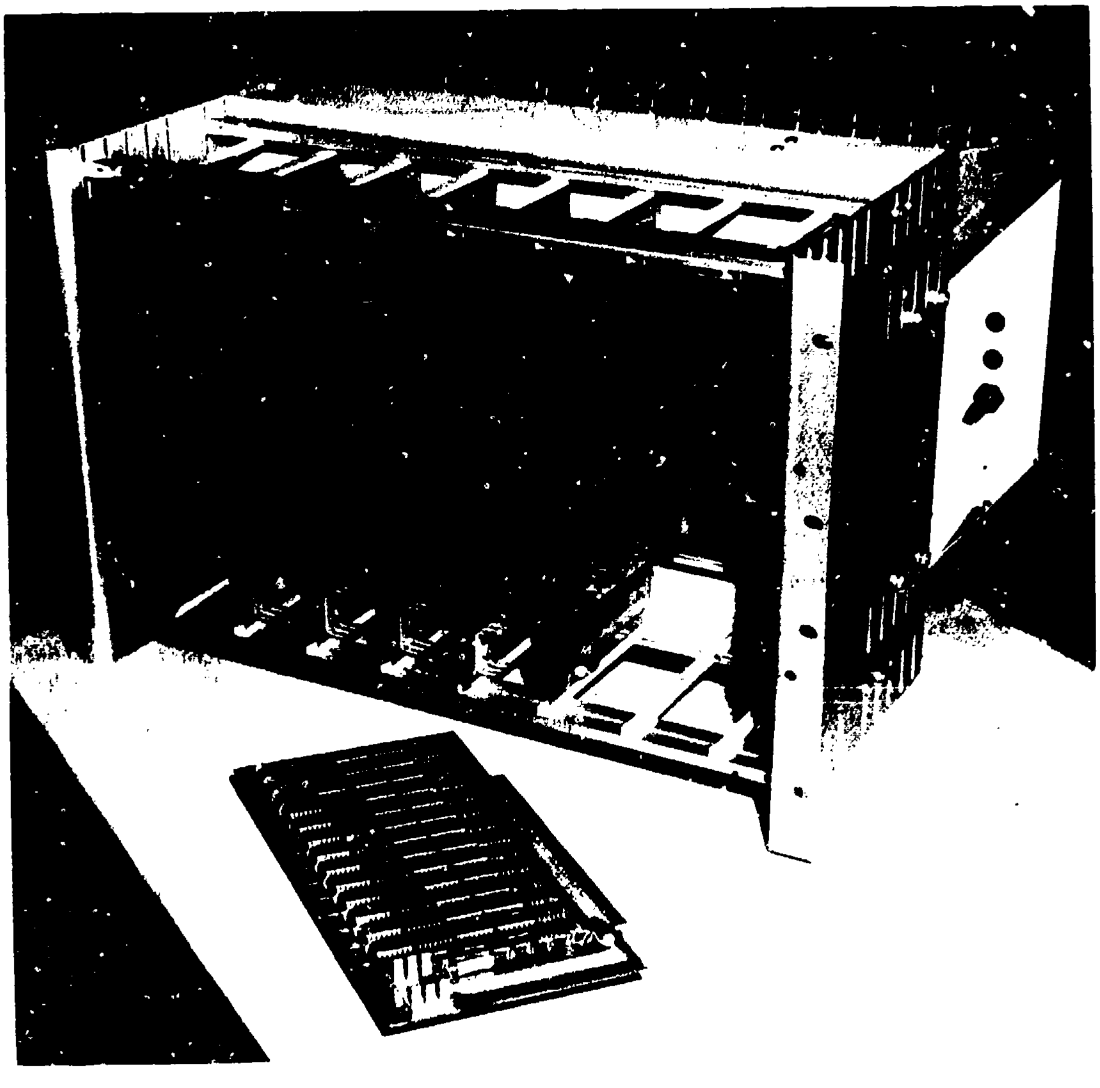
Flight Parameters

Mission Data

Status of OAS-Emulated Subsystems

Operational Faults

Alphanumeric data and control codes are input through a keyboard. Functions which can be exercised are:



INTERFACE BOX
Figure 8

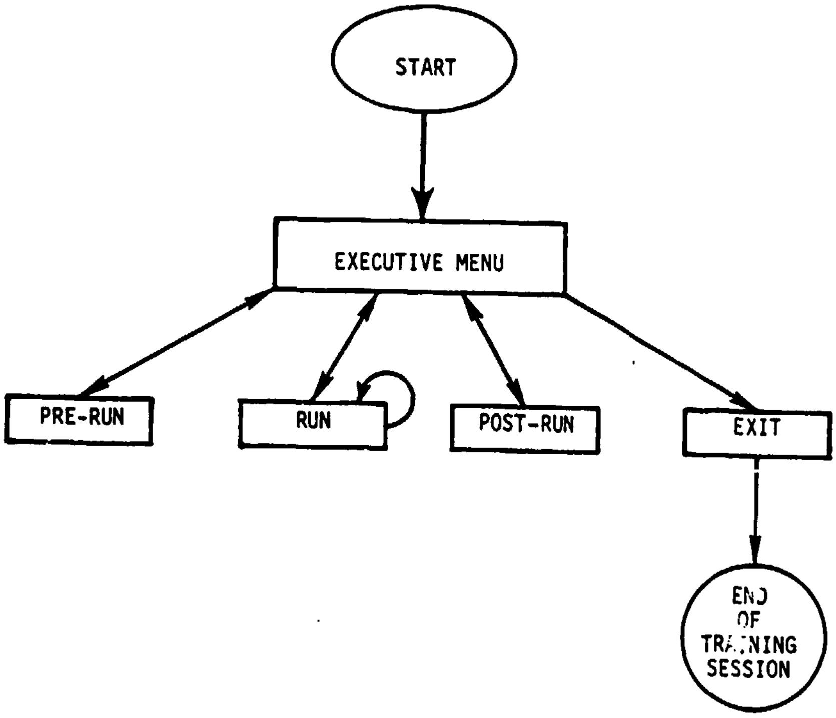


Figure 9

Trainer Session Control

Alteration of Flight Parameters

Alteration of Mission Data

Modification of OAS-Emulated Subsystems Status

Fault Seeding

Recovery from Operational Faults.

The ICS is a SOROC IQ 140 CRT terminal.

The instructor can interact with the PTT in three operational modes: Pre-Run, Run, and Post-Run. The interface has been designed to facilitate moving back and forth among any of the three modes (see Figure 9).

The Pre-Run mode occurs prior to the training (simulation) session and allows the instructor to select and edit a scenario for training, and complete setup and initialization procedures. The Run mode is the actual training period or simulation, during which the instructor monitors the crewmembers actions and injects changes into the session. The Post-Run mode occurs after the training session, in which the instructor can initiate a limited review and analysis.

All sessions must go through some minimum initialization via the Pre-Run mode of the user interface. After the appropriate initialization, the instructor will enter the Run mode, via commands available to him, to begin the training session. He will be provided with commands that allow him to abort the session and return to the Pre-Run mode, or interrupt for a time period and then resume within the Run mode itself. Once the run is complete, the instructor may enter the Post-Run mode, in which he may conduct limited review and analysis, or he may return to the Pre-Run mode to initiate another training session.

The software has a modular design, which will aid in making future changes. Software development is performed on the mainframe procesor in a high-level language. The PTT software package with the exception of the Switch Control Unit software is being designed and produced by Technology Service Corporation of Santa Monica, CA. The Switch Control Unit software is being developed by the 3300 Technical Training Wing/Technical Training Division at Keesler Air Force Base, MS. The entire software package outlined in the above paragraphs will be an 18 month effort. Funding for the B-52 OAS/CMC PTT was received on 27 April 80 and first production unit will be delivered to Strategic Air Command on 15 Oct 81.

SUMMARY

A full-capability trainer cannot be delivered prior to OAS deployment, yet procedures training is essential for the OAS conversion training and operational use of the new system. The B-52 Offensive Avionics System Part Task Trainer is a powerful training system provided at a low cost and in a short-term schedule.

Undoubtedly there are other military systems whose training requirements can also be met by a mid-range trainer. Such systems are likely to require software control of switch panels, real-time instructor interaction, multiple displays, and graphics displays--requirements which are being satisfied by the PTT. The modularity and flexibility being designed into the hardware and software of the PTT will minimize the efforts required to adapt this design to other applications.

REFERENCE

1. Offensive Avionics System Part Task Trainer, Software Performance Specification, TSC-PD-A248-6, December 8, 1980, Revised 1 March 1981.

2. Offensive Avionics System Part Task Trainer Specification Document, TSC-PD-A248-3, August 15, 1980, Revised October 6, 1980.

3. Instructor's Manual, TSC-PD-A248-3, October 7, 1980.

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FOREIGN MILITARY TRAINING PROGRAM DEVELOPMENT

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ABSTRACT

Modernization of the military posture of friendly foreign governments has placed uncontemplated, challenging demands on training program developers. To minimize total cost, foreign governments use existing equipment designs where feasible. By using existing designs, the logistics support package has already been developed; however, this package was tailored to meet the needs of United States military personnel. All items of the logistics package are satisfactory except -- training and technical publications. Problems in these two areas become especially difficult when English is used as a second language by the procuring country. Since their background and experiences are different, a training approach that is different than the one used in the existing package is required. Training developers must modify existing curriculum to allow for these differences, to remove culturally offensive situations, and to tailor the training to learning patterns of the intended student. Once the training program accomplishes its objective, problems with the technical documentation disappear.

INTRODUCTION

Military technology is advancing rapidly requiring continual updating of even the most modern weapon systems. Many of our allies maintain a modern defensive posture through procurement of sophisticated weaponry from the United States and its North Atlantic Treaty Organization Allies.

Existing equipments and support packages are usually procured, where feasible. Though most elements of the support package are universally acceptable, two of these can prove troublesome. They are: training and technical manual programs. These may prove troublesome because, of all elements of the support package, these two are developed to fulfill the specific needs of a group of military weapon systems support technicians and operating specialists who share a common core of training and experience. Unless the support technicians and operating specialists of the procuring country share this common training and experience, attempts to use the training portion of the support package can be expected to result in less effective training.

A recent example where the use of existing training programs to save time and money proved unsatisfactory was when students of the middle east were placed in nine different training programs that had been developed for U.S. Navy technicians. Existing programs were used in an attempt to save time and money. Each program was given to four different groups over an extended period. To insure that problems would be identified immediately, frequent evaluations of training progress were planned. Because of language, background, training, and experience, differences which existed between the U.S. students the group for which the programs had been developed, many problems were identified.

As it turned out, the first group of students served a dual role. In addition to becoming qualified in their selected specialty, they became a pilot group for validation of existing training programs for use to train personnel who possessed different qualifications than those for which the training had been developed.

As each problem was identified, the training program was revised in an attempt to eliminate like problems for those groups programmed to follow.

The end result was that each group successfully completed their respective training programs. This was made possible because of the extreme number of hours that had been devoted to program revision and increased training time. However, students would have suffered less frustration and total cost would have been less if the training programs had been initially developed to satisfy the specific needs of this type of student.

THE INITIAL ATTEMPT

Program Development

In the initial attempt, training courses were established around existing U.S. military curricula in every respect, including course length, course content, course subject sequencing, laboratory and classroom time, and selected media. As mentioned above, this consisted of nine courses of instruction which was repeated to different classes.

The Instructor

In each case, experienced, highly competent course developers and instructors were used. Instructor personnel had been specifically selected and their performance observed and evaluated prior to the beginning of training. Those personnel allowed to teach had been certified by the contractor and by the Government.

First Indication of Trouble

At the end of the first week, in each of the nine courses, the instructors were behind the planned schedule by 30% to 50%.

Student Reports

When questioned about their training, student comments for all courses were similar, and consisted primarily of the following:

1 - "Course is too fast"
2 - "Instructor is no good"
3 - "Instructor doesn't explain well"
4 - "Course is too difficult"
5 - "We don't have enough time"
6 - "Don't need to take tests"
7 - "We need to see and use the equipment"

ANOTHER ATTEMPT

Override in U.S. Courses

In addition to the above nine courses, many personnel with similar cultural backgrounds were provided English Language Training (ELT) then entered in U.S. military training courses, to compete directly with U.S. military personnel.

Result

The resulting attrition rate of these personnel was intolerable, especially for those students enrolled in electrical and electronic type courses. This attrition rate, in many cases, exceeded 50%.

Possible Problem

Though all courses were written and presented in English, this was not considered a problem because the students were first cycled through English Language Training, at Lackland Air Force Base, San Antonio, Texas. A requirement for graduation from this course was that they demonstrate attainment of an English Comprehension Level (ECL) of 70. This ECL of 70 was initially equated to the 7th grade; however, later investigation revealed that this score was based on a test that primarily evaluated their use and recognition of spoken English. Little reading ability or reading comprehension was checked.

Research into the Problem

Because of this high attrition rate, the Government investigated the situation and concluded that the problem was a multifaceted one. The researchers surmised that background experiences, cultural traits, and different patterns of learning were all factors which contributed to their undesirable performance in the learning situation.

Learning Pattern Differences

Researchers discovered that these Mid-Eastern cultures learn predominantly through rote memory, whereas U.S. curricula was based on the premise that the student should first learn principles, then he could be led through attainment of the training objective through analysis of the problem and a synthesis of basic principles to provide solutions to the problem. Consequently, an anomaly in training strategy had existed from the beginning.

Evaluation of Learning

U.S. military curricula is based upon a pattern of continued feedback. To insure that the student is learning sufficiently to enable him to accomplish the objective, the instructor is directed to provide interim summaries and evaluations at strategic points within the lesson. In other words, the instructor directs thought-provoking questions at specific students in order to determine whether that student has learned the subject to that point, and to insure that he does not have misunderstandings about key points of the lesson. In order to insure an adequate sampling of student personnel for obtaining this feedback, the instructor is trained to randomly select and direct the question to an individual student. Because of this procedure, a student that is not understanding the subject will not evade detection by the instructor for very long. This system is used regardless of the rank or status of individual members of the class. This works fine for U.S. students because they are considered to be of equal rank during that time when they are in the learning situation. No one student has a higher status than other students of the class.

This same philosophy with Mid-Eastern students met with sudden, overwhelming resistance. First, their cultural training seems to prevent them from engaging in any act or activity that may prove degrading to another member of their society. Consequently, if one student does not know the answer to a question, it would be degrading to him for another student to provide the correct answer. Initial reaction of the student, when placed in this situation, seems to be that if he doesn't provide an answer he cannot be wrong. When questioned about quizzes and exams, especially of the oral type, their reaction was that they were there to learn, not to be tested. It is interesting to note that this attitude is supported by the concept of rote memory as opposed to the analysis and synthesis process mentioned earlier. In other words, if they are given the question and the correct answer, they can memorize it. This is their customary means of learning. If they learn through this method of instruction, there is no need for tests or quizzes, and no competitiveness occurs. Therefore, no student is caused to seemingly degrade another student, especially one who has the higher rank or status. Usually when a question is posed to a class of students that has mixed rank, the duty of providing the answer falls upon the ranking member. All subordinate members of the class then support that answer given by their leader.

When confronted with a written exam, whereby each individual must provide an answer of his own, the students often start talking among themselves in their native tongue. A natural reaction of the instructor is to believe that they are cheating. However, when the instructor intervenes, the ranking class member usually informs him that they were discussing the time, or some other unrelated thing. They seem to feel that their group has been confronted with a problem rather than each individual having been confronted with the problem. This justifies their free discussion.

Dependence upon Instructor

Through observation and questioning of these students, their successful instructors, and training administrator personnel, it was determined that the students come to see their instructor as a friend and confidant. They develop a dependence upon their instructor for everything, not just training related problems. They bring any problem to him, and they trust and rely heavily upon his judgment. He is their friend, their counselor, and their advisor as well as being their instructor. However, not every individual instructor was able to develop such rapport with them. Because of this, an instructor that possesses a great deal of experience, who may even be considered a leader in the field, and who has been an excellent instructor for U.S. military personnel may not be considered a good instructor by such students. This possibly resulted because the foreign students did not feel safe in trusting him with their individual problems.

Similarity to the Job

Because U.S. military personnel could be expected to operate any one of perhaps 100 different pieces of equipment that has been designed to provide a specific function, only a piece of equipment that is most representative of the group of 100 different types is selected for use in the training course. For example, the U.S. Navy may have within its inventory of active equipment as many as 100 different types of communication receivers. A type is selected for use in the training course that is deemed to be most representative of the other 99 types. Though students are trained on this one type, they are expected to relate their training to any type with which they may be required to operate. They are taught the function of the "SQUELCH" control and, regardless of where the control may be found on the panel, they can relate it to the Squelch function. Consequently, they are considered qualified to operate the "SQUELCH" control to achieve its intended function on any one of the 100 different types of equipment that they may be assigned.

Through conditioning provided by the "rote memory" type training which they have received throughout their life time, Mid-Eastern students do not tend to learn the function of the "SQUELCH" knob. Instead, they tend to learn the function of the knob located in the lower left-hand corner of the receiver that is labeled "SQUELCH". Because of this, they do not readily relate to a different receiver that has a knob near the center of the panel labeled "SQUELCH". They have not been trained to operate this new knob. This is, of course, oversimplified, but used to illustrate a problem which has been identified through external evaluation of their training programs.

Consequently, the Mid-Eastern student expects to have received training on that specific piece of equipment that he is expected to operate.

Comprehension

The use of English by the instructor did not seriously impede the students' understanding, as long as the instructor was careful to insure that the presentation was preceded by an identification of new, unfamiliar technical words along with a definition of their meaning.

When the lesson dealt with a piece of equipment, it was best to have the equipment or a good, complete picture of it readily available. Since their primary mode of learning is rote memory, it is best to have the actual equipment available so they can have the operation or procedure demonstrated by the instructor, then they can perform the operation or procedure themselves, on that piece of equipment.

If the instructor feels they should take notes, the only way he can get them to do so is to write them on the board. It seems that they write in their notes everything that their instructor writes on the board for them.

The students greatest impediment to learning was found to be his reading comprehension. One major problem was that he was given study materials that had been written at or above the twelfth reading grade level. Since the average reading grade level of these personnel was below the sixth grade, a built-in problem existed. Additional problems caused by using this material were attributed to the lack of illustrations. In order for written materials to be effective for personnel who learn primarily by rote memory, it is necessary to frequently illustrate the written word through use of accurate, detailed pictures or drawings of the equipment or system being described.

FACTORS CONSIDERED IN CURRICULUM REVISION TO SATISFY FOREIGN TRAINING

The Training Situation

For this type student, it was determined that the best training situation existed when the student was instructed on the equipment in a laboratory type situation. This capitalizes upon one of their strengths -- that of rote memorization. They are adept at learning by doing.

Of course, this is not always possible. Sometimes it is necessary that principles be learned which cannot be readily demonstrated on a piece of equipment. An excellent example of this is the theory of operation of an electronic circuit. Try as one may, he cannot see the electrons moving through the wires. It is necessary to resort to pictures, illustrations, movies, and chalkboard work to supplement a lecture dealing with analogies between electronic theory and known principles which can be readily viewed, such as water systems.

Since some instruction cannot be accomplished through equipment "hands-on", it is necessary to resort to classroom presentation. This type training situation should be preceded by a demonstration of the job for which this training is designed to support. This allows each student to become involved, to a limited degree, in the performance of the job; allows him to ask questions regarding this operation, and answer those which can be answered. For those which cannot be easily answered because of the lack of background information, the instructor should show here the necessity of the classroom training, then proceed to the classroom.

Curricula developed to support this training should include many pictures and illustrations and should also make use of the actual equipment. This training should always be performance oriented.

Written Student Materials

For training curricula developed to MIL-STD-1379A, written student materials include Student's Guide, Tests, Equipment Utilization Handbook, and the On-the-Job Training Handbook.

These materials should be written to take advantage of the student's strengths. Since he has been found to possess highly developed visual memories, they can retain most readily that which they see. Consequently, this written material should be supplemented heavily with pictures and sketches which illustrate what the written word is trying to say.

In addition to illustrative supplements, when the written material is trying to explain something, the writer should attempt to draw analogies between that complex thing he is trying to explain and something that is similar in operation but less complex.

In selecting pictures, illustrations, and analogies, one should insure that no culturally offensive situations are created in this material. For example, pictures should not be used where individuals have the fingers of their left hand near their face. Also, analogies should not be made between a series electrical circuit and a string of Christmas tree lights. These are only examples, to insure that materials are not developed which are culturally offensive, developing personnel should be made aware of differences which exist between their society and ours. Editing personnel should also be made aware of these differences.

Selection of Training Equipment

Curricula written for U.S. military training courses is normally supported by equipments that are generic to the field of equipments upon which the training is designed to support. This is appropriate because the training approach is to teach principles, then allow the student to adapt to specific needs through a recall and synthesis of appropriate principles. These students learned operation of a piece of equipment thoroughly through their rote memory learning method. A problem arose if they were introduced to a version of this same equipment which functioned in an identical manner, but which contained a different arrangement for its functional controls. These students believed they should receive training on this new piece of equipment also. Consequently, the training courses must be equipment-specific. That is, the equipment selected to support the training must be a comprehensive grouping of those equipments which the graduate will be expected to operate.

Testing and Evaluation

Because of the desire among students not to compete with each other, or disagree with any one of the others openly, it is desirable to have them complete individual tests on "easy-to-mark" answer sheets. That way, no student will know the answer given by the others in the class.

Planned Course Length

To enhance the rote learning process and adapt the presentation strategy to other unique student strengths, requires considerably longer course items, especially for non-mechanical subjects.

Reading Grade Level

Those curriculum materials written for student use in support of his training should be written to a reading grade level (RGL) compatible with that of the student personnel. For those which have just completed English Language Training (ELT) of the type given at Lackland Air Force Base, where the requirement for graduation is an English Comprehension Level (ECL) of 70, this falls somewhere between the 4th and 6th reading grade level. Because of this, materials written for their use during the first six weeks of training, immediately following ELT, should not exceed the 6th reading grade level.

Because reading comprehension can be expected to improve through use, and because the student is rapidly increasing his technical vocabulary for his field of study, the RGL of materials can, and should be increased as he progresses through his rate training.

However, care should be taken to insure that no sample of the student materials is allowed to go beyond an RGL of 8.9, as measured by the Flesch-Kincaid procedure for determining the Reading Grade Level of written materials.

Though most U.S. Navy technical manuals, when evaluated using the Fry or Flesch-Kincaid methods, prove to be written at or near the 12th reading grade level, I do not believe that any attempt should be made to raise the reading grade level of this type student above the 9th grade because of the amount of time it would take. Since their basic military training, and all specialized rate training is being conducted in English, their reading proficiency can be expected to improve through normal use as they progress through their specialized rate qualification training. I believe that the motivated student who meets the sixth reading grade level requirement upon entry into his rate training can be expected to increase his proficiency to the ninth reading grade level upon graduation. This leaves a three-grade discrepancy between his reading proficiency and the level to which his technical documentation is written. It has been my experience that this discrepancy does not represent an insurmountable problem. I am convinced, after having studied this problem, that an individual can adequately comprehend materials written up to three reading grade levels above his own, if provided sufficient time.

Standardization

When dealing with personnel of friendly foreign governments, there is much room for misunderstanding because of differences in the way in which the two countries conduct business, and communication difficulties which result from the different languages.

Because of this, it is essential that all deliveries of training material follow the same concept and format as that with which they are familiar. Since previously developed curriculum materials were developed to MIL-STD-1379A, and its associated Data Item Descriptions, it is recommended that this remain the standard which governs the type of curriculum materials, their content and format.

SUMMARY

Curricula developers and instructors, who present the planned training for foreign military personnel, must be ready to change thought patterns and complete considerable learning and research if they expect success. They must temper their thoughts relative to what constitutes a good training program in accordance with differences which exist between their new target population, versus the population for which they have been writing and presenting training.

Educators must become thoroughly knowledgeable of cultural differences, i.e., different religious beliefs, different patterns of learning, concepts of training, and background experiences. They must design the curriculum around a training concept that takes advantage of the strengths of the target population, while overcoming their weaknesses. Much research will be required before they will be able to identify these differences, strengths and weaknesses, and this research must be completed before they begin developing a concept of the training situation.

ABOUT THE AUTHOR

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NEW FRONTIERS FOR COMPUTER AIDED TRAINING

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ABSTRACT

Computers have been introduced in training since many years, but with good results only for limited subjects. The main reason of the failure seems to be the passive rôle of the student not sufficiently motivated by the simple contact with the machine. The System we are introducing combines the programmed learning method we developed for military technicians through 30 years of experiences, in which the student himself discovers the phenomena reaching the theory through experiments, and the possibility offered by today Computer Science, getting the advantages of both, in courses starting from basic subjects up to the most advanced electronic techniques. In a classroom equipped by our system the individual computer gives the student a procedure for the experiments he has to perform, but the student himself has to work on an especially designed desk to set the circuit and to study it, making measurements and giving the computer his conclusions. The computer can evaluate student's answers, letting him proceed if they are correct, asking him to repeat in the opposite case, adding other explanations to help him and keeping his score. Furthermore, it controls an integrated audiovisual system, showing to the student automatically films or transparencies connected with the current group of experiments he is performing. Instructor's function has not been cancelled, but exalted, because through his master computer he can control the complete classroom, checking students' work at any step, and helping the one who really needs his presence, not disturbing the others. Resuming, we realized a system in which the student has at his disposal two instructors, the computer for the routine, and the teacher when necessary proceeding at his own pace.

THE LIMITS OF COMPUTER AIDED APPROACH TO THE TRAINING OF MILITARY TECHNICIANS.

Talking about Computer Aided Instruction could seem obvious today, as this kind of machines is more and more influencing our way of life.

As a matter of fact the effort to apply computers to this important field started since a very long time, probably with Computer Science itself, but if we look deeply inside the results, we can see that these results are encouraging only when limited subjects are involved.

It is not easy to resume in a few words the reasons of this partial failure (which someone can call a partial success), but we think that it was mainly caused by an originary vice, still uncancelled: the unlimited trust in the computer as in a sort of magic box, which is able by itself to solve any problem, without taking into account that the learning process is the result of a lot of elements, and that it is not realistic to pretend to reproduce this process simply by putting a student in front of a machine.

In this way we can explain the fact that good results have been achieved when, for example, what we call "the student" was a previously trained technician whose aim was to get some particular specialization in his field.

In this case it is possible to get positive results due to the capacity of the computer to sort informations and to show them to this special student, to its speed in evaluating his answers and to change accordingly its teaching strategy, together with the limited extent of the subject.

But let us consider another figure: just to keep close to my company's experience, and to my own, too, let us take a student who knows nothing about electronics, and who is supposed to become a technician able to maintain the sophisticated circuits of a Fire Control System.

Even if from a theoretical point of view we can imagine a computer able to manage the enormous quantity of informations necessary to achieve this goal, we have to face, at least, two problems: the first one is the cost of such equipment, which must be able not only to store this amount of informations, but also to identify and correct a number of possible mistakes, which is very big due to the wideness of the subject itself.

If, as we told above, it is relatively easy to implement a program to teach a technician how to use a new component or a new piece of equipment, it could be more difficult for a computer to cancel student's doubts about Ohm's Law, and in no other field as in computer business the difficulty of the problem is increasing the final price.

But the second point is even more important. To maintain and to repair electronic equipment, a technician does not only need theoretical knowledge.

What he knows about electronics must be integrated by his ability to use it to solve practical problems; it means to be able to use measuring instruments, to correlate different phenomena and, last but not least, to use his own hands.

Moreover, if the technician we are talking about is a military one, the difficulty of his duty is increased not only by the complexity of the equipment he has to cope with, but very often by the particular conditions he is working in, which ask or better, force him to solve the problems in a time as short as possible.

To reach this target he needs what we can resume in a single word: experience.

But Armed Forces, who need this kind of skilled technicians, are seldom in the conditions to prepare them, due, for example, to service reasons which often compell to move experienced people to different positions, but mostly because of the shortness of time which is at disposal for training together with the necessity to send people to their final jobs as soon as possible.

A NEW COMPUTER APPROACH

The Computer as an Element of the Training System.

These problems cannot find a satisfactory solution by traditional training methods, neither a computer can do it by itself.

But really it can be done in an easy way using a computer as a component, no longer as "the component", of a training system including other elements which a computer can coordinate and control in the proper way.

Before starting the analysis of the Computer Aided Training System we are introducing, it is better at this point to have a step backwards, because the system is the result of an evolution lasted for years, and to understand it completely it is usefull, perhaps necessary, to have a look at the intermediate levels of this evolution, which are strictly interconnected with the development of the company which implemented it.

The Gajon Experimental Programmed Learning System for Military Technicians.

The Gajon Institute of Technology, established in 1949 and since the very beginning involved in military technicians training, realized the necessity of studying a new training methodology to solve the problem of preparing skilled manpower at the satisfactory level in a shorter time, and, if it was possible, at a lower cost.

A basic point is the following one: the student has to partecipate to the learning process in an active way.

This active behaviour can be resumed into two aspects:

1) the student has to reach the fixed level of knowledge working according to his learning rate
2) the student himself must be considered an interesting teaching resource, both from the self teaching point of view and as a useful help for the real teacher.

On the other hand, the continuous increase of scientific knowledge to be assimilated pushes the students to accelerate their learning rate; but unfortunately, very often the learning rate is slower than the transmission of knowledge.

Deep changes in the methodology are therefore necessary to improve teaching productivity.

Another problem is the growing of scholastic population, and the increase of knowledge in quantity and quality is not balanced by a proportional increase in number and preparation of teachers.

To solve the problem, we have to work towards two directions: a better use of the teacher as didactic means and the realization of an individualized autonomous teaching.

These considerations together with the study carried on learning process, suggested to adopt a "learner centered" method.

The Gajon answer is a learning philosophy different from the traditional one: through a direct experimentation the student is pushed to observe and to analize phenomena to reach the conclusions by himself.

On the contrary, the normal training method is composed by theoretical lessons and subsequent experiments to apply and test the studied concepts.

With the Gajon system the student is brought to discover by himself the laws regulating the phenomena following the same way of the scientists; it is evident that in such a way the student will understand completely the laws and will be able to apply them without forgetting them.

The teacher's task is exalted as he has not only to dictate formulae but he must amplify and deepen the concepts and, above all, help the student to develop his own capacity of observation, synthesis and reasonment, the real bases of knowledge.

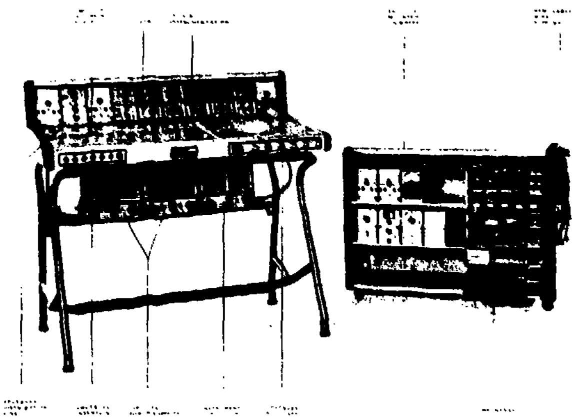
The Gajon Desk: an Open System. To reach these targets a new training medium had to be designed as most of the training systems employ pre-assembled block circuits which become obsolete because of the fast evolution of electronics.

On the contrary, the Gajon desk is an open-end system as it allows the greatest liberty in assembling every kind of electronic circuit, also the most complex ones, employing standard components; on the desk even a complete TV set or a radar bearing generator can be assembled.

All these things are the best guarantee that the Gajon system will never become obsolete, saving customers' investments.

Another confirmation of this fact is that, except for obvious technical improvements, Gajon desk has been maintaining for 30 years the same basic principles without losing validity, and the desks built in the 1950s are still employed with good results.

Main Characteristics of the Gajon Desk. The desk provides a work surface which allows to assemble even very complex circuits without soldering, using electronic tubes, transistors, integrated circuits, microprocessors and any kind of other components.



1- The Gajon desk mod. 1001B, designed to match the necessities of a modern programmed learning experimental method.

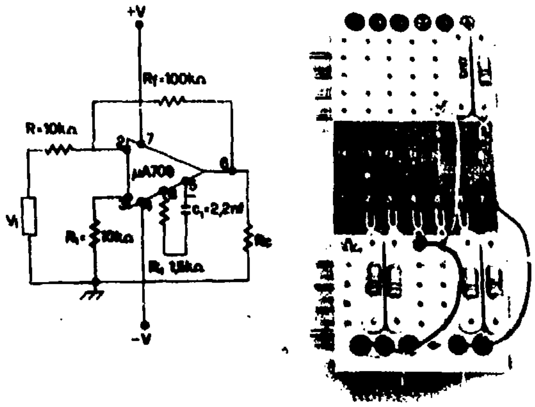
The work surface is composed by amovable plates which may be taken out with the assembled circuits, leaving the surface free for other students.

The desk power supplies give all the voltage values necessary to make the circuits work through an automatic feeding line integrated in the work surface.

All the power supplies are electronically protected against short circuits; an acustic alarm indicates overcurrent conditions and a control panel shows the overloaded power supply.

A special turret is provided to keep measuring instruments and signal generators which are modular and plug-in type.

After the use, instruments and components can be stored into a special trolley supplied with the desk.



2- Sample of the special amovable assembling plates which form the work surface of the Gajon desk. It is possible to see here the components (mounted on standard supports) and the special connecting elements.

How the Computer Can Improve the Gajon Method.

The results we have been getting for twenty years by the employ of our very special programmed learning method have been satisfactory, but as a matter of fact, in the educational field you cannot pretend to have reached the top, and that is even more true for an Institute engaged in the training of electronic military technicians.

On the other hand, we realized that there were some problems due to the particular market we were working in: very often, the instructors we prepared in our Center in Genoa, after two or three years had to leave their schools for other destinations because of changes in their careers and it was not easy to replace them.

In our training philosophy, the equipment are important, but even more important is the method to use them, and this is something that only instructors prepared by us know; in our after-sale services training for several groups of instructors is included, but it seldom happens for a lot of reasons connected to the rigidity of military organizations.

Therefore, we started trying to add something to the equipment to make easier for the new instructor to follow our training method.

The solution of the problem could not have been a simple manual, but it had to be something alive and able to guide the instructor step by step keeping him close to the right procedure.

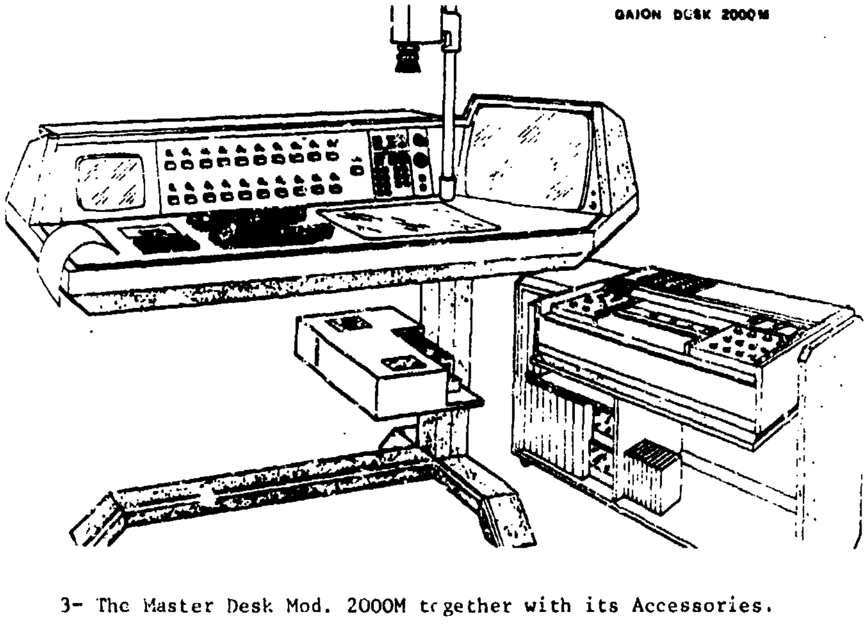
But we were also looking for something so flexible to let the experienced instructor modify the medium itself according to its philosophy, once he got the complete control on the system.

We found out that a properly designed computer could give a positive solution to our investigations.

Of course, the possibility offered by the computer added to the basic desk to avoid problems connected to the change of instructors has not been the sole reason why we took that decision.

As a matter of fact, the computer aided training is a logical improvement of an experimental programmed learning system as the one we developed; it adds to the system several advantages:

- it makes it easier to have a wider possibility of ramifications, with a consequent increase of self-adapting capability and personalization of the course itself
- the informations, can be automatically stored and managed
- through special algorithms the computer can satisfy requests which ask for elaboration (like execution of mathematical operations)
- with some restrictions, answers freely expressed can be accepted and evaluated
- it is possible to generate files of data, having a fast access to use or to correct them. This is an important condition to have the necessary feedback in the program: the changes which experience may suggest are not so easy to be done if the training means is a manual or a teaching machine
- taking into account the previous curriculum (preliminar test results, previous answers,



3- The Master Desk Mod. 2000M together with its Accessories.

etc.) automatically stored in the memory, it is possible to adapt the sequence of the course to students' characteristics.

Due to the modularity of our programs and to the step by step procedure of our courses it did not seem difficult to modify them slightly to transfer them in a computer memory.

Moreover, we wanted to take the advantages offered by the development of audiovisual aids, as well; our computer should have had the possibility to manage a complete audiovisual set, integrated in the classroom, including CCTV system, video-slides, VCR and automatically operated by the computer at the proper moment of the course.

Taking into account all these requisites we had to make a first important choice: an intelligent terminal for each student connected to a main computer managing the complete classroom or the whole school, or an individual minicomputer?

We prefered the second possibility, as the best one from the economical point of view and due to its flexibility.

We could not find on the market a minicomputer matching all our requirements, so we designed our own one; we solved a lot of technical problems, but we think that the results can be defined satisfactory.

Gajon Computerized Training System.

In a classroom equipped by our computerized training system we have two different types of desk: a master desk for the instructor and the student desk, each one computerized.

In the steel structure of the student desk is included a complete computer assisted electronic laboratory.

The student has at his disposal: the computer with its keyboard, an automatic feeding system, a complete set of plug-in instruments, a special work surface where, as in the previous model, he can assemble without any soldering any kind of electronic circuit, starting from the simplest up to the most advanced ones, using the standard components which are stored in the utility trolley.

The Master Desk Mod. 2000M. The desk 2000M for the teacher has exactly the same steel structure as the student desk, but it is missing all circuit assembling systems, circuit feeding system, instrumentation and components.

On the front panel, instead of instruments, all digital interfacing with the student desks and a 9" monitor used by the teacher to preview audiovisual programs are included.

On the surface there are two keyboards, the computer, cassette recorder/player and a transparent crystal used as an overhead projector thanks to the CCTV camera placed on top of the crystal.

Slides are projected on the same crystal from the slide projector placed underneath, allowing the pick-up from the CCTV camera.

In the trolley beside the desk the video cassette recorder is mounted, and a storage area is provided for video-cassettes, transparencies and slides cartridges.

The desk includes:

- front panel with all controls
- 12" CRT video graphic alphanumeric display
- 9" CRT monitor
- alphanumeric keyboard
- electronic symbols graphic keyboard
- computer and interfacing facilities
- computer cassette recorder/player
- intercom
- CCTV camera
- slide projector
- video cassette recorder
- computer printer

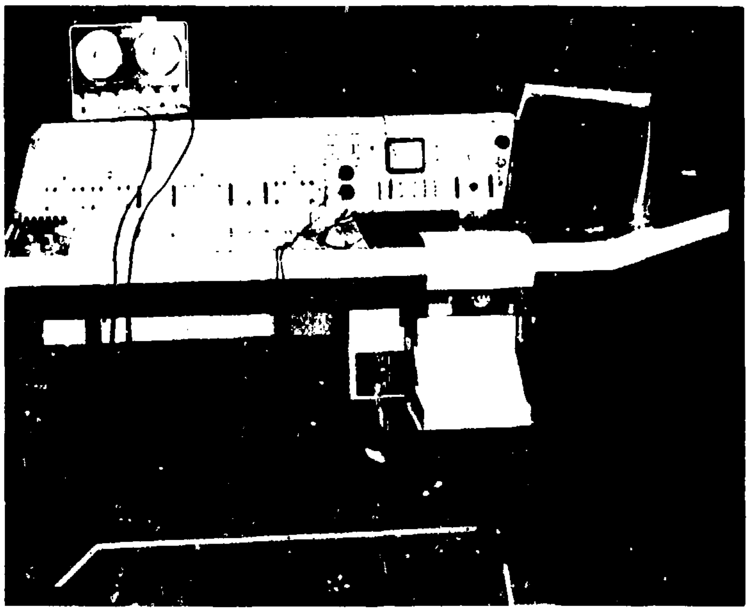
Monitor and computer are plug-in modules, allowing quick substitutions in case of breakdown.

The computer is provided by an autodiagnosis board to reduce trouble-shooting time.

There are some differencies between the student's computer (that we call CAT/S) and the teacher's one (CAT/M).

The Computer for the Student's Desk (CAT/S).

The CAT/S is a dual processor microcomputer system with a dual on-board/off-board multiple bus



4- The Student's Desk Mod. 2000. The Instruments in the Turret are Standard Plug-in Modules; on the Top Surface some Additional Instruments Can Be Placed.

structure that allows each processor to use its own memory and input/output without utilizing a common system bus.

A common system bus is used only when either processor requires access to the common memory.

The system generates bus busy and bus request signal. Under these conditions two independent programs or data exchange programs can be run simultaneously.

Both processors can accept parallel data from any eight bit bus peripherals.

Serial I/O via UART is provided. Easy user access is provided via multipins connectors to data and address buses. All control signals are accessible.

Main features:

- 8080A processor
- crystal controlled clocks
- crystal controlled baud rate for cassette load
- crystal controlled composite sine pulse for CRT display
- TTL compatible input/output
- 30 Kbyte of static RAM memory
- system control program stored in ROM

All components are mounted on fiberglass through-hole-plated plug-in boards of double Eurosize with gold plated edge connector; each board is mounted on a mother board with gold plated connector sockets.

All boards are housed in a metal cabinet with forced air cooling system. Connections between computer and peripherals are made via flat ribbon cable.

The following peripherals are standard in the basic student desk:

- cassette: standard audio playback unit with remote computer control. Tape speed is 4.75 cm/sec.. No special cassette tapes are required.
- printer: matrix inpact with ink ribbon. No special paper is required. Paper width 8".
- monitor: standard 12" black and white video display with antireflection screen. Bandwidth not less than 8MHz. Composite video signal.
- keyboard: alphanumeric keyboard ASCII encoded. Cursor control and special function key.

The Computer for the Instructor's Desk (CAT/M).

The basic microcomputer system of CAT/M is the same as CAT/S.

Additional software control functions allow the teacher to generate special graphic characters, to prepare lessons and to dump them on cassette tapes.

The CAT/M contains audio cassette playback and record facilities.

The teacher has at his disposal VCR and slide projector combined with telecamera as additional facilities for interconnections between his desk and the display units of any or all students.

Audiolinks enable contacts between teacher and any or all students simultaneously.

The following peripherals are standard in the master desk:

- cassette: standard audio playback/record unit with remote computer control. Tape speed 4.75 cm/sec.. No special cassette tapes required.
- monitors: same as monitor of CAT/S used as video monitor or student's control monitor. Preview monitor for VCR, telecamera and slide projector.
- VCR: black and white and colour with three international standards of decoding. All functions are remote controlled by the teacher or by the students' computer according to the lesson program.
- slide projector: standard Kodak Carousel.
- telecamera: Vidicon interlaced 1/2" camera of medium brightness type; bandwidth 10MHz giving a resolution of 700 lines.
- keyboards: ASCII encoded alphanumeric keyboards; special graphic keyboard; cursor control and special function keys.
- audio communications system: low power duplex, speaker impedance 600 ohms.

A very interesting feature offered by our master computer is the possibility for the teacher to modify the standard programs we supply together with the system, or to write brand new programs even if he is not a skilled computer programmer.

To make it possible we developed a very simple programming language and to solve the problems usually connected to graphic programs, we designed a special graphic keyboard.

To each key of the last a graphic electronic symbol or a part of a symbol are corresponding in the computer memory.

If the teacher needs an electronic symbol to draw a circuit on the screen, what he has to do is simply to press the key corresponding to it.

If the symbol he needs is composite, it means composed by several parts on different keys, he can press a special sequence key corresponding to that symbol and automatically the computer shall collect the single parts to draw the complete symbol.

Two symbols correspond to each key; the choice is made by pressing one of the two function keys, the yellow or the green one.

The Gajon Computerized Training System at Work.

The philosophy of the training method is unchanged: the student has to work on the desk, making his own practical experiences and reaching the laws which regulate the phenomena correlating his observations and the measurements he can take.

At any step the student is guided by his own computer.

In fact, as we told above, each student's desk is provided by a microprocessor with alphanumeric keyboard, display and cassette player; the lesson is stored on the cassette, ready to be transferred to the computer memory.

The instructions for the student and the graphical representation of the circuit he has to assemble appear on the screen controlled by the computer.

This special display developed by Gajon can be used as a graphic terminal for the computer and also as a normal video screen or the audiovisual aids.

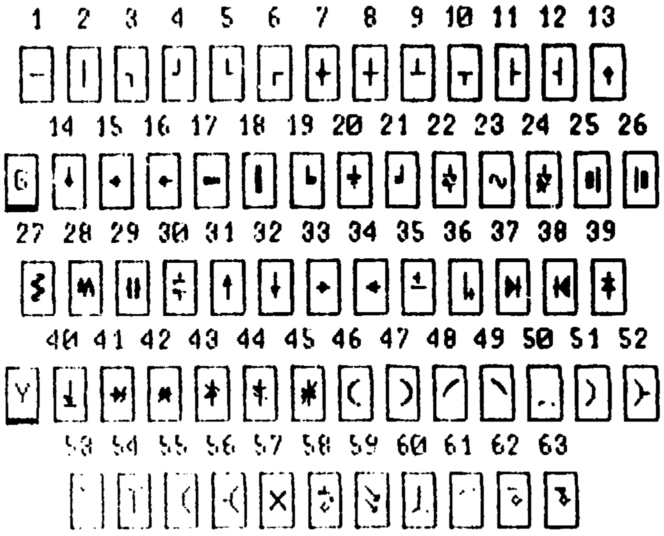
Through the keyboard the student gives the data to the computer about the measurements he has done on the circuit, answering the questions the computer asks him.

In the student computer memory the complete sequence of the experiments has been stored together with the numerical results of the experiments; the student must perform them according to the instructions received from the computer.

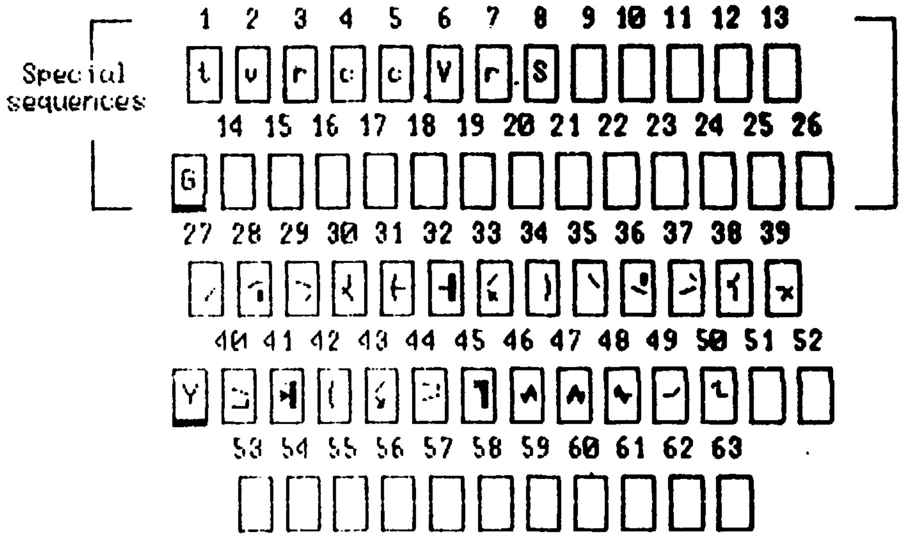
A special program makes the comparison between students' results and the right ones in a range of approximation.

If the student's answer is correct, through the display the computer shows to him the next experiments to be performed; in the opposite case it

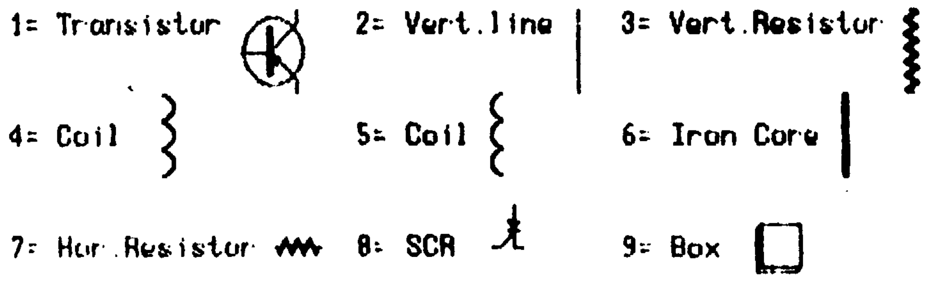
YELLOW SPECIAL CHARACTERS KEYBOARD LAYOUT MODE



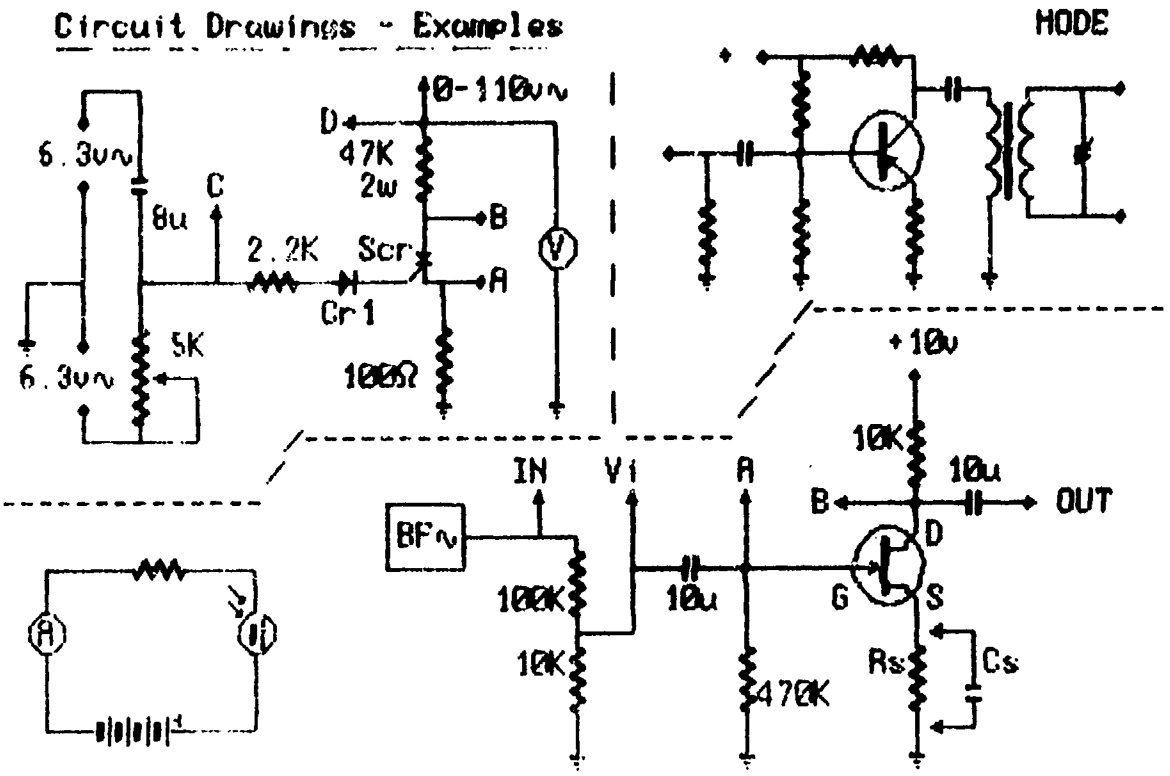
GREEN SPECIAL CHARACTERS KEYBOARD LAYOUT MODE



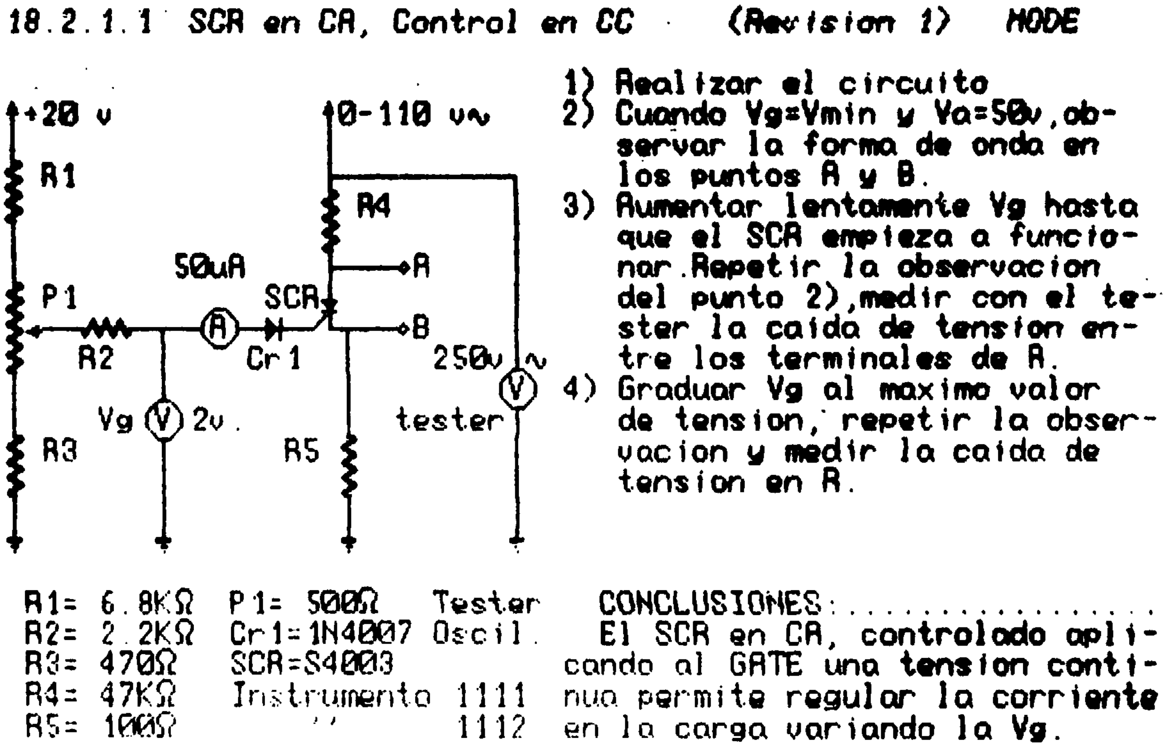
Special Sequences: GREEN 1 to 26 MODE


1= Transistor
2= Vert.line
3= Vert.Resistor
4= Coil
5= Coil
6= Iron Core
7= Hor.Resistor
8= SCR
9= Box

5-6-7- Computer Printed Graphic Keyboard Map.



8- Sample of circuit drawings executed by the CAT/M under special graphic keyboard control.



18.2.1.1 SCR en CA, Control en CC (Revision 1) MODE

1) Realizar el circuito
2) Cuando Vg=Vmin y Va=50v, observar la forma de onda en los puntos A y B.
3) Aumentar lentamente Vg hasta que el SCR empieza a funcionar. Repetir la observacion del punto 2), medir con el tester la caida de tension entre los terminales de R.
4) Graduar Vg al maximo valor de tension, repetir la observacion y medir la caida de tension en R.

R1= 6.8KΩ P1= 500Ω Tester
R2= 2.2KΩ Cr1=1N4007 Oscil.
R3= 470Ω SCR=S4003
R4= 47KΩ Instrumento 1111
R5= 100Ω ,, 1112

CONCLUSIONES:...............

El SCR en CA, controlado aplicando al GATE una tension continua permite regular la corriente en la carga variando la Vg.

9- Sample of experiment sheet printed by CAT/S.

asks the student to check again the circuit, to set it up in the correct way.

If the results remain incorrect, automatically the computer sends the student back to the point of the previous lesson he did not understand.

At the same time the machine keeps the score of the student, which will be a part of his curriculum.

To complete the subject the student is studying, the computer automatically shows to him short films or slides on the display.

The complete system is controlled by the master desk.

At any moment the instructor can copy on his screen what is appearing on student's one and vice-versa; he can also verify the individual score or the score of the complete class to check the general behaviour.

At the end of the lesson the conclusions written by the student using his keyboard are automatically transferred to the teacher, to let him check them.

In such a way the teacher gives the final judgement about student's behaviour if it cannot be resumed by a simple numeric answer.

As the lesson goes on, everything the student is writing is printed on paper automatically, so that at the end of the course each student will have his personalized manual.

All the system is continuously checked by an autodiagnosis apparatus, allowing a fast fault-finding and replacing of the damaged boards.

Behind the previously remembered ones, the advantages of the system are very interesting.

We have a program including all audiovisual aids, allowing the student to proceed at his own pace, according to his learning capability; the proceeding of the course is the best available, because it has been prepared by the Gajon specialized instructors.

In this way each student has an instructor at his own disposal, the computer. Teacher's function is not cancelled, but exalted, because his aim will be to help the student where the computer, as a machine, cannot succeed without being bothered by routine explanations; it will not be necessary to keep the marks of each student, because this is done by the computer.

The time the teacher can use to perform new researches has been increased and he can modify the program whenever it is needed.

In fact, as we told above, he can change the programs in the computer memory simply typing on the keyboard the new lesson, even if he does not know anything about computer programming, due to thespecial microprogrammed keyboard he has got at his disposal.

Courses which Can Be Performed by the Gajon System. The Gajon desk with the components, the instruments and the computer programs supplied in the basic version allows to perform the following courses:

- Basic Electricity
- Basic Electronics
- Basic Digital Electronics
- Basic Communications

Moreover, accoridng to customers' necessities, there are some standard advanced courses; to perform them additional components and instruments are needed to complete the basic desk equipment.

They are covering the following subjects:

- Electrical Components and Circuits
- Electrical Machines
- Logic Circuits
- Basic and Advanced Computers
- Electrical Machines and Controls
- Synchro and Servosystems
- B/W Television
- Colour Television
- Antennae
- Microwaves
- Radar
- Sonar
- Pulse Communications
- Wire Communications
- Gyrocompass

Of course, thanks to the flexibility of the system and to the experience of our company, new programs can be designed by our specialized instructors according to customers' requirements.

Advantages of the Gajon Computerized Training Systems.

Beyond the advantages offered by other computer aided programmed learning methods, the Gajon system offers the following ones:

Coherence - It is a big advantage to utilize the same didactical system from basic electricity up to the most advanced specializations, because in such a way every course gives exactly the knowledge required for the following ones, without useless repetitions, jumps and dangerous changes in the methodology.

Costs - To have a unique system covering different specializations avoids the necessity to have multiple equipment and laboratories, with an evident saving. The additional kits are adding only the components and the specific instruments for each technique utilizing the same space, the feeding system, the standard instruments and the other facilities offered by the basic desk.

Up-to-dating possibilities - As it is of open-end type, the Gajon system is always efficient because even the new techniques which will be developed in the future can be integrated in it.

That happens also thanks to the modularity of the program which lets new lessons be inserted.

Flexibility - Even if each experiment is following a careful planification according to a programmed learning system, the instructor who considers it convenient can design different experiments, as the system allows it.

Training time - One of the most evident advantages of the Gajon system for Military Schools is the reduction of the training time, without compromizing the quality of the result.

Realization of special courses - The Gajon Institute can modify the standard programs according to customers' requirements. This service is free of charge and lasts for ten years to guarantee the continuous matching of the system with school needs.

Instructors' training - The cost of the equipment is including a one month training period for the instructors in Genoa Gajon Center, with board and lodging to give them the practical experience which is necessary to get the best results from the system.

Furthermore:

- it allows a self-tailored training; each student proceeds according to his capacity
- every student can call the teacher at any moment without disturbing his fellows
- it is not as cold as the other computer aided training systems because it is interactive and teacher's presence is not cancelled

- it allows continuity in the methodology even when the teacher is replaced
- the instructor can dedicate more time to each student because the routinework is done by the computer
- it allows the continuous check of the class eliminating the needs of periodical examinations
- at the end of the course the student will get a complete personalized manual, automatically printed by the computer during each lesson
- it allows an automatic and continuous communication between students and instructor
- the flexibility of the system allows also to graduate the deepness in which every subject has to be studied. In fact, the same circuit, for eample, an operational amplifier, can be studied at informative, technical or university level. The choice can be done at the beginning of the course, when a lot of elements must be defined: targets and plan of the course itself, type and required output level of the personnel, number of necessary people to cover service needs, time at disposal.

Final Considerations.

The computerized system we presented above is a brandnew product, and therefore we cannot pretend to have in one-year experience on the field conclusive data about its success.

Anyway, we have to take into account that it applies and improves the method we have been utilizing for more than 30 years and which have been carefully tested in several occasions.

The most important test consisted in comparing in the various countries two different groups of students.

The first group included students who had been taught according to traditional methods while the second group included students trained with Gajon methods.

The first noticeable fact was that, even though the initial level of instruction of the students taught with Gajon method was inferior to that of the other group, it was necessary to teach the students following traditional methods for a period of 22 weeks as against only 9 weeks with the Gajon method.

Traditional method trained students' final percentage of passes was 28%.

Gajon method trained students achieved 70%.

A much higher percentage of passes has been registered when students began their initial preparation with the Gajon system.

For what Computer Aided Training System is concerned, the first courses are now in progress in different countries and we can affirm that the partial checks we are making are showing what we expected, confirming the advantages of the CAT combined with the Gajon programmed learning training system.

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"TRAINING WITH A SHORTENED RANGE CARTRIDGE FOR AUTOMATIC RIFLE"

JEAN CHEVALIER (Colonel S.T.A.T.)
FRANCOIS AMBROSI (Ingénieur en Chef de l'Armement D.T.A.T.)

ABSTRACT

In order to allow for firing manoeuvre, on the ground, of the combat group in reasonably safe conditions, a shortened range firing system, adaptable to the French automatic rifle, has been developed.

In a first part, after having recalled the military requirements, the system's conditions of use are exposed, and in particular those of its associated 5,56 ammunition.

The second part is devoted to the description of the materiel which has been studied on the ground of the military specifications issued from the requirements stated before.

The materiel is composed of a kit adaptable to the rifle and of a 5.56 cartridge with a plastic bullet said "balplast".

This system is at the last stage of its development and should be proposed for evaluation to the official services by the end of 1981.

INTRODUCTION

When adopting at the beginning of the century high velocity small calibre infantry weapons, the French Army necessarily grew interested in shortened range training systems (Cf. fig. 1).

Whereas service ammunition requires heavy infrastucture (firing ranges) and large size layouts (safety limits) which are more particularly unpermissible in Europe, use of shortened range ammunition brings forth notable reduction of utilisation restraint and cost.

In particular, in as much as it has very short lethal range, such ammunition affords collective practice on the training ground, and firing manoeuvre for combat groups, which cannot be thought of with service ammunition.

Widespread adoption throughout the past ten years of automatic individual weapons ipso facto led to the necessity of automatic fire practice.

In order to meet this particular military requirement, viz., "combat group training to automatic fire in open ground", a special shortened range system has been elaborated which can be adapted without any tooling, by sub-assembly replacement, on the service rifle.

For obvious medium range accuracy and safety reasons, the 22 LR system was left aside and an original solution was preferred, consisting of a lightened body and a specially designed round, with a training purpose bullet.

The round is derived from the service ammunition 5.56 cartridge case, with a rebated rim diameter.

A very light plastic bullet (10 grains boattail) is propelled at 4,000 ft/sec muzzle velocity by 12 grains of fast powder, with external ballistics matching exactly that of the service ammunition bullet up to 100 meters.

The characteristics of the ammunition and its subcomponents are described in detail.

The French automatic rifle can be classed as a delayed blowback type. With respect to the low impulse available, the weight of moving parts had to be cut down consistenly so as to afford automatic firing mode.

The lightened training subcomponents are supplied as a kit comprising the breech block, the bolt head carrier and the delay lever, directly interchangeable with the respective parts of the service weapon.

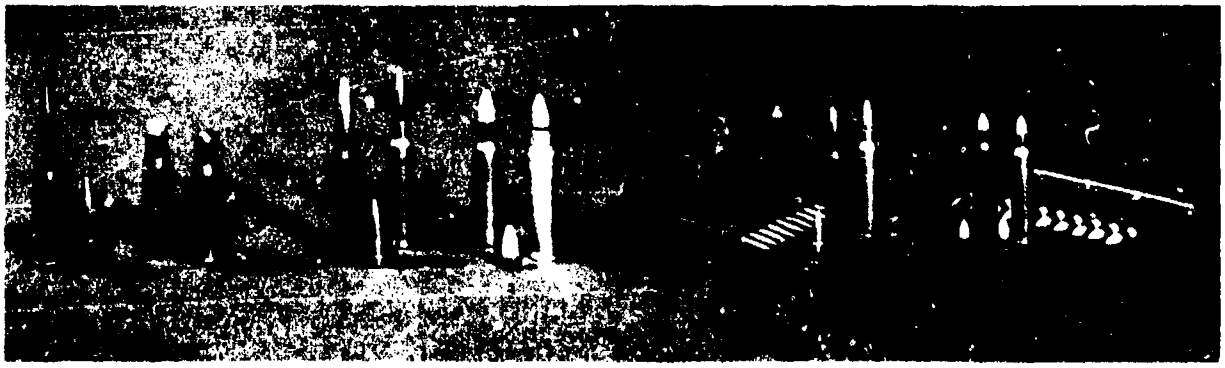

Fig. 1 The shortened range cartriages family since 1900

In order to forbid use of service ammunition (most unadvisable both for the gunner and the people around) during a practice session, the diameter of the recess in the bolt head of the kit was reduced so that only a special profile balplast cartridge with a rebated rim can be fired.

MILITARY REQUIREMENTS

In fact the military need is not new, but it has been modifided with the widespread use of automatic assault rifles.

In France, the need for a shortened range system able to work in the automatic mode has been confirmed by the adoption, in july 1977, of the FAMAS 5.56 F1, and the wish to use fully for training the potentialities of the new 5.56 weapon system.

Military requirements

The external ballistic characteristics of the service ammunition are such as to lead, on the one hand, to important safety space requirements, on the other hand, in the case of a use inside a military enclosure, to non negligible structures.

According to these safety space requirements, the firing grounds have to be very large, and so are generally quite distant from the barracking of the troops, this heads to frequently important movings.

Besides, in the camps used in France for manoeuvres as well as for firing, the execution of the firing course necessary for the infantry troops individual and collective training makes it compulsory to neutralize, for safety reasons, wide spaces which are therefore not available for the tactical training of the troops

It was therefore necessary to elaborate an ammunition having the same ballistic characteristics as the service ammunition, but with a shortened range (1,000 m)

This ammunition makes possible : the use of light structures inside the barracks.

The performance of instinctive fire practice without blocking more space than is necessary.

Use of 5.56 balplast cartridges

Due to its charactéristics, the balplast cartridge has the same external ballistics as the service ammunition between 0 and 100 m, but its terminal efficiency is very much reduced beyond this distance therefore a simple brick wall stops it beyond 100 m.

The safety area is limited to 500 m (instead of 3,500 for the service ammunition).

This ammunition is used for the soldier's elementary training, the time of which being very short during the 12 months "Service National". The movings, which involve delays and wastes of time, are limited to a minimum, as the firings take place inside the barracks of the troops.

For the infantry's individual as well as collective further training, with as small safety areas as possible.

For firing with a cine simulator in enclosures destined to this purpose
It is therefore necessary that the functions held by the service ammunition, in particular the automatic firing, be possible with this shortened range, yet real firing ammunition.

THE BALPLAST KIT

Therefore, in order to meet the requirement corresponding to the tactical use of the automatic rifle FAMAS 5.56, a shortened range firing system has been developed.

a) it has been STUDIED on the ground of military requirements the priorities of which are recalled there after.

1. Safety :

   - Dangerous range limit inferior to 600 m
   - The kit design must not allow firing with service ammunitions.
   - The pieces must be easily recognized as well as the ammunitions.

2. Firing :

   - the performances are judged in comparison with those observed for the rifle with service ammunitions, on the same targets, at the same ranges.
   - In various respects, this also concerns :
     - probability of hit
     - the accuracy (group and zero) in the case of firing with a rest (bipod, or sand bag, and so on...)

3. Reliability :

   - adverse conditions
   - climatic extremes
   - fouling
   - miscellaneous incidents

4. Life expectation :

   15,000 rounds per kit (with the possibility of exchanging the striker, springs, ejector, extractor...).

b) it is COMPOSED of :

- an adaptable kit for the whole bolt unit
- a cartridge with a plastic bullet.
- a magazine (which is in fact polyvalent, as it allows the rifle to work with any of the adopted cartridges : service ammunitions, blank, dummy).

c) it ENSURES the different firing modes of the rifle, with 5.56 plastic bullet cartridges, and a useful range of 100 m.
Fundamentally, the problem to solve is not a simple one.Automatic firing requires a lot of energy, and that is a priori at the opposite of shortened range,let alone with the requirements about accuracy.

Nevertheless, the question once put, the firsideas to come forth in answer were these :

For the ammunition, try to scale down and adapt for the 5.56 automatic rifle, the existing cartridge used for the 7.5 rifle, and in particular its projectile.

As for the weapon, considering the low energy available with the balplast, design a blowback unit, the FAMAS being a priori suited for this

The first idea, i.e. reduction of the 7.5 round, misfired, so to say... because of the shape of the flat based bullet. As for the second idea, it was quickly dismissed for two major reasons : a technical one and a human one.

As a matter of fact, in the FAMAS the automatic sear is controled by one of the lever lower wings, replacing the present bolt unit by a simple blowback lightened block meant that firing was suppressed ! As this is precisely one of the safeties of the FAMAS. Moreover, it is necessary that the soldier should acquire and retain the knowledge of one mechanism for this weapon, and this would not have been true any more had the working system been transformed in the exchange between the pieces of the bolt unit and those of the adapter.

This being said, and although the working principle of the FAMAS is well known, it is now necessary to do some mechanics to understand the whys of the retained solutions.

The FAMAS, a small bullpup design works according to the principle of delayed blowback with a delay lever. This lever couples the breech and the bolt-carrier (1), (2), (3), (4).

In order to avoid the gripping of the case in the chamber, there are canelures along the chamber in such a way that the case floats in the gas with an equal pressure on both sides of the wall of the case.

So, as the pressure increases, and as the bullet moves down the barrel and the head of the case pushes back the breech, the bolt carrier starts to shift back, linked by the delay lever.

At this time the floating case acts as a differential distributor of momentum.

$$\mu = \frac{\text{surface of the HEAD} \quad \text{of the case}}{\text{surface of the MOUTH} \quad \text{of the case}}$$

So the conservation of momentum before and after the firing of the cartridge is expressed by :

$$P_\rho + P_g + P_a = 0$$

Where : P_ρ = momentum of the bullet and propellant gas

P_g = momentum of the rifle (in recoil)

and P_a = momentum of the single equivalent moving part. (for breech, bolt carrier...)

we find : $P_a = - \mu P_\rho$ and $P_g = (\mu - 1) P_\rho$

Another relation between the mass of the single equivalent moving part (m_r) and the mass of the moving parts (m_h) for the breech and (m_{bc}) for the bolt carrier is obtained from the conservation of energy : (Cf. fig. 2);

$$m_r \dot{x}^2 = m_h \dot{x}^2 + m_{bc} \dot{y}^2$$

With $\rho = \frac{OB}{OA}$ Ratio of the arms length (upper and lower) of the delay lever.

So $\dot{y} = \rho \dot{x}$

In fact ρ is not a constant with the FAMAS. During recoil its value changes from $\rho = 3.6$ at the beginning to 1, a mean value of $\rho = 2.77$ is a good one in most cases.

As a first approximation, these two equations represent the working of the rifle :

$$P_a = - \mu P_\rho$$

$$m_r = m_h + \rho^2 m_{bc}$$

For example with the FAMAS 5.56 : $m_r = 3.2$ kg
With "standard" ammunition $P_\rho = 6$ Ns.
So for automatic firing the total mass of the moving parts should be less than 11.6 kg.

The kinetic energy of this mass (3.2 kg) with service ammunition is ranging about 22 joules* ; and a minimum momentum of 3 Ns is needed to work the FAMAS with this mass.

To conclude, with a shortened range firing system where the cartridge must give out a momentum ranging between 1.2 and 1.7 Ns, it is necessary that the equivalent recoiling mass should range between .5 and 1 kg.

	SERVICE	TRAINING
Bolt head / Breech	110,5g	109g
Bolt carrier	240,5g	148g
Delay lever+Firing-pin	29g	23g
Cocking	153g	153g
Total weight	533g	433g

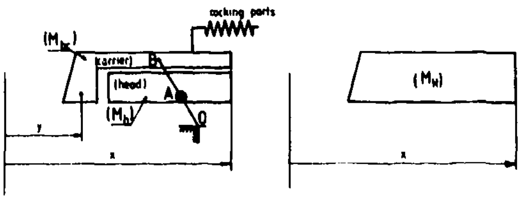

FIG:2 WEIGHT OF BOLT PARTS

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* 1 joule = .72 ft.lb.

The adapter of the bolt unit (cf. fig. 2 and 3)

In the weapon, the adapter must substitute for the following items :

- the bolt (breech)
- the bolt carrier

and ensure the functions of the existing parts.

For human engineering (E), technical (T) and industrial (F) reasons, the following solutions have been retained :

- to keep the working principle (E and T)
- to keep the breech (E,T and F) ($m_h = 140g$)

The only alterations effected in the breech have been performed for safety reasons.

- a smaller diameter for the recess in the bolt head so as to avoid the accidental firing of a service ammunition.
- the setting of a foolproof device so as to forbid the improper exchange of one of the breeches for the other.

Then again, as it was necessary to keep the main spring & miscellaneous (m_r 150 g) and that the design made it quite impossible to lower the ratio of the lever beyond 1.6, it was found that the ammunition had to fire out a momentum superior to 1.3 Ns, with a bolt carrier mass of about 150 g, that is to say a total of about 300 g for.
$(m_{bi} + m_r)$

Concerning the mass of the rifle mobile unit elements and of the adapter, see fig. 2, their outline is shown on figure n° 3.

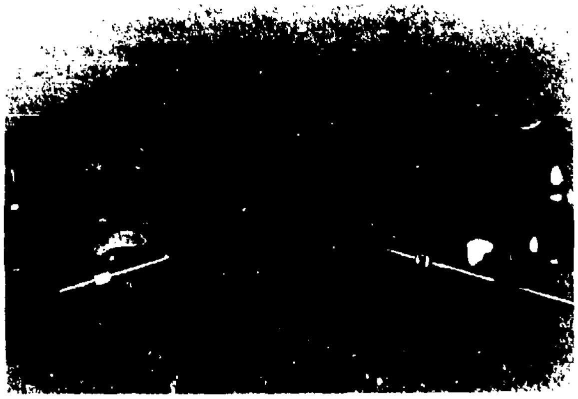


Fig. 3 - BOLT PARTS (left-Service items and "balplast" adapter at the right)

The balplast cartridge

Since about 1960 the French Army has been using with its 7.5 armament (MAS 36/51 and FSA-MAS 49/56) an ammunition. This cartridge only allows hand operated firing.

The projectile of this cartridge is a plastic ogival bullet, made out of orange colored RILSAN, with a flat brass base. This base has a double fonction as a gas-check inside the barrel, and as a support for the crimping of the cartridge mouth.

At the time, the characteristics required for this projectile were as follows :

- a 7.5 bullet (.308)
- total weight of the brass base : 0.77 g
- total mass of the bullet : 1.25 g

At first this cartridge (see. fig. 8) used the service ammunition brass case, and this caused many incidents. As a matter of fact, the pressure developed while firing being too low, the case could not be an efficient gas seal in the chamber, and this frequently caused discomfort for the shooter. In order to put these incidents right on the one hand, and to reduce the cost of the cartridge on the other hand, a much softer case made in a light alloy was worked out, which is still in service.

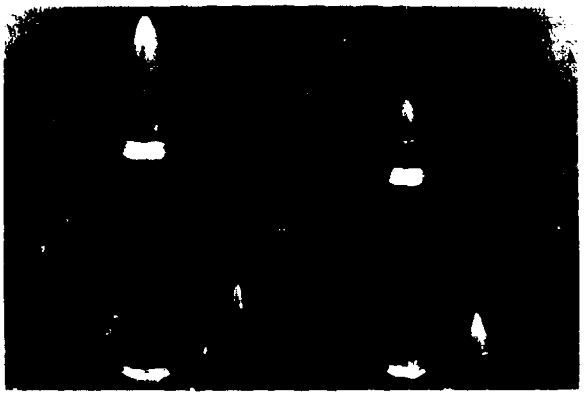


Fig. 8 - Down scaling from 7.5 to 5.56 mm

The first idea was therefore to reconsider this cartridge and adapt it to the 5.56 caliber. No sooner said than done and that was the beginning of troubles all the more embarrassing as they appeared late, too late. As a matter of fact, these cartridges are loaded wtih an extremely fast burning powder (the same as the one used in blank cartridges). As it was not possible to rely on the crimping of the mouth of the light alloy case for a good ignition of the powder, the diameter of the bullet had been slighly enlarged of 0.05 mm (.002"). The forcing was sufficient and the pressure regular (on the other side, this was a great contraint from the industrial point of view because it meant recalibrating the neck).

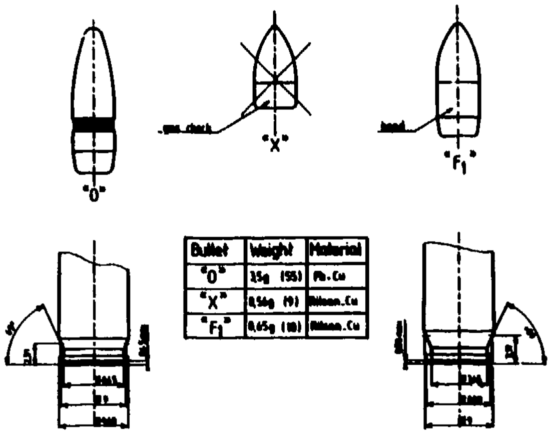
And then, one day, it happened that the impacts observed on a target were tipped and even keyholed and that dispersion was also aberrant. After a few investigations it became obvious that the profile of this projectile was not suitable because it was far too sensitive to the barrel state of wear (a phenomenon that unknown in the 7.5).

Under this shape, it has not been possible to come back to a smaller projectile diameter and to ensure a better ignition by using strong crimping only, in particular by changing the material of the case because, with a steel case, ruptures of the projectile were observed to happen at the upper level of the gas check due to the crimping.

Therefore, the whole study had to be resumed from the definition of the bullet, and this resulted in the "F1" design.

This misadventure explains you the presence of two sketches on figure 4, where the diagram "X" is related to the projectile that was left out.

It is a 5.71 mm boat-tailed projectile ; its mass is of 0.65 g (10 grains). A real rotating band constitutes the cylindrical part upon which the Rilsan is moulded.



Bullet	Weight	Material
"0"	3,5g (55)	Pb.Cu
"X"	0,56g (9)	Rilsan.Cu
"F1"	0,65g (10)	Rilsan.Cu

FIG:4 CART 5,56 (Bullet "0" - Bolplast "F1")

It is obvious that this design is very much ill suited to create an important drag. However, after many tests, it is the only one which is satisfactory with the arms on the field, and which enables us to reach the level of performance required by the French H.Q.

The CASE

The service ammunition brass case has been chosen, since, as explained before, the steel one was not suitable.

In the FAMAS, there is no tightness problem since, on the contrary, the chamber is designed so as to allow the powder gas pressure to release the case thanks to longitudinal grooves cut a long the wall of the chamber (the cartriges fired with a FAMAS are easy to recognize by the fluting on the neck).

For obvious safety reasons, it is necessary that it should be impossible to fire service ammunition in a rifle which has been modified for practice firing. Apart from the fact that the components are easily recognizable by sight as well as by touch, it has been judged useful and safer to reduce the diameter of the recess in the bolt head. In such conditions, it is not possible any more to fire unperposedly a ball cartridge.

This arrangement has brought about two other modifications concerning :

- the cartridge case which ressembles now a small .284 WINCHESTER
- the lips of the clip, which have been stretched so as to be able to grasp the cartridge tightly while remaining compatible with the rifle's other accessories (loader, bandoleer...).

On the other hand, it has been necessary to study a new magazine, the clips of which are better suited to lead these rebated rimmed cases.

At present, works are dealing with this magazine so as to make it really polyvalent with ALL the cartridges which are used (service ammunition, blank, dummy, a.s.o.)

PERFORMANCES OBTAINED

The results which are presented are relative to the works state of advancement in May 1981.

With the objective of a presentation to the technical official services by the end of the year, the results of these works evolve every day, and will not be definitely fixed until December 1981.

This being said, the nature of some of the tests may surprise, but one should keep in mind that this is about a pratice system where, up to a certain extent, men and projectiles will have to coexist with somme reservations (it has not happened so far, but this projectile can cause an almost fatal wound up to 60 m and a certainly very severe one up to 100 m).

Interior ballistics

At the end of this stage of the study, it should be possible to choose a powder and a charge, so as to get in a way the required performances :

- a momentum sufficient to allow automatic firing
- a maximum pressure compatible with the mechanical strength of the projectile for all temperatures ranging from - 15°C to + 40°C (5° F to 104° F)
- taking into account the small mass of the projectile, the chosen powder had to be very fast burning, with a low density so as to have a good loading density of the case, and therefore good pressure steadiness.

The double base powders have been eliminated because they proved to be far too erosive. Within 400 or 500 rounds, the beginning of the rifling is almost erased !

In the scope of this study, the results obtained with various temperatures for the same powder have been tabulated hereafter (table I).

In table II the temperature is constant but with a different powder in each case. The charge is the lowest possible providing reliable automatic functionning, with less than 1 per cent jamming incidents. In fact, the charge from one powder to another varies very little, about one grain differences (.065 g).

Conditions : - Pressure gun with electronic transducer
- average firing : three series of ten rounds
- bullet :.65 g boattail F1
- brass cases.

TABLE I

t°	V_{25}	σ_V	Pm	σ_p	Tb	σ_T	S
+40/104°	833	32	1024	96	1,05	0,07	3
+ 21/70	815	18	980	40	1,05	0,06	2,5
- 18/0°	775	27	900	60	1,1	0,07	3

t° = temperature - ° C/F

V_{25} = velocity at 25 m from muzzle (m/s)

σ (v, p, t) = standard deviation

P_m = pressure (electronic and bar)

t_b = barrel time (m/sec)

$$S = \sqrt{\tfrac{1}{2}(\sigma_x^2 + \sigma_y^2)}$$

In both tables, accuracy is quoted for information only. However it can be derived from the values mentioned in table I that accuracy remains satisfactory in the whole range of temperatures, it can hence be concluded that bullet material and design are suitable.

TABLE II

Powder	V25	σ_V	Pm	σ_P	Tb	σ_T	S (+)
BPs 100	1030	20	1615	115*	1.01	0.06	< 2 cm
BS 30 Ba	815	18	980	40	1,05	n,06	≙ 2,5cm
GBPs**	920	13	1284	53	0.95	0.06	≙ 2.5cm

t° = 21° C / 70°F

(*) = queerly enough, the highest σ_p, yet the lowest S

(**) = discarded (too erosive)

(+) = indoor range at 100 m

EXTERIOR BALLISTICS

Ballistic tables

Traditionally, the designing work for a new cartridge always results in a great number of test data being collected in two large families :

on the one hand interior ballistics,
on the other hand exterior ballistics, the latter resulting eventually in a ballistic table.

The case of terminal ballistics in definitely beside the question for the moment.

The interior ballistics data could be gathered with little difficulty.

Reversely, it has not been so far possible to establish complete ballistic tables beyond 200 m's range.

Actually, beyond this distance, the trajectory becomes so randomly that it is practically impossible to display the measurement facilities.

Let us quote two observations in support of this assessment:

at 100 m's range, the accuracy of such bullets is comparable to, and maybe better than that of ball ammunitions.

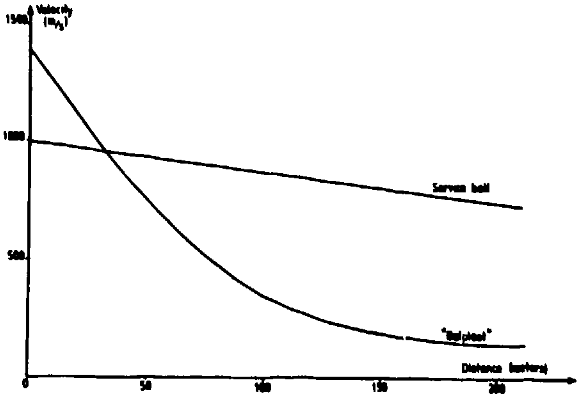


FIG.5 VELOCITY V DISTANCE (Service ball and "balplast")

Reversely, at 300 m's range, whereas accuracies of 10 cm s 15 cm are frequent for service ammunition, out of 10 balplast fired at a 6 by 6 m target standing at the same range, 3 bullets only impinged the cardboard.

Again, during the maximum range evaluation tests, the proving ground had to be chequered on a large area to help recover the bullets on the ground. In particular, 3 m/s gusts of wind may alter the range by over 100 m, which is easily explained by the low weight of the projectile, which has approximately the same bulk as the M 193.

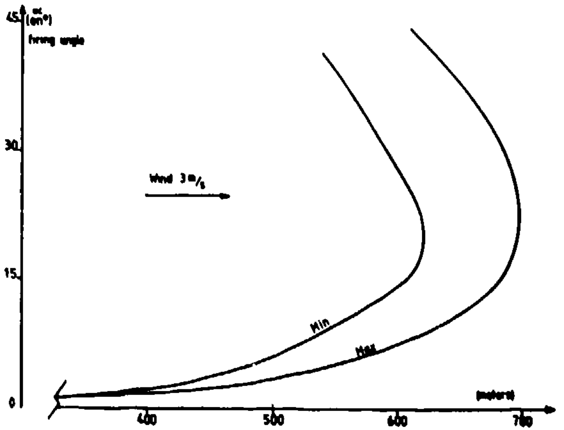


FIG.7 RANGE

This summer, (1981) an extensive testing program is scheduled for determination of the velocity vs range data as far as the flight can be detected, this being capital information for reliable determination of safety area.

Last year during trials with a view to determine the ballistic table of a 5.56 bullet, doppler radar (type vezero-graph lambda 10) was used to follow the trajectory of the projectile up to 900 m's range.

Today this facility seems to be our only hope to try and determine the velocity of balplast at the end of flight, without having to close the horizon with acres of cardboard.

The results obtained up to now are gathered in table III hereafter and are also to be found in figures 5 and 7.

TABLE III

Range (m)	Velocity (m/s)	Energy (J)	Energy density (J/cm²)	Energy density ft.lb/sq.in
5	1050	330	1290	6030
25	810	218	850	3970
50	550	100	390	1820
100	320	34	133	620
200	180	10	39	180
X?	130	5,5	21.5 (*)	100

(*) On the basis of GI. JOURNEE's works (7) it is considered in France that the limit of bruises and wounds in the soft parts of a naked men is reached when the energy density of the bullet is 21 J/cm².

Considering this value, the velocity threshold should be about 130 m/s (425 ft/sec), and hence the limit of the hazardous area should be about 250 to 300 m (1,000 ft), which confirms the result of the safety area determination led in 1964 for the Mle 61 bullet of the 7.5 mm cartridge.

In order to give a more precise idea of the magnitude of this energy density
.Ib/sq.in.), this corresponds approximately to the energy of a No 7 ½ pellet 70 yards from the shooter.

NOTA : For this and the following paragraphs, all data quoted refer to firings performed with rifles equipped with a balplast kit ; the

the production line, and have fired about 1,500 rounds in previous tests. All firings are performed by able shooters (not marksmen), using the production type

bipod.

Accuracy

On firing balplast cartridges with the rifle, a displacement of the mean point of impact is observed with respect to the results obtained with ball ammunition.

This displacement results in a target at 100 m's range by : (cf. fig. 9 hereafter)

3 to 5 cm drift to the right
15 cm rise in elevation

It is most likely that nothing can be done as regards the drift, the latter being inherent to flight physics ; on the other hand, it has been observed that by adding a muzzle mounted device, it was possible to decrease, and even suppress the rise in elevation. Works are being led in that line.

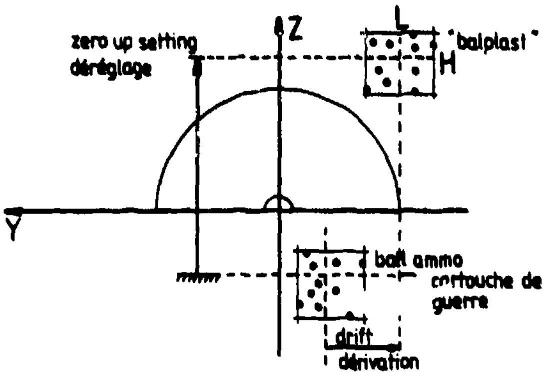


Fig. 9 Shifting of the mean point

Table IV is a report of the results obtained on rifle firing in the conditions below :

- indoor range
- firing on the bench with bipod as a rest
- metallic sights
- rifle Nr P 127 equipped with Balplast adapter
- 10 rounds series fired shot by shot
- BS 30 Ba powder

TABLE IV

V5(m/s)	(m/s)	H + L	S	Z	Y	Δ Z	Δ Y
1045	40	16.7	2.8	19.6	4.4	15 (up)	3 / 5 right
		19.1	3.2	24.3	7.9		
		20.3	3.3	18.3	8.1		

NOTA : Unless otherwise mentioned, all measures are in cm.

Time of flight

The system being designed for elementary training and practice to automatic firing, its utilization should in no case develop in the shooter reflex behaviour differing in any way from that implied by firing service ammunition.

We have seen above what concerns accuracy (group and zero). For time of flight, all data obtained are tabulated versus time of flight of the service ammunition in fig. 6.

At 100 m's range, the time of flight of balplast is 0.05 sec longer than that of the ball ammunition, which would result in a necessity for 25 cm correction in the case of a target moving sideways at 5 m per sec velocity (which is a maximum).

In the same conditions, between ZERO and 70 m, target correction is less than 10 cm (plus or minus).

Such values should prove a hindrance for the probability of hit, as well in shot by shot firing as burst firing.

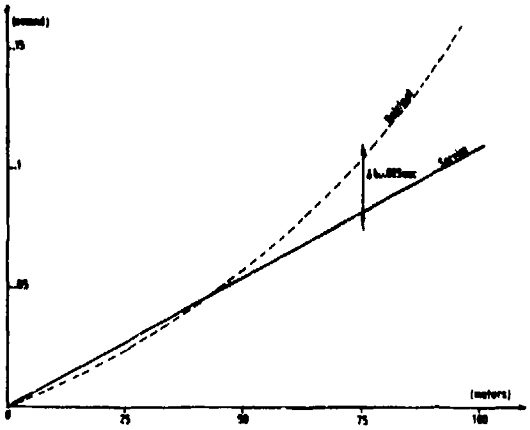


FIG:6 TIME OF FLIGT

SAFETY

The maximum range is about 500 to 700 m, according to wind velocity, but at such distances, the danger is null.

300 m is likely to be the limit retained for the hazardous area (according to the criteria taken in consideration).

The system being liable to be used in firing course practice, the necessary protections and the behaviour of the projectile at short range had to be determined :

At 45 m (50 y) and for a remaining velocity of 800 m/sec (2,620 ft/sec) under zero incidence, the minimum thickness of protective material is :

- 100 mm for poplar wood
- 6 mm for 2017 A light alloy (AU4G)
- 3 mm for A 33 mild steel

50 % penetration of 41 mm thick poplar wood is obtained at 600 m/sec velocity, that is at 65 m's range (71 yards)

Rebounce

Still in the scope of firing course practice and more precisely for street fighting, or cine simulator the behaviour of the balplast on impact against various materials was observed :

a) in all cases there is no rebounce or fragment projection beyond 7 m above the limit angles of impact given hereafter :

- mild steel	10°
- light alloy	30°
- concrete	60°
- wood	80°

As concerns wood, the projectile sticks deep into the protector and does not get through, even should 5 or 6 projectiles stack up in the same hole. For other materials the projectile breaks up into unsignificant fragments with less than 7 m lateral range.

b) beyond the above mentioned limit angles, the projectile more or less deformed, will skid along the surface. Use of metallic plates for protection is therefore not advisable if grazing fire is likely to be performed.

Foolish interferences

Experience unhappily proves that every year, in spite of all advice, some unconscious people (the term is euphemistic) will meddle with cartridge modification, and get spectacular ballistic results endangering not only their own lives but also their neighbours'.

It is worth knowing what will happen if a service ball is mounted instead of the balplast. Considering the type of powder used (BS 30, hence fast burning), we may wonder which end the whole stuff is to be expected to pop off... We plan to film the experiment for training purpose.

CONCLUSIONS

This communication is the syntheses of works led by the research teams in 4 arsenals of GIAT :

Pyrotechnics and cartridges	A.L.M.	Atelier de fabrication du Mans
Pyrotechnics and cartridges	A.T.S.	Atelier de construction de TARBES
Rifle	M.A.S.	Manufacture Nationale d'Armes de SAINT-ETIENNE
Project management	E.F.A.B.	Etablissement d'Etudes et de Fabrications d'Armement de BOURGES

It reports the present stage of development in May 1981 of the "shortened range practice system" adapted to the French assault rifle.

The system definitely maintains the same human engineering and performance criteria of the service weapon, and provides the same types of firing modes as with the ball ammunition.

In particular, the system will allow training of the combat group to instinctive automatic firing in adapted firing courses with a hazardous area limited to 300 m.

There still remains much to be done before final homologation, yet the characteristics of the system are already definetely settled and production

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SURVIVING THE PITFALLS AND TROLL BRIDGES
IN STATE-OF-THE-ART CBI DEVELOPMENT

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ABSTRACT

Most computer-based instructional (CBI) system development is done using proven technologies in proven ways. Sophisticated development models are available for determining software (e.g., top-down design) and courseware (ISD) decisions and structures in these systems. For state-of-the-art (SOA) CBI system development, however, there are additional probelms peculiar to that form which require specific considerations and solutions. This paper is designed to define the specific characteristics of this type of development and to discuss some of the problems, considerations, and solutions involved in SOA training system research and development. These include personnel concerns, such as work environment characteristics and the type of people best suited to it; management concerns, such as the style of management required; communications concerns, such as the required interaction between different staff disciplines; and the different technical approaches required for this specific form of development.

INTRODUCTION

Logicon specializes in the integrated applications of advanced technologies and advanced concepts to system engineering problems. Within this context, the Tactical and Training Systems Division has undertaken several state-of-the-art CBI (computer-based instruction) system development projects. (1,2,3) The purpose of this paper is to present some of the problems associated with doing work in this area and some possible methods for avoiding those problems.

The problems covered in this paper are of basically two types: pitfalls and troll bridges. Pitfalls are those problems which occur where you don't expect them. You think you're on solid ground and then suddenly you're at the bottom of a hole with a lot of angry natives looking down at you. Troll bridges are generally problems which you know about. The trolls have a unique way of conducting business: they peacefully accept whatever payment you believe is reasonable for crossing the bridge. Then, when you're at the middle, they demand you pay more or they toss you off.

It is important, at this point, to define some terms. SOA development means attempting to implement the most recent technologies available within a given field. This is, by definition, a high risk endeavor with unknown commodities. It makes the developer vulnerable to many levels of non-success. A CBI system is based upon computers and associated peripheral devices such as CRTs, printers, audiovisual delivery systems, and computerized speech generation and voice recognition hardware. The techniques used include computer assisted instruction (CAI), computer-based performance measurement (PM), and computer managed instruction (CMI).

In an area as diverse as state-of-the-art (SOA) development of CBI, there are lots of pitfalls and troll bridges. They come in large (general) and small (specific) sizes and can appear anywhere. This paper attempts to present some of the ones of both sizes that Logicon has encountered in several different development areas.

This paper has been structured to move, more or less, from general to specific. The first three sections deal with more general concerns. These sections are titled "State-of-the-Art," "Computer-Based Instruction," and "People." The final two sections delve into more of the specifics of CBI development. These sections are titled "New Hardware to USE" and "New Things We're Doing."

STATE-OF-THE-ART

There are generally two sets of attitudes regarding SOA technologies. These can be categorized as "bandwagon" and "tradition-based." A good example of the bandwagon approach is the present "love affair" going on with the videodisc. It seems that lately just about every other training system RFP has requested the use of videodisc. In many cases, however, traditional technologies could provide better performance with less risk.

The tradition-based approach is characterized by people not using new technologies solely because the technologies are new or using them as an expensive version of the more traditional media. An example is the use of videotape in the classroom. Initially, there was a great deal of resistance from teachers because they thought they were going to be replaced. Then, when television finally was accepted into the classroom, if was often used to present lectures...just as though there was a teacher standing there.

Because there is no body of experience upon which to base design and development decisions, it is important to realize that state-of-the-art development involves taking risks and makes you vulnerable to failure. Thus, there must be a commitment to this vulnerability. RAdm. Albert J. Baciocco provides this perspective:

> "When I state a willingness to take risks, I am simultaneously stating a willingness to accept some failures. In my view, failure is also a measure of success in basic research...as long as it's not 100% failure." (4)

If you get involved in producing a "successful product" the first time out, you'll most likely limit your use of the technologies to the more familiar realms rather than exploring the further limits of their capacities. If the decision has been made to do SOA development, it is important to apply the knowledge that has been accrued from work in similar areas. This knowledge should be used as a starting point for identifying means for using the SOA technologies in way most amenable to their inherent characteristics. If there is no commitment to vulnerability in the use of the new technology, you would probably be better off adapting an older, more familiar and secure approach.

Early in the project a **needs assessment** should be done. In this case, you are assessing your need to actually utilize new technologies: how are they appropriate, what do they add, and are they cost effective. In some cases, you may be responsible for providing a technology test bed. In that case, you should carefully examine the possible applications for ones that will stretch the limits of the technology. When you're not responsible for testing the technologies, you should carefully analyze your application and choose the technologies (be they new or be they old) that most closely fit your identified needs, resources, and allowable risks.

COMPUTER-BASED INSTRUCTION

In CBI, as with most instructional approaches, it is important to define a task that can be accomplished with your given resources (people, time, money). The task itself should be driven by considerations of the instructional system outcomes: what is the system supposed to do, how quickly, for how many people, how well.

In most instructional approaches the instructional designer knows the medium sufficiently well to make many intelligent decisions concerning equipment, budget, and approach. CBI, because it involves complex and expensive components, requires three sets of specialists who **must** be involved in most of the initial system decisions and who must communicate continuously during the design and development process to insure that everyone understands what, precisely, is going on.

The three sets of specialists are hardware, software, and courseware designers and developers. Since they represent entirely different parts of the system development process, communication to ensure understanding becomes imperative. These people must establish a mutually held concept of the system and its capabilities before the limiting, defining, and restricting decisions (e.g., what hardware, what software language, what instructional outcomes) have been made. Then they must continue the cross discipline communication to ensure that the picture stays congruent for all three staff disciplines.

PEOPLE

There are several sets of people involved in the development process of SOA CBI. In addition to staff, there are managers and users. The users can be further categorized into students and instructors. This section addresses pitfalls and troll bridges associated with each of these sets of people.

Managers

SOA CBI development often lacks much of the extrinsic structure common to training systems which use more traditional methods and media. Additionally, the stress levels will typically be higher as a reflection of the risk (chance for error) associated with exploring new territories.

Many of the problems associated with this area may be avoided by maintaining a more active, more psychological project management approach than usual. It is important to reduce staff stress. This may be done by supplying strong leadership to provide structure where it is absent. Managers will want to encourage innovation and analysis at the outset to insure that the technology is being utilized in the best possible way. They will want to ensure communication between the groups (hardware, software, courseware).

Perhaps most importantly, managers should identify "inch pebbles" (as opposed to milestones) for identifying project progress and should be very aware of places where the inch pebbles are not being reached. This will provide a methodology for forestalling the large crises to which SOA development is more vulnerable.

Staff

In attempting SOA CBI development, your choice of staff members becomes a little more important. Of course you will want to choose people with as good skills and experience as are available to you. However, **staff members for SOA development should, if possible, be flexible persons with low "final product" attachments.** SOA work does not lend itself to obvious first time success and often requires multiple iterations or complete redesign in order to derive a useful product. Indeed, sometimes you may find that success with a particular technology configuration is impossible. Therefore, a person working on SOA CBI would be better served to get satisfaction from getting a job done as well as they can, rather than depending on traditionally successful end results.

Students

In terms of the student-system interface, CBI presents the design/development team with a new set of considerations. Major amongst these considerations are the learners' attitude toward automated instruction, how to supervise information presentation, and how to teach the learner to use the system.

Learner Attitudes. There are two main attitude problems. Up until the recent past the average person has stood in awe of computers. Learners have been initially reticent to use computer systems for fear of "breaking" the very expensive equipment. With the rapid inclusion of computers into many aspects of day-to-day life this concern is diminishing, but still must be considered. Fears have also been voiced, on a more or less continuous basis, about computers dehumanizing the learning experience.

The designer must take both these factors into consideration. The CBI system must be user oriented. It is wise to go to the learner population and poll their attitudes about computers. By concentrating on identifying any fears the students have about CBI, you can know where to start in providing a stress reducing introduction to the system and the experience. Both the computer fears and the possibility that the lack of human intervention will degrade the instructional effectiveness can be at least partially solved through (1) careful inclusion of humans into the system design and (2) giving the computer a "personality." Building a human-system rapport can serve to reduce both the potential effects of dehumanization and learner fears about system use.

Presenting Information. A computer-based instructional system can provide the learner with information in a variety of ways. These include CRT, various audiovisual media, printers, and computer generated speech. Guidelines about how to present information using various media already exist. Instructional Message Design (5) is one good example.

However, when you have more than one information source available in your CBI system, your problem becomes one of directing the learners' attention from one source to the next and ensuring that the learners know precisely what behavior is expected of them at all times. Not knowing how to initiate the next step can cause the learner to experience a sort of stress-induced paralysis or may result in a random pushing of keys and buttons until **something** happens.

Learning How to Use the System. The use of computer-based systems provides you with another new problem, that of familiarity. The student will not usually be familiar with computerized instruction in general and your system in particular. You, therefore are left with the task of teaching the student how to use the teaching system.

This is a very important problem inasmuch as, if the student cannot use the system, the system cannot train. It is critical that you identify what the student will need to do to use the system and then carefully teach those behaviors. It is a good idea to separate this instruction from the general instruction so the student may review aspects of system use whenever he is unsure of what he is supposed to be doing to make things go.

Instructors

As with the students, the instructors are users of this system. Their responsibilities will usually extend to managing system use and providing a human control over system use and misuse by the students. Their attitudes and knowledges must be considered in your system design and development.

Instructors will generally resist the implementation of a CBI system within their teaching realm. This is a result of fears that they are going to be replaced by the system or that they will become simple technician adjuncts while the system does the important tasks. In our experience with CBI, the instructors generally become comfortable only when they see they have some control over the system (6) and that they are still involved in important instructional system tasks.

It becomes very important, therefore, to make the system as easy to supervise as possible. It also becomes very important to provide the instructors with training on the roles that they are expected to fulfill and to accentuate how important these roles are to system success. In one system presently under development, we are developing an instructor tutorial using the system to teach the instructors as well as the students.

In any case, the current SOA CBI system tends to put the instructor into three roles: system manager (controlling and logging system operation), instructional facilitator (overseeing and smoothing system-student interactions), and tutor. Since most instructors are only familiar with being in the role of primary instructional resource, the three new roles must also be taught.

NEW HARDWARE TO USE

The new hardware which is mentioned below is but a small sample of the wondrous things which are becoming available for use in instructional systems. In this paper the two types of hardware discussed are automated speech hardware and the videodisc.

Automated Speech Hardware

Automated speech includes speech generation, speech recognition, and speech understanding. Speech generation and recognition are mostly hardware based and will be discussed in this section. Speech understanding is mostly software based and will be discussed in the NEW THINGS WE'RE DOING section.

Automated Speech Generation. There are a variety of devices available which can produce speech under computer control. Most of these devices fall into two general categories: speech synthesizers and speech encoder/decoders.

Speech Synthesizers. The synthesizers produce artificial sounding but intelligible speech by combining electronically generated sounds which correspond roughly to English phonemes. Some synthesizers are capable of performing the translation from English text to speech directly; others require human intervention to specify the phoneme strings and inflections. The devices also vary in cost and in the intelligibility of the speech output. The synthetic quality of the speech has been identified as a disadvantage, but the small data storage and I/O processing overhead requirements make synthesizers an attractive solution to many speech generation problems.

The one outstanding drawback to the synthesizer encountered in certain applications is the fact that the simulation of many different voices is impossible. Another difficulty is that it is usually impossible to vary speech rate under program control. Even at the highest available speech rate, the synthesizers tend to speak relatively slowly. This caused difficulties when they were used to simulate air traffic controllers because the synthesizer was sometimes unable to provide enough control information in the time allotted.

Speech Encoder/Decoders. These devices utilize a technique which digitally encodes and compresses of human speech in such a way that it can be subsequently decoded to produce speech. These devices provide a range of fidelity from superb (and expensive) audiophile quality, to lower cost units which provide correspondingly lower fidelity. Even the low fidelity units produce speech which is unmistakably human and sufficiently intelligible for many applications. These devices can easily be used to simulate different voices simply by recording voices of different talkers. Depending upon the encoding technique used, these devices can offer the advantage that speech is simply recorded, and there is no need for painstaking encoding of phoneme strings. Others require off-line processing of the encoded information to reduce the data requirements to practical levels. The disadvantage of the encoder/decoders lies in their relatively much larger data storage and I/O processing requirements.

Speech Recognition. Commercially available hardware ranges from inexpensive units which recognize a few words spoken in isolation to more expensive devices which recognize a large vocabulary of isolated words or phrases with high accuracy, to even more expensive devices which recognize continuous speech. Most units are still "speaker dependent" which means they must be configured to recognize an individual talker's voice by having the person repeat each vocabulary item one to ten times.

Our experience has shown that recognition accuracy is affected by several factors, including the vocabulary itself. In some applications, the vocabulary is defined a priori. In many others, it can be defined by the system designer. In the latter case, great care should be devoted to the development of a vocabulary tailored both for user acceptance and for machine recognition. The optimization for machine recognition almost has to be done by experimentation because the machine ear has different characteristics from the human ear. The inability of many systems to distinguish reliably between "five" and "nine" is often cited. In our applications, we have also found many other pairs which cause trouble, including "above" and "below," "left" and "right," and "port" and "four."

Videodisc

The videodisc is a marvelous tool for providing color, still, or moving pictures and high quality audio under computer control. It could, of course, be used to provide lecture material, but its great advantage lies in the fact that demonstrations by experts, mini reviews of specific topics, etc., can be randomly accessed by the computer or at trainee request. Theoretically, the technology could provide the basis for a talking, moving book, with a sophisticated indexing and retrieval capability.

The disadvantages to the technology include that, unlike videotape, the production aspect is akin to audio record mastering, hence the audiovisual materials cannot readily be changed. The unreliability of early devices also has proved problematical.

It is very important to carefully identify precisely what kinds of graphics and sound you wish to present in your CBI system and then make sure that videodisc is the proper presentation medium for your needs. Once that's determined, your next concern is choosing the videodisc player appropriate for your application. There are several varieties of this technology presently available with others undergoing prototype development.

Another important hurdle is production. Since this is a relatively infant medium, many of the production bugs still must be worked out. Premastering, mastering, and quality assurance are all areas to which you should pay attention. (7) It is also important to note that, as of the beginning of this year, none of the videodisc production companies had the ability to do classified premastering or mastering. If you have security related materials to show you should check carefully to see if this problem has been overcome.

NEW THINGS WE'RE DOING

This section describes some of the parts of the CBI system such as courseware, automated instructor model, and automated speech understanding. Herein are described some of the problems associated with working in these SOA areas.

Courseware

In a CBI system the courseware materials are mostly embedded in the computer memory. Therefore, the courseware language you use becomes very important. Because of the iterative nature of SOA CBI development, it becomes practically a necessity to be able to a quick, easy review of the materials you have developed. As you add hardware devices (e.g., videodisc, simulated job station) or capabilities to your system, it becomes increasingly important to have a supporting courseware language which offers simplicity in your specification of devices, what they do, when they do it, and how long they do it. The language, if possible, should also provide for easy revision of materials.

A typical CBI system development will require parallel development of software and courseware. Unless you have a very long timeline and can develop and test the whole system before you have to write and enter any of your materials into computer memory, it is a good idea to devise your system so that you can see and revise pieces (i.e., text pages, scenarios) before the entire system is finished.

There are several different courseware languages available on different systems (e.g., Pilot, Decal) and others under development. If none of those you can find offer what you need, you may want to do as we have done and develop your own courseware language to precisely fit your application. If you choose to develop a language, define very carefully amongst the three work specialties (courseware, software, and hardware) what the instructional system will be designed to do, given your particular resource parameters.

Automated Instructor

The simulation of any complex human behavior is certainly not a trivial task. In the course of our work in automating the instructor's task of evaluating a trainee, we have come to appreciate just how non-trivial the assessment of human performance can be! The following discussion highlights some of the pitfalls and troll bridges we have encountered.

Components of an Automated Instructor Capability. An automated instructor capability should have several components. It should:

- Provide an objective measure of trainee performance on a particular problem relative to objective criteria;
- Collect data suitable for statistical analysis and norm development;
- Provide the human instructor with a meaningful assessment of trainee performance at a particular stage of instruction, as well as an overall assessment;
- Provide positive and negative feedback and annotated replay;
- Provide adaptively tailored learning materials.

Distinguishing all these capabilities makes it clear that the specification of the raw performance data which the system is to collect requires detailed task analysis, and further that these data must be analyzed in various ways to serve meaningful ends.

Task Analysis. The CBI system designer is at a great disadvantage with respect to other training program developers. When one has a human instructor to deal with, one can simply say, "teach this." The computer is obviously unable to do that. It can be a profound shock to the subject matter expert (SME) to find that the task analysis has to be specified to an incredibly detailed level to satisfy the needs of the CBI system. In fact, SMEs are asked to quantify those qualitative judgements which they make almost automatically. This can prove to be very difficult. The system designer must be especially sensitive to the fact that the SME is being asked to think in a new way and that revisions to the task analysis outcomes will be inevitable.

Measures of Performance. On the one hand, statisticians have demonstrated that the overall performance evaluation an expert instructor provides can be emulated by considering only a very small number of measures of performance. Statistical techniques like these are very useful for the specific purpose of providing an overall grade. However, it would be a mistake to conclude that other measures were of no use. In fact, a rich set of measures based upon the task analysis data is needed to enable the training system to identify the trainee mistakes which lead up to an undesirable outcome and provide indications of correct procedures.

Like any test items, these performance measures must be tested, validated, refined, and tested again. When this has been done, it is necessary to combine the measures to provide various overall measures of trainee performance. Again, these combined measures must be validated and refined. It is foolhardy to ignore this basic principle of test instrument development just because the test items do not look like standard test items.

The validation procedure may reveal problems not encountered in the validation of standard items. For example, in evaluating ongoing performance, there can be a "domino effect" in which failure on one mini-test can cascade and cause other errors to be reported. For example, a procedure may involve several actions which have to be performed in sequence and within a certain time limit. If the learners take too long on the first step, they'll also fail the second and subsequent steps.

Another difficulty which can arise is that, on occasion, the trainee will be unable to perform a required action because another, more important action is required. This can lead to double bind situations in which the system reports an error no matter what the trainee does.

Feedback. Care must be devoted to the design of the feedback given to the trainee. An automated performance measurement system can detect every minute violation of every obscure rule. If the system merely reports errors, several problems arise:

- The feedback can become overwhelmingly negative.
- It becomes difficult for the trainee to appreciate the distinction between serious errors and nit-picking errors.
- If feedback is provided during a performance task, it can be distracting; yet if provided after the problem, it can be difficult to correlate with behavior.
- A special problem which arises in speech recognition based systems is that performance errors can be accumulated due to the fact that the system misrecognizes the trainee's speech.
- The sheer number of error reports encourages the trainee to stop paying any attention to them at all.

Adaptive Learning Material Selection. We have been striving to develop an automated instructional capability which can diagnose problem areas, prescribe remedial work, recommend further practice at a given level, and advance the trainee to the next learning task. A successful implementation depends first of all upon well validated performance measures. Secondly, it requires a thorough understanding of what learning problem a particular constellation of errors represents. This is at best difficult to achieve for a complex performance task.

Computer Based Simulation. Learning a performance task has its purely cognitive aspects, but achievement of proficiency requires practice. Often, supplying such practice can be costly and can even involve safety hazards. Air traffic controller training is an example: the novice controller cannot be entrusted with responsibility for "live" aircraft until he or she has attained to a certain minimum level of proficiency, and yet practice is needed to attain that proficiency. Simulation provides the obvious fulfillment of this training need.

Simulations of operational environments vary in the degree of fidelity which they provide, and the question the training system designer continually faces is: what degree of fidelity in simulation is required to assure transfer of training to the operational environment? To be safe, the designer can specify that a perfect simulation of the environment is necessary. This can not only prove to be expensive, but has been shown to be unnecessary in many cases. Some SOA issues we consider in developing simulations for training systems are described in the paragraphs which follow.

Environment Simulation. Environmental simulations need not be extremely complex to provide sufficient fidelity to assure transfer of training. For example, just because the AIC must learn to control a variety of aircraft which differ greatly in response characteristics, it does not mean a training system needs complex simulations of these various aircraft. The sweep rate on the radar indicator is only one sweep every twelve seconds, and a simple model of aircraft speed and altitude and perhaps radar cross section provides all the information the AIC can normally distinguish on the operational gear. Thus a relatively simple environmental simulation can support training in a cost-effective way. Furthermore, aspects of the environmental simulation can easily be manipulated to vary the difficulty of the training problem in a way that could not be done at all in the operational environment. For example, in the precision approach radar controller training system, wind speed, direction, and gusting characteristics were varied adaptively because this controller's job becomes more difficult in windy conditions. In the AIC training system, more bogeys (bad guys) could be added to increase problem difficulty without the expense of sending up more F-4s.

Team Member Simulations. The simulation of the other humans who interact with the learner is one of the more interesting training system design problems. The traditional approach of using human pseudo pilots is not necessarily the most effective because these pseudo pilots may not have been trained to respond as a pilot would. Often the trainees themselves take turns serving as pseudo pilots. This is good insofar as the trainee gets some sense of what it is like to be on the receiving end of control information, but it can be less helpful when one trainee acting as a pseudo pilot decides to make life either easy or miserable for his buddy. When the human pseudo pilot is replaced by a computer simulation, control can be exercised over this facet of the environment. In the precision approach radar controller training system for example, pilot ability was an adaptive variable. When the trainee was just beginning to learn the task, a very good pilot was provided. As the controller's proficiency increased, a few poor pilots were introduced to give the trainee experience in dealing with a variety of control situations.

The modelling of these other persons in the environment requires that mini task analyses of their respective jobs be conducted as well. The cost of this analysis is easily offset by eliminating the need for pseudo pilots, and a significant training advantage is gained in being able to control the responses of these simulated individuals.

Automated Speech Understanding

Speech understanding is a far more difficult technical problem than speech generation. There are two main aspects to it: speech **recognition** (performed more or less accurately by hardware devices), and speech **understanding** (the process of making an appropriate verbal or other response based upon the speech input).

The advent of the speech recognition technology has led us into new realms of adventure in training automation. It made it possible in theory to automate the training of the primarily verbal tasks of the air traffic controller. If the computer can understand the controller's advisories, it can effectively simulate pilot responses and obviate the need for human pseudo pilots in training. In our attempts to do this, we have learned a bit about how to evaluate a speech understanding application on the one hand and how to assess hardware speech recognition systems on the other. The speech understanding concerns are discussed immediately below. Speech recognition device concerns were presented in the NEW HARDWARE TO USE section under *Speech Hardware*.

Speech understanding, as defined above, refers to the entire process of responding intelligently to speech inputs. This involves determining what was actually spoken, and then generating appropriate verbal replies and queries, and modifying the simulated environment. The problem of determining what was actually spoken is necessitated by the fact that recognition errors will occur. Manufacturer's claims of 99+% speech recognition accuracy will probably not be realized, especially in the training environment where the trainee is just learning a verbal task. Thus, it is crucial for the speech understanding algorithm to expect misrecognitions and to check on the reasonableness of any input before taking action on it.

In our experience in the automation of this kind of training, where the trainee is engaged in a performance task and the computer is providing the simulated environment, there is a great deal of information in the system which can be used to check the reasonableness of an input and either automatically correct the input or request that the trainee "say again." This latter technique has to be used with caution, for there is nothing more frustrating than hearing the computer repeatedly demand a repeat.

When the system designer is faced with the need to incorporate a continuous speech recognition device, the speech understanding problem becomes vastly more complex. The training system developer must be aware of this fact. The decision to use such a device must be based not only upon user acceptance considerations, but also upon ability to employ talented software engineers to design the speech understanding software and the ability to commit significant computational resources to the speech understanding process.

CONCLUSION

The above discussion of pitfalls and troll bridges in SOA CBI development is not nearly comprehensive, as it reflects only our particular experience with this field. It does show some general principles to keep in mind: use a systematic approach, define your need for and uses of the technologies at the outset; use flexible, creative persons to staff the project; insist on cross discipline communication throughout the project; and leave plenty of resources for iteration and reiteration.

It's also a good idea, when you encounter problems, to try to find someone who's been there before so you can avoid reinventing the wheel. There will be plenty of new mistakes left for you to make.

State-of-the-art computer-based instruction systems represent a lot of risks and a lot of work. But, as we have found out, if you're diligent and careful, they're very satisfying to build and to use.

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THE SENSOR IMAGE SIMULATOR

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ABSTRACT

The primary objective of the digital sensor simulation investigations being conducted at the Defense Mapping Agency (DMA) is to establish an editing and analysis capability for the digital culture and terrain data bases. For purposes of quality control and data base applicability investigations, DMA has developed the Sensor Image Simulator (SIS), a very high speed data base edit station and static scene simulator that allows for interactive query and manipulation of individual features in the data base displays and/or simulated sensor scenes to determine the corresponding data base elements responsible for the simulated features. The SIS was installed at DMA in 1981, and is designed to play a key role in determining the applicability of prototype data bases for use in advanced training simulators, as well as to ensure the quality of, and coherence between, the various digital data bases prior to new data insertion into the master cartographic data base files.

INTRODUCTION

The primary objective of the digital sensor simulation investigations being conducted at the Defense Mapping Agency (DMA) is to establish an editing and analysis capability for the digital culture and terrain data bases. These data bases are being produced by DMA to support advanced aircraft simulators by providing an improved high, medium and low level radar training capability offered by the digitally generated radar landmass images. As a result of the technology developed for the aircraft simulator support, sensor guidance reference scenes are also being generated.

In addition to radar scenes, visual and multi-sensor scenes are being digitally generated. For purposes of quality control and data base applicability investigations, DMA has developed the Sensor Image Simulator (SIS), a very high speed data base edit station and static scene simulator that allows for interactive query and manipulation of individual features in the data base displays and/or simulated sensor scenes to determine the corresponding data base elements responsible for the simulated features (see Figure 1). The SIS was installed at DMA in 1981, and is designed to play a key role in determining the applicability of prototype data bases for use in advanced training simulators, as well as to ensure the quality of, and coherence between, the various digital data bases prior to new data insertion into the master cartographic data base files.

DATA BASE CONTENT

The current DMA standard production data bases (Level I) contain large area cultural information and digital terrain data sampled at a 3" interval. The cultural data consists of point, linear, and areal features described by characteristics such as surface material category, generic identification, predominant height, structure density, and percentages of roof and tree cover. The cultural data is in lineal (planimetric boundary) format and, although feature sizes may vary depending upon local circumstances, reflects a resolution on the order of 500 feet. Smaller features are aggregated into homogeneous features described by predominant characteristics. The current high resolution (Level II) data bases contain small area cultural information and digital terrain elevation data sampled at a 1" interval. This translates to a resolution of about 100 feet, with smaller features aggregated. Detailed information is available in "Product Specifications for Digital Landmass System (DLMS) Data Base" (1).

The terrain elevation data is produced by contour digitization from charts or directly from stereo pairs of photographs using advanced analytical stereoplotters. The cultural data is produced from both charts and photographs with a much higher level of manual effort required in order to perform the complex feature analysis. Because of the labor intensive nature of the task, the production of Level II cultural data ranges from 10 to 50 times the production cost of Level I data, depending upon the area. The current Level I data base program covers roughly 24 million square nautical miles, with estimated data base completion dates in the 1985 to 1995 time period. Level II data is programmed only for small selected areas of interest.

The DLMS data bases have been shown to be adequate for support of long and medium range radar simulation, and for short range radar simulation where Level II data is available. In addition, these data bases have shown some applicability for multi-sensor simulation (3,4).

THE SENSE SYSTEM

SENSE (2) is a software package developed for sensor simulation investigations by the Defense Mapping Agency Aerospace Center. A powerful simulation tool, it runs in batch mode on one of DMA's Univac 1100 series computers,

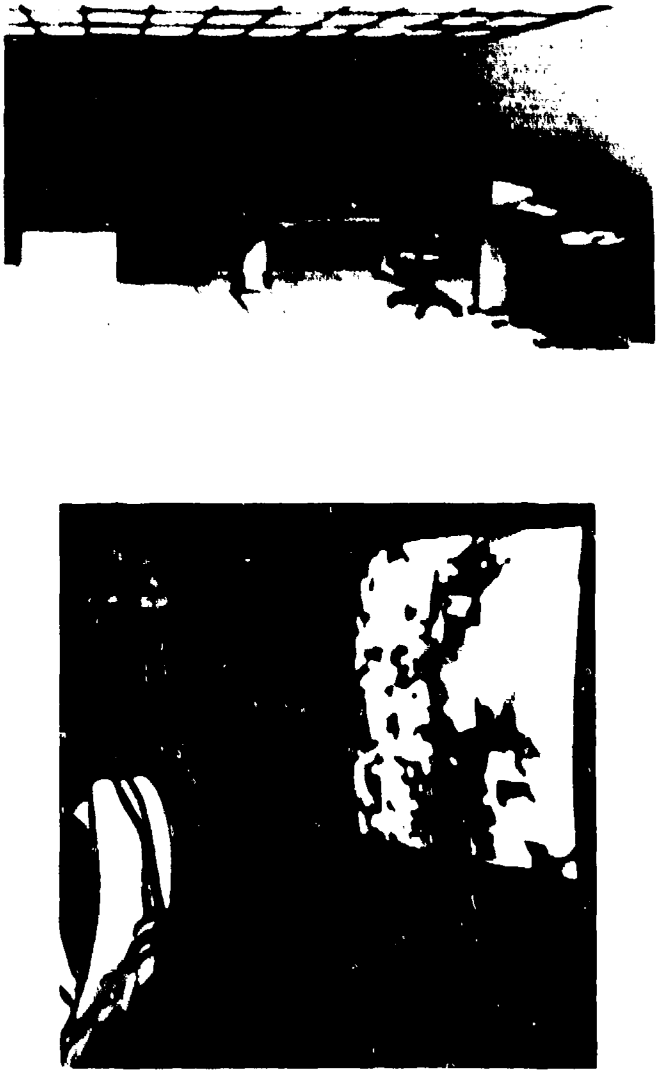

Figure 1. The Sensor Image Simulator

The SENSE process begins by defining the area for which an on-line data base is to be constructed. Either center coordinates and areal extent or limiting geographic boundaries may be entered. In both cases, output spacing is specified. Transformation to a local coordinate frame for a number of point coordinates may also be specified.

The second step in the process is concerned with transforming the off-line data base to on-line format. Two formats for input terrain (i.e. DLMS or DMA standard) may be accepted. The latitude and longitude boundaries of the area are also input. For the input cultural feature files, a variety of options may be exercised to define which manuscripts or features are to be utilized. Synthetic feature breakup of the data base in accordance with feature characteristics may also be specified. Output displays for terrain, culture or merged data may be generated for the line printer or an Optronics film recorder. The principal output of this step, however, is the on-line data base in blocked matrix format.

Once generated, the on-line data base may be processed by four separate program structures; (a) the data base may be reblocked to provide an on-line data base of different spacing, (b) it may be input to a plot module to provide a variety of plot types, (c) it may be unblocked to provide a single large data base, and (d) it may be used as the input for sensor simulation software.

For sensor simulation, considerable variation in the SENSE output is possible by appropriate selection of input variables. These include:

1. Input data base characteristics and portion utilized.

2. Sensor coverage and characteristics (type, receiver characteristics, antenna pattern, etc).

3. Constants defining sensor position and the projection coordinate transform.

4. Weather options and atmospheric variables.

5. Output plot options.

A number of deficiencies result from the computer environment in which SENSE operates:

1. DMA's 1100 Series computers cannot be totally dedicated to quality control/validation.

2. The system is not interactive; editing is therefore not feasible nor are the results of processing stages immediately available.

3. Both the off-line to on-line transformations and sensor simulation tasks are slow (typically 10-30 minutes).

4. Program structures are not optimized.

THE SIS CONCEPT

The natural evolution of sensor simulation at DMA led to the design and fabrication of the Sensor Image Simulator (SIS), a dedicated minicomputer-based image processing system capable of performing simulations in an interactive mode.

The SIS brings together, in a self-contained integrated hardware/software facility, a significant capability to evaluate the DLMS data base. All operations are conducted under interactive control. Both the software structure and operations sequence reflect a top-down implementation philosophy wherein principal control functions are resident at the top of the hierarchy and functions concerned with processing individual data elements (I/O, computation, etc.) are at the lowest. The system is implemented in such a fashion that future changes in processing can be accomplished at the highest level of system software support.

Basic input data to the system consists of the off-line DLMS data base tapes and operator commands specifying which tape data available is to be transferred to secondary storage (the system disk). Editing commands revising the off-line data (on secondary storage) may also be utilized, and a designated portion of the changed data may be transferred back to tape, with appropriate optional diagnostics documenting transfers in either direction.

Once resident on the system disk, any portion of the off-line data may be transformed into a viewable on-line format. In order to permit viewing of the data base, a sensor module must be specified to transform feature data to sensor-related quantities (reflectivity, albedo, etc). The local coordinate transform may also be specified. The on-line version is constructed in such a fashion that the operator may easily interrogate and change the data base and relate these revisions to the off-line data base.

The final step of processing under normal interactive control is concerned with sensor simulation. Two types of scenes are generated during this stage. The first of these (selectable by the operator) is the perspective view. This option permits selection of position and line of sight for mapping the (three dimensional) data base into the observer's image display coordinate frame. The second type of scene generated is the sensor display. Data used is common to that generated for the perspective view. Modifications which may be introduced into the sensor display include sensor parameters (e.g. beam error) and sensor display variations (e.g. gain). An important characteristic of the display transform is that the operator can easily establish the relationship between the sensor display and the on-line data base.

In addition to the processing stages (including editing), normally under operator control, software development and maintenance is also an interactive function using the system's text editor and FORTRAN compiler.

SIS OPERATIONS

The Sensor Image Simulator performs five major functions:

1. Digital Data Base File Input and Output. The capability of loading operator designated sections of the DLMS off-line data base (both terrain and/or culture files) onto the system secondary storage device is provided. The

capability also exists to off-load such data (including modifications) onto tape in DLMS standard format. A line printer listing documenting the loading process may (at the operators discretion) also be provided.

2. Off-Line to On-Line Transformation. The SIS system performs the processes (coordinate transformation, area fill, etc.) necessary to transform the off-line DLMS data base, stored as described above, into an on-line format capable of being viewed, and modified by the operator, as well as used in subsequent stages of processing. The transformation is accomplished in approximately two minutes for a 1°x 1° Level I area.

3. Sensor Simulation. The SIS facility generates simulated sensor displays using the on-line data base. The system is structured such that data from intermediate stages of processing is available for viewing and/or the introduction of operator controlled variations.

4. Interactive Data Base Editing. As a quality control tool for DLMS, the SIS provides the operator with the ability to both define the characteristics of and modify the three principal data structures present (off-line DLMS, on-line DLMS, and the sensor display).

5. Software Development and Maintenance. In order to provide the future evolution of sensor simulation, the SIS is structured to permit changes in function by modification of the appropriate software module/sub-modules affected. Whole modules may also be inserted or removed. This allows for variation in future data base formats. The commercially supported real time multi-tasking operating system supports software development via system utilities (text editor, assembler and FORTRAN compiler).

SIS HARDWARE

The SIS hardware may be discussed in four general areas (6).

1. Host Computer. The host computer is a Data General "Eclipse" S/250 with integral array and floating point processors.

2. Soft-copy Image Display Subsystem. Data base and sensor images are displayed on either the Aydin 8026 Color Monitor or the Aydin 8037 Monochrome Monitor. Both units display 1024 x 1024 images and are controlled by the Aydin 5116 Display Editor Keyboard and Joystick and the Aydin 5216 Display Computer. Graphic data may be displayed on the Tektronix 4006-1 Graphic Display Terminal.

3. Hard-copy Image Display Subsystem. Color hardcopy images are obtained from the Matrix Instruments 4007 Color Graphic Camera yielding both 8 in. x 10 in. instant copy and 35mm film output. For quick inexpensive monochrome copy, the Tektronix 4634 Video Hard Copy Unit is used.

4. Peripheral Devices. The SIS configuration is completed by the following peripheral devices:

a. Analogic AP400 Array Processor.

b. Data General 6026 1600/800 FPI Tape Unit.

c. AVIV TFS 706-125 6250/1600/800 FPI Tape Unit.

d. Data General 6061 190 MB Disc Storage Unit.

e. Data General 6070 20 MB Disc Storage Unit.

f. Data General 6040 Terminal Printer.

g. Teletype 40 Line Printer.

SIS SOFTWARE ARCHITECTURE

The development of software for SIS was determined by the following requirements:

1. The software structure must be user programmable to support changing data base and sensor support requirements.

2. The throughput capabilities of the hardware elements of the system must be accessible at the highest levels of software development.

3. User interaction with the system must be accomplished in such a fashion that personnel not intimately familiar with digital processing are capable of utilizing its functions.

Orderly development of SIS software was accomplished via a top-down implementation philosophy wherein the software structure is strongly reflected in the operations sequence. All application functions are accomplished via interactive control. The hierarchial system structure guides the operator in defining a processing requirement with an increasing level of detail until all necessary parametric entries are available. The defined processing then takes place, after which the operator is given the choice of returning to a higher level in the system or repeating the processing sequence with a redefined set of parameters.

Accommodating a variety of users within the system has led to the development of entry and menu display software which combines fail-safe operation and comprehensive explanation capabilities with features designed to reduce redundancy for highly knowledgeable personnel. Although the principal application language is FORTRAN, the decoding of operator entries is handled via application routines rather than standard FORTRAN formatted I/O. Thus, the detection of errors may be handled by the application program, rather than at the systems level thereby avoiding execution abort due to input error. In addition, the operator is given the opportunity to revise entries before proceeding (via a simple carriage return on the system console). At the level where a large number of entries (each with a variety of possible settings) is required, submenus for each parameter are not initially displayed unless requested by the operator (by simply entering the parameter number). In addition, an entry of several parameter values may be made simultaneously with repeated menu displays. At the same time, a detailed explanation of possible entry values for various parameters is available directly at the system console via a simple procedure for each level of the process.

CONCLUSIONS

The Sensor Image Simulator is designed to play a key role in both the requirements analysis and quality control of the DLMS data bases being produced by DMA. Current investigations are allowing for the development of production quality control scenarios to maximize the capabilities offered by the SIS. The usefulness of the SIS is being expanded through the development of new sensor modules designed to determine data base requirements for a variety of sensors.

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PART TASK TRAINERS:

AN EFFECTIVE MEANS TO MEET TRAINING REQUIREMENTS

By

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ABSTRACT

With the development of increasingly complex weapon systems comes the need to train personnel to operate these systems, which now require an increasing array of aircrew skills. This paper focuses attention on the need for development of Part Task Trainers (PTT) which enable aircrews to acquire these skills in a timely and cost-effective manner. It presents a multidiscipline view of PTTs, as perceived by an Engineering Psychologist, a Fighter Pilot, and a Design Engineer. It briefly reviews the record of PTT development, focusing on the importance of front-end analysis of training requirements as the basis for considering and selecting training approaches that may effectively be met by PTTs. Target areas for PTT applications are discussed and proposals are offered for the development of some unique PTT concepts including the potential for increased use of generic and specialized PTTs. Potential solutions, cost savings benefits, and improved training expectations are discussed.

INTRODUCTION

Aerospace weapons systems (and military equipment in general) are becoming increasingly complex as growing technology provides increased total system capability. Modern military aircraft employ a sophisticated and complex integration of digital avionics, sensor systems, fire control and weapons delivery systems. The degree of complexity is illustrated by aircraft such as the F-15, F-16, and F-18; sensor systems such as PAVE TACK and LANTIRN; and Precision Guided Munitions (PGM) such as the GBU-15 Guided Bomb and AGM-65 Maverick Air-to-Ground Missile.

Operation of these complex systems requires an increasing array of cognitive, manipulative and psycho-motor skills. Methods for training the associated tasks have received considerable attention, but only recently has much notice been given to organizing the tasks so that specific behaviors are treated in specific devices. For a long time, the main thrust of trainer design has been toward designing for maximum training potential...and a much worn out phrase...just like the aircraft. The response to simulator (training) requirements for the newer sophisticated aircraft has also been generally to produce simulators which will fly like the aircraft. Lacking sufficient quantitative data on training effectiveness, simulator users and developers have played it safe and opted for maximum fidelity in simulator engineering. Simulator technology, particularly in the visual area, has made rapid advances and some current simulator programs are pushing the state-of-the-art, sometimes beyond technology limits. Simulators, therefore, have become much more complex and sophisticated...and increasingly expensive. The new B-52/KC-135 Weapon Systems Trainers (WSTs) are examples of highly complex training devices which are representative of current state of the art for full-mission training. The approach to simulating various subsystems for electro-optical(EO)/infrared imaging, fire control and weapons delivery has also been driven by a similar desire to replicate the "real-world." Without definitive analysis to prove otherwise, a fully integrated system has generally been the requirement. This approach is usually based on the general user feeling that only a "fully operational" cockpit will provide effective training.

Recent trends in training systems design have therefore emphasized the large WST systems with intensely accurate visual and sensor simulation subsystems that attempt to emulate the "real-world" environment. This can result in a costly development and production program when (for example) Forward Looking Infrared (FLIR) or Digital Radar Landmass Simulation (DRLMS) is required to be integrated into an existing simulator to produce full-mission simulation over an extensive gaming area. We believe that not enough consideration has been given to identifying related sets of training requirements suitable for smaller, less complex devices to be used as PTTs. This paper focuses attention on the possibilities for part-task training to cost-effectively train many of the unique and complex tasks associated with the operation of modern aircraft and their weapons systems.

Basically, the USAF defines the use of trainers into several categories. Weapon Systems Trainers (WSTs) are the most complex (and expensive) simulators, but they permit each crew member to practice a full-mission task and become proficient in a very realistic environment. Operational Flight Trainers (OFTs) provide training in basic flight maneuvers and aircraft systems operation as well as normal and emergency procedures. Cockpit Procedures Trainers (CPTs) permit pilots to develop proficiency in routine procedures and to react to emergency procedures like engine failures, fire or electrical malfunctions. Cockpit Familiarization Trainers (CFTs) provide basic practice on location of switches and indicators, and are normally used to initiate pilot training for a particular aircraft. Part Task Trainers (PTTs) permit crew members to master and maintain currency in specific tasks like aerial refueling, gun sight dynamics, sensor system interpretation or system tuning. Such mastery can often be achieved in less complex trainers more effectively than using a single WST or OFT. This becomes particularly important when acquisition and maintenance costs limit the quantity of trainers and result in training "bottlenecks."

An operational definition that we have come to use for PTTs is: a device, limited in scope, that is designed to treat a specific set of behavioral events that will...at some time...be integrated with other behaviors to perform a broader task. Part Task Trainers are not new; in fact, they represent possibly the earliest form of "active participation" training aid to be employed (WWI Aerial Gunnery). Groups of PTTs have been known as trainer "families," "building blocks," and more recently "modular" approaches to training. Some recent PTTs have also become large systems, nearly as complex as WSTs...because of the extensive list of cues apparently required by the training task. An example of a complex PTT is the B-52 Aerial Refueling PTT (by Redifon), which has a full cockpit with a Duoview visual display system mounted on a hydraulic motion base (Figure 1).

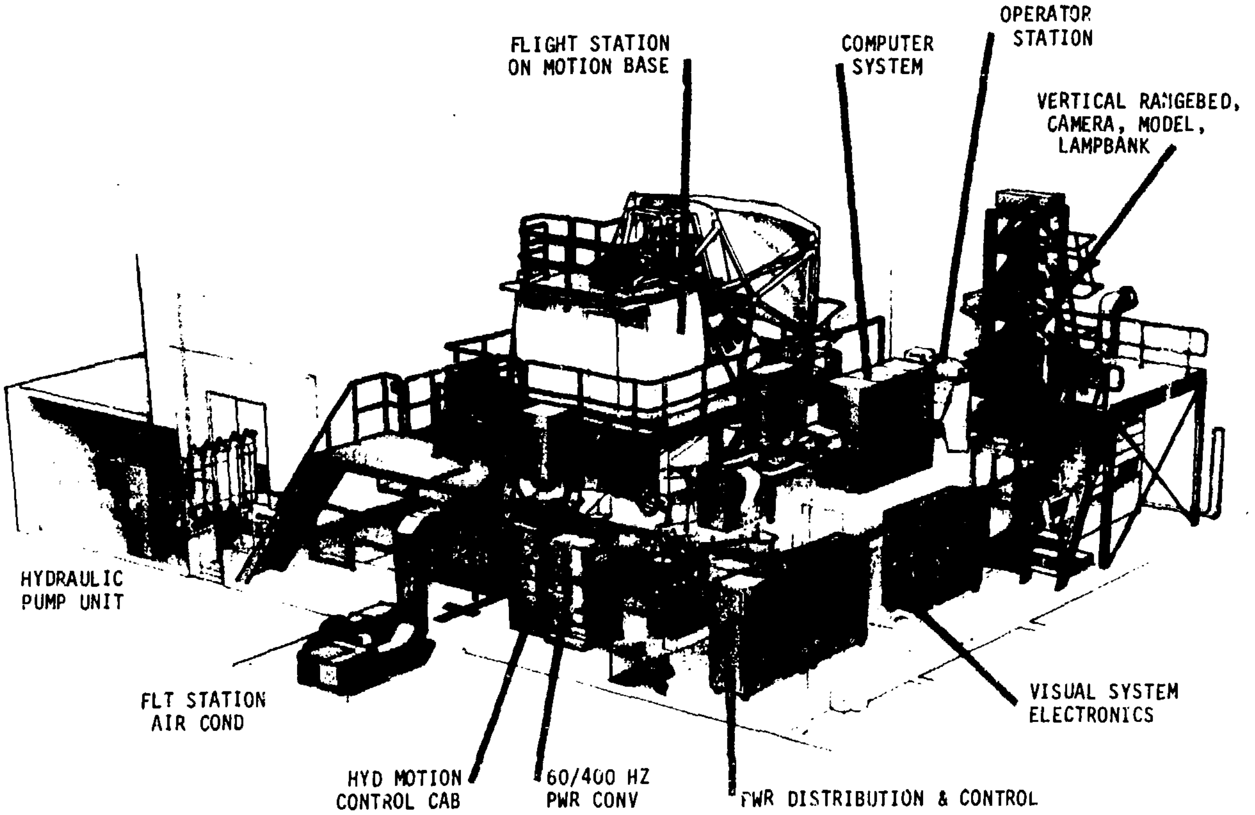


Figure 1. B-52 Aerial Refueling Part-Task Trainer

The KC-135 Boom Operator PTT (by ASD and SRL), with a true perspective visual display and range bed camera/model image generator, represents an intermediate level of PTT complexity (Figure 2)(4). The Functional Integrated Systems Trainer (FIST) (by SRL) for the AC-130H Gunship is another example of a medium complexity PTT (Figure 3)(2). This PTT is somewhat unique because it provides for simultaneous training of tasks associated with several crew stations, and is the equivalent of multiple interconnected part task trainers. The recently delivered F-106 Aerial Gunnery PTT (AGPTT) (by Honeywell) represents a part-task training system of modest complexity (Figure 4). Prior to AGPTT development successful construction and use of the MA-1 Fire Control System PTT for F-106 aircraft demonstrated a high training value in proportion to overall size and facility requirements (Figure 5)(16). The prototype ARN-101 Navigation System PTT for the F-4 aircraft represents a smaller, but fully interactive training device (Figure 6). This PTT is an attachment for existing ARN-101 mission data preparation consoles, utilizing spare computer capacity for training the aircraft system operation. The smallest part task training devices are represented by the desktop EW trainers produced by several different companies. They allow interactive student instruction not possible with video tape or classroom lectures.

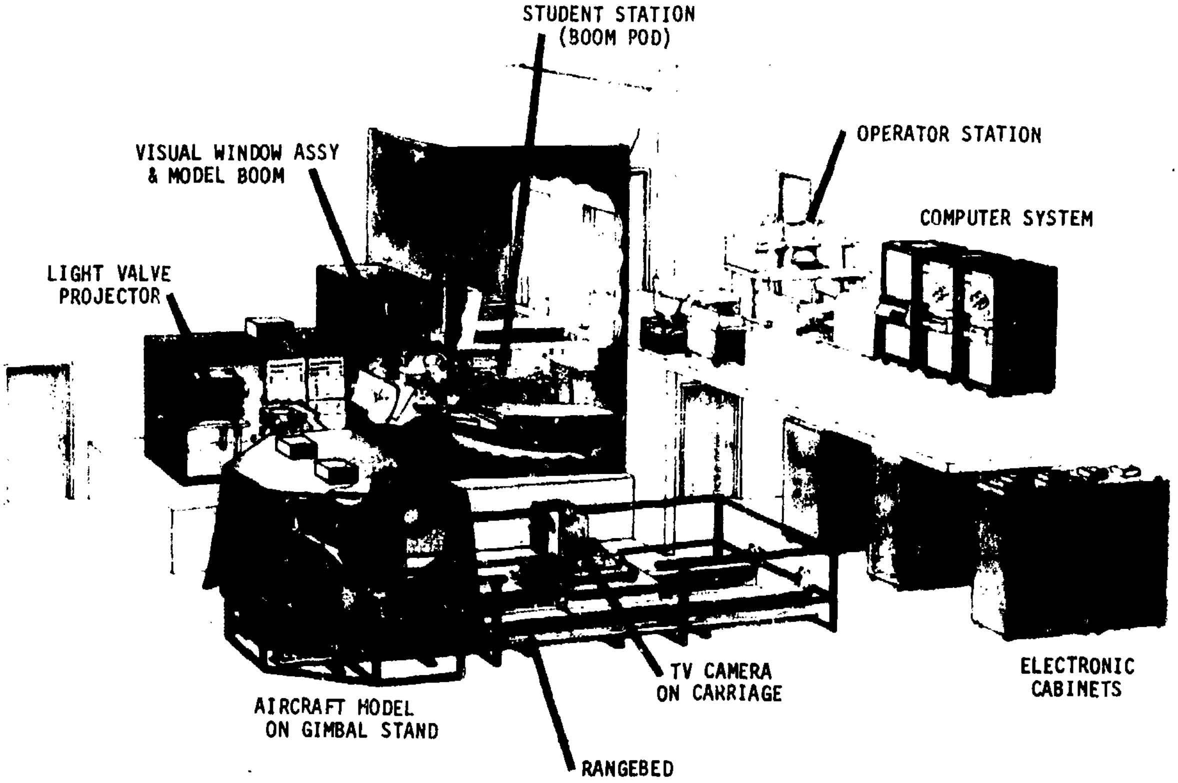


Figure 2. KC-135 Boom Operator Part-Task Trainer (BOPTT)

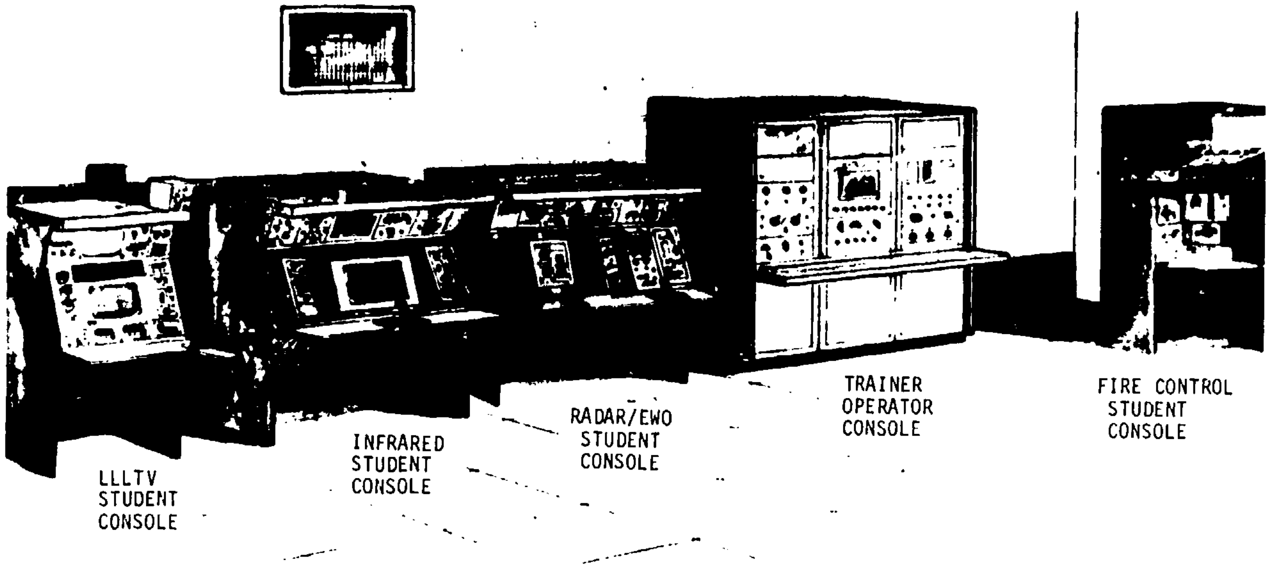


Figure 3. AC-130H Functional Integrated Systems Trainer (FIST)

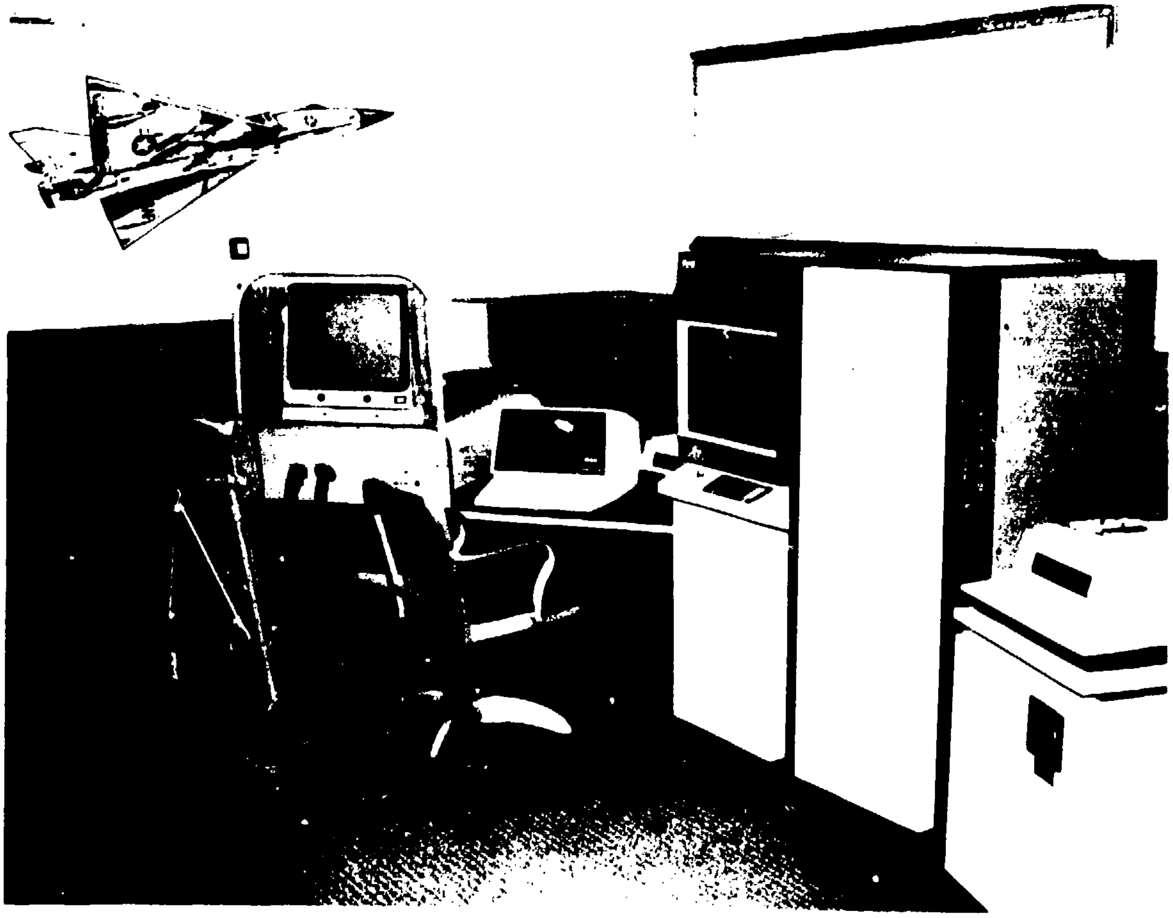


Figure 4. F-106 Aerial Gunnery Part-Task Traine. (AGPTT)

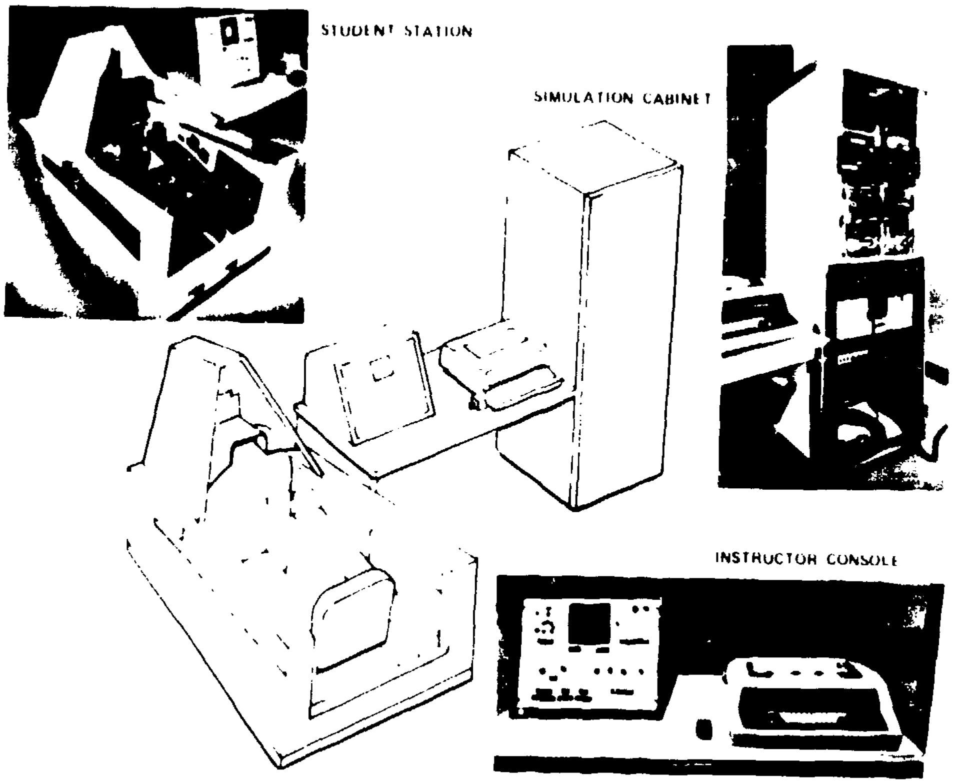


Figure 5A. F-106A MA-1 Radar/IR Part-Task Trainer

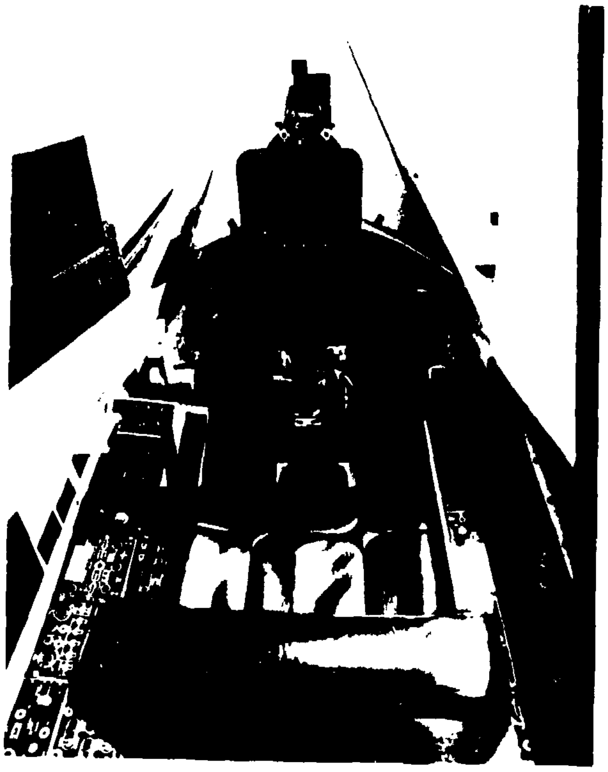


Figure 5B. Cockpit Interior

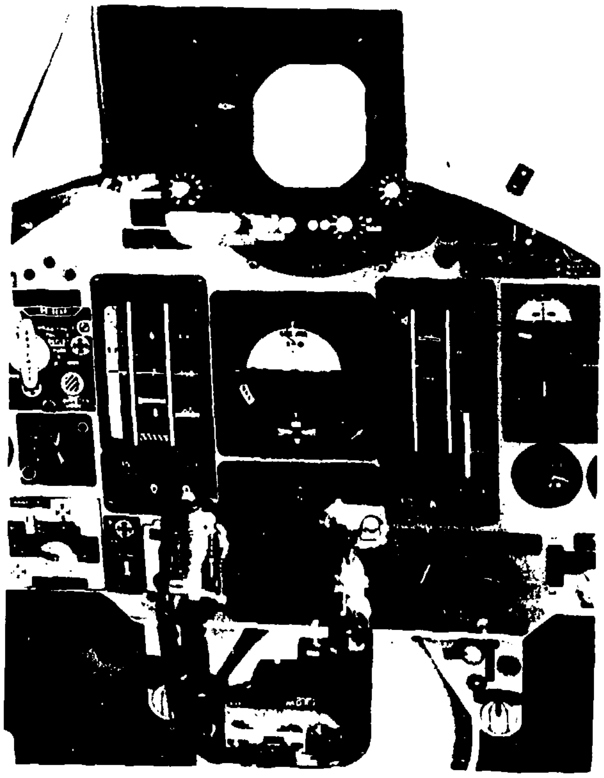
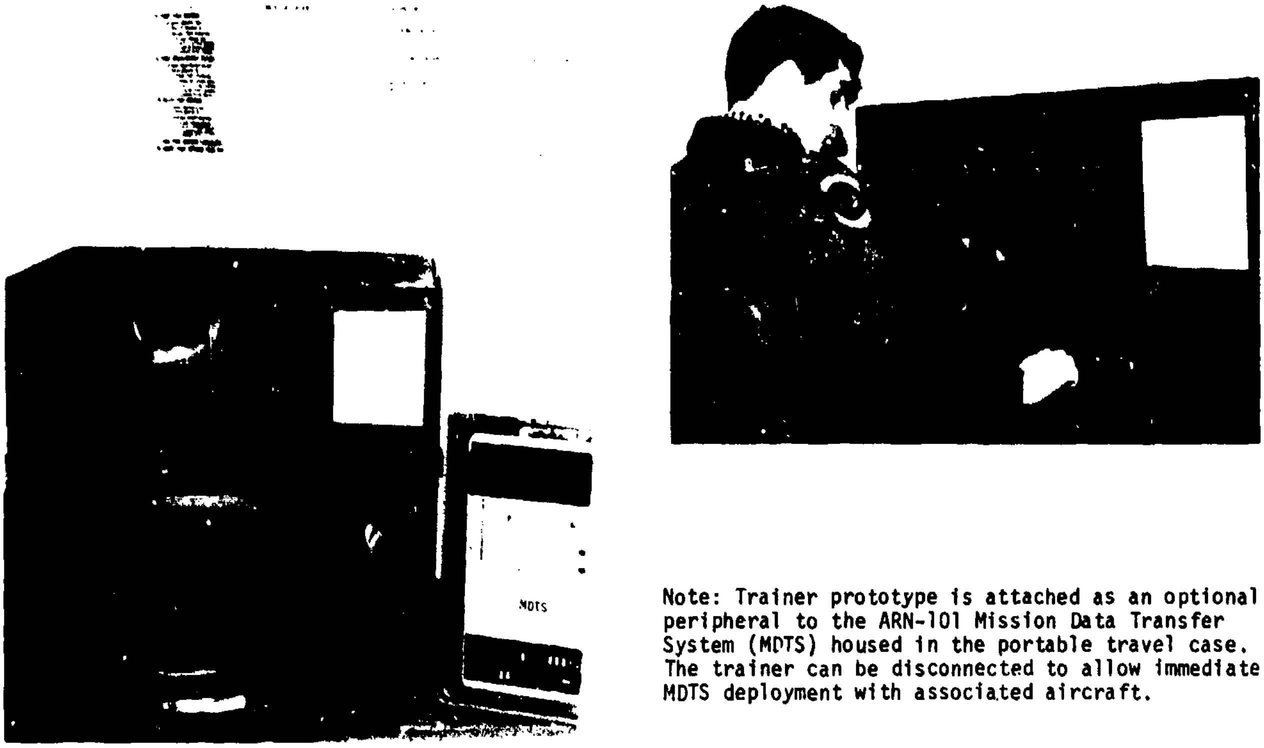


Figure 5C. Control Stick and Radar/IR Display



Note: Trainer prototype is attached as an optional peripheral to the ARN-101 Mission Data Transfer System (MDTS) housed in the portable travel case. The trainer can be disconnected to allow immediate MDTS deployment with associated aircraft.

Figure 6A,B. ARN-101 Navigation System Trainer Prototype

In a time when worldwide commitments for short notice deployment are typical of operational requirements, the status of crew daily mission readiness could be determined by the regular use of a capable, effective training system. The capability of the training system is frequently driven by cost considerations and the time required to manufacture and deliver a system. The future looks like a move is appropriate toward more low cost devices available to more students simultaneously. This approach would enable better use of fewer high cost, full-mission trainers. By using a family of modular training devices, the training and operating commands could have a better potential for keeping the air crews mission ready, while reducing the training backlog created by the part task use of scarce WSTs (where available) and eliminating the reluctant necessity to do "training" in powered-up aircraft parked on the ground.

THE FRONT END PROCESS

From the early start of the Systems Approach to Training (SAT) (19) in the Air Force through growth of the Instructional Systems Development Process (ISD) (24), emphasis has been given to development of the academic process. Analysis of training requirements concerned teaching steps, course content, supporting equipment and media mix. From some of the comments by Montemerlo (13), the Navy took similar approaches. Acquisition managers picked up on the process and wrote training requirements into need documents as though the ISD process was designed to describe training in terms of specific equipment and technical approaches to trainer design. The ISD task analysis was not designed to define performance specifications for training devices. As a result, much interaction has occurred in each of the services about how to accurately and completely provide training requirements to trainer acquisition managers in terms useable by design engineers and program managers. Additionally, we in the USAF simulator acquisition business have sometimes found it difficult to get the simulator user to choose a set of training tasks (or cues) realizable with near-term technology...and within available fiscal constraints. Although the acquisition management process has been amply "procedureized," the needed work to tie training analysis and acquisition management processes for training devices together is still in a growing stage.

Growing interests in clarifying initial descriptions of training requirements and updating on-going training has come from in-depth studies of the analysis process. The current term for this evolving process is being called front-end analysis (FEA) (8, 14, 15, 18, 23). In fact, what is happening is a closure of awareness between training managers, design engineers and acquisition managers of the varying approaches each takes toward doing their part of delivering a useable training device. By somewhat getting into each other's business, we are, in fact, beginning to understand the larger process.

Since training analyses were not designed to specifically describe training devices, a holistic view has existed that designing a trainer to meet most training event requirements was the best approach. This generally led to the evolution of designs for OFTs and WSTs.

For several existing weapons systems, PTTs were designed to deal with specialized training needs that either could not be satisfied in the WST or that saturated the WST schedule while doing skill level training. As overall skill levels increased, training managers found the PTTs to be useful assets and relatively easy to maintain. Successful use of these PTTs (such as the F-106 Aerial Gunnery PTT) has spurred many discussions and proposals for use of PTTs, and has caused the Aeronautical System Division's Deputy for Simulators (ASD/YW) to place more emphasis on the use of PTTs as alternative solutions to training requirements. Additionally, the current economic situation is driving consideration of low cost training devices as interim solutions to training requirements.

The USAF approach to developing technical solutions to training requirements has been couched in a multi-discipline team approach to provide functional specialists to analyze the requirements. The team performs an evaluation at an early stage in evolution of the weapon system or changing mission. This team then utilizes their collective experience and the wealth of available information on simulator design to look for innovative solutions to training requirements. In addition, they are guided by documented policy to ensure that Air Force goals in training, supportability, costs, etc. are met. A program is now underway to develop a systematized concept for analyzing training requirements and comparing the analysis to various technical solutions. Using models that may be automated, an iterative cycle of analyze-compare-analyze-compare will occur until functional managers are satisfied that the best alternatives have been described.

It is in participating in the FEA process that the authors have perceived the forthcoming impact of digital avionics and "smart" weapons systems on training requirements, have seen the opportunity for PTTs to meet these requirements and have seen the need for the tri-services and industry to look for some common ground in the development of training devices for these systems. As a start point, we now need to consider some of the tasks and system applications common to modern weapons systems which are particularly applicable to PTT solutions.

SOME TARGET AREAS FOR PTTs

Many of the newer airborne weapons systems possess a high degree of complexity but have similar components. Features such as digital entry keyboards, displays, computers, laser rangefinder/designators, radars, and inertial navigation interfaces, provide some possibilities for cost effective combinations or re-use of engineering effort to model and simulate one particular system. Most new systems are also controlled by a digital computer, which can facilitate the resolution of interface problems. These weapons systems are also intended to be "modular" or "add-on" in nature, a feature that should also lend itself to the concept of a PTT for the weapon. To illustrate possible use of PTT's for these systems, some selected tasks and system applications are described in the following paragraphs.

Task Difficulty/Training Time:

In modern aircraft, despite the technological sophistication, or perhaps because of it, there are an increasing number of tasks which take a disproportionate amount of time to train. In other words, a student will spend extra missions in a simulator to reach the required performance standard in a few tasks, each of which may occupy only a short time in the real-world mission. Additionally, the demands of the more difficult tasks may be such that the student's necessary attention to other tasks is degraded, thereby reducing the total value of the training session. Some of these tasks, such as air-to-air target tracking and air-to-ground weapons deliveries, traditionally require extensive training in the aircraft. With modern simulator technology they can be trained in a simulation device, and because of their criticality and required training time, might well be trained in a PTT. Other unique tasks which require considerable training time, mainly in initial training, include Heads Up Display (HUD) interpretation, Hands on Throttle and Stick (HOTAS) operation, radar and Infrared (IR) image interpretation, PGM operation and control, Inertial Navigation Set (INS) operations, and Electronic Warfare (EW) operations. These are the more obvious tasks; for each aircraft there may be unique tasks which require extensive training time. Provision of PTTs for these types of tasks should reduce total WST training time and therefore reduce required WST numbers. However, analysis of student throughput rates, task training times, training device costs, initial versus continuation training, etc. will be needed to provide the correct mix of training devices.

Visual Discrimination Tasks:

There are many operational tasks which require a high degree of visual discrimination. While some aircrew members may have a greater inherent ability for visual discrimination, the more difficult processes have to be learned through practice and knowledge of the mechanisms by which the visual image is received. These visual discrimination tasks involve out-the-window scenes as well as imagery presented on various cockpit displays such as radar and IR. Although out-the-window discrimination tasks such as low-level flying could merit some discussion, we will consider only the on-board imagery such as radars, EO, and IR. In general, the development of high fidelity simulation of this type of imagery is extremely expensive. However, depending on a complete analysis of the primary task requirements and any associated tasks, it may be possible to train the basic task on a PTT, using such media as slides, videotapes, movies or a combination of media. A complete training program including lecture, written and PTT training will insure that the aircrew member, upon reaching the simulator or aircraft, does not spend a disproportionate amount of time on visual discrimination tasks.

Further complications arise when considering the provision of simulated radar and IR imagery in a WST. The question of fidelity becomes vital, because for some visual discrimination tasks, negative training could result from poor simulation. State-of-the-art radar simulation is generally regarded as providing positive training for the radar discrimination task; FLIR interpretation is a more difficult technical challenge to train by simulation. "Real-world" IR imagery has a high dynamic range, and the variable scene conditions, weather effects, time of day, seasonal effects, and other peculiarities are very difficult to simulate fully. At present, no system can provide full training for IR imagery interpretation while simultaneously allowing random low-level flight over a large gaming area.

It may be more cost effective, or simply provide better training, to use a PTT device for IR imagery which uses videotape or film to provide real-world training in IR interpretation for a limited gaming area. Further analysis will indicate the degree of interaction of other tasks with the discrimination task. Frequently there is a requirement to lock-on to an image so that lock-on parameters can be fed to the aircraft's navigation system. The trainee may learn to lock-on to a representative image in the WST while the target discrimination task is trained separately on a PTT. Alternatively for full-mission training in a WST, it may be possible to reduce the cost of radar and IR simulation by confining the high fidelity simulation to limited gaming areas or corridors, with a lower fidelity generic simulation elsewhere, so that the trainee having learned target discrimination on a PTT, need spend little time actively performing this task in the WST. For simulator mission training and evaluation, the aircrew need only perform the task in defined critical areas such as navigation way points and target discrimination. It may also be cost effective to use the aircraft system for final training and validation. Finally, as will be discussed later, there are a number of PGMs which utilize visual displays, and whether integrated in a WST or as stand alone PTTs, the requirement to train the visual discrimination task will need a critical analysis. Many of the above considerations could well apply.

Mission Critical Tasks:

Part task training is particularly applicable to mission critical tasks. These are tasks where successful task execution at the first attempt is essential to mission accomplishment, for reasons of surprise, hostile environment, or other. The following examples illustrate some mission critical tasks suitable for PTT training: PGM terminal delivery/guidance; electronic warfare terminal threat warning recognition; air-to-air gunnery/missile engagements; and FLIR/radar target identification.

With modern PGMs, strike aircraft will carry fewer of these complex weapons (due to weapon cost and compatible stores position availability), so the accurate delivery of a single weapon is inherently mission critical. Targets that would previously have required multiple passes with conventional bombs to assure destruction, must be "taken out" by a single precision-guided weapon. Another mission critical task involves the rapid recognition of a surface-to-air missile (SAM) radar mode change from search-to-track (or especially from track-to-launch) that may be required to save the mission aircraft from imminent destruction. In some cases, only seconds may be available for the proper sequence of recognition/decision/reaction. The air-to-air engagement of an enemy aircraft will almost certainly be mission critical for a fighter aircraft with an air offensive/defensive mission. However, the same task may not constitute a mission critical task for a ground attack aircraft. These are the sort of considerations which must be examined when determining the required type of training devices. The transition between radar and FLIR sensor systems is another task which may be deemed mission critical. The system operator must correctly correlate target appearance on both sensors in minimum time, acquire and identify the proper target so that a successful attack may be completed. Again, there may only be a matter of seconds to correctly carry out this task.

Precision Guided Munitions:

By its very nature the systems application area of PGM training readily lends itself to the concept of part task training. PGMs are add-on weapon systems that, although utilizing aircraft systems and data, and requiring varying degrees of hardware installation in the parent aircraft, may be regarded as complete systems on their own account. Hence, the development of a PTT to train PGM weapon systems readily (and even intuitively) comes to mind. Other factors combine to strongly suggest the development of a PTT to meet PGM training requirements. Many of them utilize high-resolution imaging sensors for target acquisition and homing, and have associated cockpit displays which require the training of operator visual discrimination skills. Some, such as the GBU-15 and PAVE TACK, require special manual skills for tracking and weapon control...skills which are perishable and which require continual training. Usually the delivery of a PGM is also a mission critical task and requires intensive training so that successful delivery of the PGM is virtually guaranteed.

Other factors resulting from the increasing proliferation and complexity of PGMs and related systems need to be considered. Newer aircraft with digital avionics are being developed with provision for a range of add-on systems and PGMs. For example, some tactical aircraft will be capable of carrying the PAVE TACK IR sensor/laser designator, with some combination of GBU-15, AGM-65 Maverick, and laser-guided ordnance. Each of these complex weapon systems requires extensive system knowledge by the aircrew and also requires considerable continuation training in the associated cognitive and manual skills. For example, the HUD and Multi Function Display (MFD) may display different symbology and different alphanumerics for each weapon system. The tracking handle may perform different functions for different systems. Different radar functions will be required to support different PGM operations. Apart from the task of individually learning to operate each system, a requirement to remain current in more than one system also adds weight to a PTT approach. Ideally, crews should be designated for one particular PGM system; however, this may not always be possible. If crews are required to be proficient in more than one PGM system, careful thought will have to be given to the training program so that all the tasks required for one particular PGM system are trained as one training unit. This is to ensure that the operation and interaction of switches, function displays and controls are learned to be associated with that specific PGM system and are not confused with other functions. This training of PGM systems as a separate unit again suggests a PTT approach.

Also, given that the delivery of the PGM is normally a mission critical task, a PTT may well be appropriate so that extensive pre-mission training can be provided on the PGM tasks. Thus, the system operator will be trained and "hot" on PGM delivery tasks prior to each mission. In this context, the possibility of crew room PTTs suggests itself as means of encouraging aircrews to attain pre-mission peaks in their PGM skills. A light-hearted extension of this training system envisions a scene where PTTs, dressed up as arcade machines with flashing lights and sound effects, line the walls of a crew ready room. Utilization would not be a problem!

A major concern for PGMs, of course, lies in the individual weapon cost. With some weapons costing hundreds of thousands of dollars, it becomes a very costly exercise to train regularly using live weapons. Dependent on relative cost, it is likely that a realistic PTT may be more cost effective. However, there may also be a requirement for a PGM training capability to be integrated into selected WSTs for full-mission training. Depending on requirements, a range of training devices including WSTs and PTTs may be required. Some suggestion in regard to mixing WSTs and PTTs will be discussed later.

Digital Avionics:

A major area for PTT application is digital avionics familiarization in both pre-flight and flight areas. Many new systems now require significant data entry (way points, targets, delivery modes, etc.) in the pre-takeoff period, and in-flight data alteration due to mission changes. Modern aircraft, particularly tactical aircraft, can have several of these sophisticated systems arrayed at each crew station (pilot, WSO). The training problems inherent in these systems, which eventually are control centers for all missions, are extensive. A complete understanding of the operating modes, interactions, and anomalies of each system will allow the crew member, with regular practice, to perform the assigned mission task using alternate or backup modes as necessary.

Single copies of unique PTTs for some of these avionics systems have been produced through a variety of means (organizational, inter-unit projects, contractual, research, etc.). Often the driver was a desperate need from the field for an effective means to allow operators to master the skills associated with new, unfamiliar, complex systems. The effectiveness of these part-task devices has usually been high, possibly because the crews perceived a real need for a trainer, and were willing to live with minor inconveniences and non-relevent inaccuracies where correction would have increased trainer complexity and cost. A recent example of such a device is the ARN-101 Navigation System Trainer prototype assembled by Ogden ALC for the Tactical Air Command (TAC). The ALC personnel, with depot ARN-101 hardware and software experience, assembled an add-on crew training device as a peripheral for the existing Mission Data Transfer System (MDTS) already used by TAC aircrews to prepare and load ARN-101 waypoint data during pre-mission ready-room preparation. Since one MDTS will be colocated with each ARN-101 equipped unit, and the MDTS computer system has spare computational capacity available, the construction of an interface assembly to drive a subset of the aircraft mission avionics "black boxes" and indicators has produced a very profitable training device in minimum time with little additional new hardware. The prototype device has received excellent reviews from users, who look forward to the completion of several more of the MDTS add-on trainers. We must be alert to these opportunities to provide current, effective training devices, and attempt to utilize skilled resources (often from existing programs) to assist the timely development of training equipment. This opportunity is often neglected or ignored during aircraft hardware development and integration. By such neglect, the operational user is often denied an effective means of training assigned mission tasks for the life of the weapons system, and may even resort to sending aircrews TDY to the weapons system contractor's plant to train on any available device. Such an arrangement is not attractive to the using command, which experiences loss of aircrew availability and uncertain training effectiveness, nor to the weapons system contractor who is "coerced" into maintaining a training facility... often by conversion of a portion of internal R&D facilities and resources.

Electronic Warfare:

A third applications area where PTTs have already been applied with resounding success is in EW training. Practical EW PTTs have ranged in size from a desktop device (the size of a hi-fi receiver) used principally for equipment familiarization by individual students, to a multi-station, multi-computer driven electronic "classroom," with multiple, individual student positions (Simulator for EW Training (SEWT) (by AAI) at Mather AFB CA). The two basic simulation techniques of software modeling and equipment "stimulation" have been used alone and in many hybrid proportions to produce a variety of EW training equipment. Some of these PTTs can be (or are presently) attached to a WST or OFT to produce a realistic, correlated cockpit EW display as a segment of an overall integrated training mission, or used in a "stand-alone" mode as true PTTs if the scheduled WST training mission does not involve EW in the scenario. An example of such a device is the EW section of the A-10 OFT (Figure 7). Included with the basic A-10 OFT configuration is a dual section console desk/equipment rack, with a sliding partition between the two console sections. Although the computer which operates the EW section is one of several that also operate the OFT, and is not readily separable from the balance of the OFT, the concept of a "modular," multi-use, attachable PTT is worthy of further exploitation. In the example above, the sliding partition allows student and instructor, seated side-by-side, to work closely together without interphones or other distractions for an initial period. When student evaluation is desired, the partition is extended between the student and instructor positions so that the student is not aware of instructor actions except those visible on the student EW displays. Thus, the A-10 OFT (by Reflectone, with EW by AAI) can provide a separate EW part-task training mission to another student when the primary student in the OFT cockpit does not require EW displays.

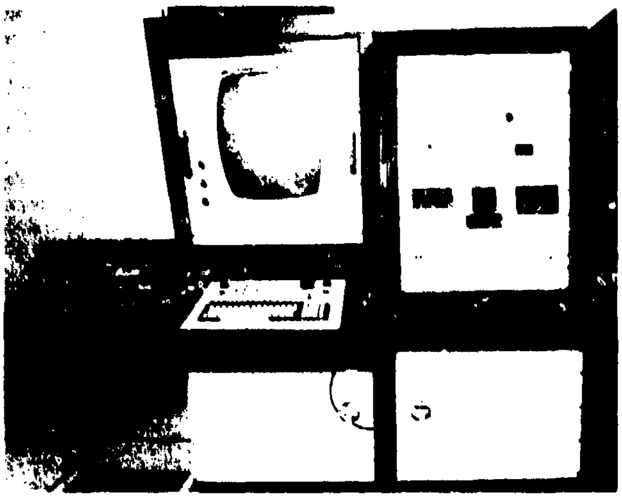


Figure 7. A-10 Operational Flight Trainer EW Auxiliary Station

Recently, a generic EW PTT has been announced (Figure 8) (20). This device is reprogrammable, through its own keyboard (an option with associated optional software), and thus can be self-supporting at individual sites for many aspects of operation. If a careful choice is made for the PTT system components (Computer, displays, interface equipment, etc.), commercial supportability can be facilitated for many years. At the user site, if operational hardware is available, the utility of the device would then be a function of the effort raised by Air Force instructor personnel, many of whom have proven to be skilled innovators in using less capable systems to a greater degree than the designers had expected.

EW PTTs will soon become airborne in an innovative experimental program to provide in-flight training for B-52 Electronic Warfare Operators (EWO) while reducing flight hours in their rated aircraft. The Strategic Air Command (SAC) has proposed the Companion Trainer Aircraft (CTA) program to retain flying hours for B-52 crew training while lowering the operating cost of the training flight vehicle. Initially, two T-39 aircraft will be temporarily fitted with B-52 crew training facilities, including an EWO station with a subset of the EW systems found on the actual B-52. The reduced size of the CTA training station is primarily due to the size limitations in the T-39 passenger compartment. The proof-of-concept EWO station will provide a pre-canned playback of a pre-determined mission scenario, with threat signals appearing at pre-scripted times. The student EWO actions will be noted by the controlling microcomputer and logged on a miniature paper tape printer for post-mission analysis and debriefing. No outside signals are radiated or required. During initial operational test and evaluation (IOT&E), SAC will test whether this simple PTT concept can provide the required training.

Figure 8. EW Part-Task Trainer for Individual Self-Paced Instruction

AN APPROACH FOR CONSIDERATION

We have illustrated some of the areas of modern digital weapons and avionics systems where PTTs can be effective solutions. The point to be made at this stage is that these types of digital systems are being developed at an increasing rate. The use of digital systems, micro-miniaturized computers and technology advancements, particularly in the optical and sensor field has facilitated the rapid development of on-board and modular weapon systems. The adoption of a simulator interface bus could facilitate integration of modular PTT systems in a similar manner as the MIL-STD-1553 Aircraft Internal Time Division Command/Response Multiplex Data Bus has assisted airframe/subsystem integration. An added spur to the development and use of modular systems is the rapidly increasing cost of modern aircraft. With the high cost of new aircraft, we are looking to higher technology to provide improved avionics, missiles and guided weapons to enhance the basic parent aircraft capability. A classic example of this process is the adaptation of the cruise missile to the B-52. For other examples, consider some of the modifications to our current aircraft, such as the F-111F, F-15, A-10, F-18, and another classic example...the F-16...originally designed as a lightweight, visual fighter. This increasing proliferation of digital weapons affects all our Armed Services, and unless we plan carefully, we may well be swamped by the training impact of these complex systems. Already, we are starting to feel the impact. Within the Deputy for Simulators, we have recently considered training devices for PAVE TACK, GBU-15, AGM-65, LANTIRN and the ARN-101 Navigation System. The Navy and Army and other DOD components have obviously been looking to similar training requirements. Since most of these systems require the type of training tasks described earlier, which are particularly applicable to PTTs, we suggest that development of PTTs to meet the training requirements will be effective solutions for cost, schedule and training value. Development of PTTs for these systems should allow for the integration of these devices into a WST to provide full mission training. Ideally, PTTs should be designed to facilitate this integration when and if required.

As a first step, we believe the Services and Industry should collectively expand their studies of unique training problems presented by these weapon systems. Many of the tasks such as the visual discrimination tasks apply across a range of aircraft and weapon systems. There may be some general solutions where a basic development program may provide a solution which is useable on different systems. As a fundamental approach however, we believe that many of these PTTs for digital avionics and weapons systems could be developed according to a modular concept and therefore interface requirements need to be determined and defined across the total simulation spectrum. "Modular" and "standardize" are almost dirty words in the simulator world, so let us point out that by modular we do not necessarily mean two units connected by cables. In our context, modular means a device which can be stand-alone, but is also relatively easy to integrate into a WST or multi-task trainer if required. This concept for PTTs may require considerable innovative engineering for some task combinations. A modular concept for PTTs should provide a great deal of flexibility in the utilization of such devices. As a basic satisfaction of training requirements, it means that the PTT can be used as a stand-alone device...perhaps even in a crew ready room...or it can be integrated into a WST at some central location. Thus, initial and qualification training can be conducted on the PTT, full mission training can be trained on the integrated WST, and continuation training of perishable and manual skills can be carried out on the PTT.

Another benefit of the modular PTT approach is that the developed PTT can be utilized across the range of aircraft which utilize the weapon system. For example, the AGM-65 Maverick Missile is presently used by at least seven aircraft types. A point to be made here is that it will not always be possible for the PTT to have a common interface definition with a series of WSTs, particularly older aircraft WSTs such as the F-4. However, if future PTTs are developed with common interfaces, one side of the interface problem is determined, and a later upgrade or change of PTTs is facilitated. Another benefit of standard interfaces is that it may be useful to combine certain PTTs into a combined trainer to utilize a common student station, common data bases and common display equipment such as radar or FLIR displays (where practical). This would be particularly useful where the parent aircraft utilizes both systems.

The flexibility of modular PTTs should allow them to be relocated easily if a squadron or wing moves or is equipped with a new weapons system. They can also be rotated through operational units (and maintenance/upgrade) on a regular basis. A further refinement could provide that the PTT be designed so that the various PTT components (controls, displays, etc.) fit into appropriate removable blank panels on a CFT or CPT. This would provide an even more realistic training environment.

One approach to assist the modular/common interface problem is for the WST and PTTs to be designed to accept control and interface signals over a standard simulator interface bus. This could give the simulator and PTTs some commonality with the weapons systems being simulated. The parent simulator or PTT may not need to have any actual aircraft avionics control computers within it, because MIL-STD-1553 interfaces for several types of general purpose computers have already been designed, tested, and introduced as standard products (21, 22). These interfaces allow software simulation of functional portions of an active multiplex bus within a general purpose computer, and thereby facilitate interconnection of varying amounts of aircraft hardware such as HUDs, air data computers, stores management system displays, etc., to a basic simulator or PTT (9).

We do not believe that the full potential for utilization of aircraft multiplex bus equipment to augment simulator performance has been examined. Avionics system design adherence to MIL-STD-1553 and other recently published standards may indirectly facilitate the interface of PTTs with one another and with WSTs because of the common design features. These standards are: MIL-STD-1589B (JOVIAL J-73 Programming Language); MIL-STD-1750A (16-Bit Computer Instruction Set Architecture); MIL-STD-1760 (DRAFT) (Standard Store

Interface; Aircraft/Stores Electrical Interface Definition); and ADA (The new DOD standard programming language for command, control, and avionics systems)(3). The impact of these standards on simulation must be thoroughly examined to determine optimal design policies before the increasing development of new weapons systems and the resulting call for simulator upgrades/modifications becomes an avalanche.

THE PAYOFF

The success of training devices is usually measured in terms of cost, schedule, and training value. Training value has various meanings to different people, but generally will include the elements of training effectiveness, aircrew acceptability, and inherent availability. Historically, PTTs have been successful in these areas, probably because they were generally less complex and because they were directed at training one particular task or set of tasks. PTTs of modest scope and complexity have also been successful in terms of acquisition cost and schedule. For example, a recent device, the F-106 Aerial Gunnery PTT, was delivered 2 months ahead of schedule and has received favorable reports from the users. In looking at the impact of an increasing number of complex weapons systems on current and future training requirements, we have described some typical tasks and systems where we believe PTTs will be particularly useful in the future. Because of the scope of these applications, we have also suggested a coordinated and planned effort in the development of these PTTs...including the standardization of interfaces to facilitate integration (modularity). We believe the pursuit of these approaches will provide opportunities for reducing cost and schedule during development and production, while meeting training objectives.

For any new program, the concept envisages a spectrum of training devices, with lesser numbers of complex, costly WSTs...because of the effective use of PTTs to train certain tasks. Ideally, the PTTs which are developed for any program would be modular so that they could be readily integrated with a WST where required. WSTs will still be required for full-mission training, but they will tend to be more centralized, with an optimum mix of WST/aircraft for full mission training. The thrust here is that the WST and aircraft should be utilized more for full-mission training and evaluation than for individual skill training.

One approach to simulator development which has proven useful is to develop the simulator capability either ahead of, or in parallel to the aircraft development (e.g., F-15 program and the McDonnell Douglas F-15 Engineering Simulator). Although this concurrency requires extra cost and coordination, the simulator may primarily be used as a design tool or prototype, and can also be used as a training device for test pilots and initial aircrew cadre. The same principle is very relevant to the development of PTTs. Initial front-end analysis will identify target areas for PTTs (e.g., HOTAS and HUD operations and displays; EW operations; avionics operations and displays). The prime aircraft contractor could be required to build hot mock-ups or proof-of-concept devices for these systems(15). This type of process would have several advantages. The test devices are useful to both the aircraft prime contractor and the aircraft system program office as proof-of-concept for the new systems before design freeze. From the simulator procurement point of view, early involvement of the simulator design team with aircraft development will produce a better, more timely training simulation product. When the aircraft design is "frozen," experience gained with the proof-of-concept devices can then be used as the basis for competitive acquisition of the final training devices from interested simulation contractors. A further advantage of this approach is that the training effectiveness of particular PTTs can be assessed before commitment to a production program. This assessment should include the intended users of the training devices, and should allow some re-definition of training requirements. One result may be suggestions for alternative concepts for production PTTs or WST integrated systems, thus avoiding training devices of low or minimal utility. Because, under this concept, the initial development work on the experimental PTTs may be carried out by the aircraft prime contractor (whose personnel should have maximum access to development data), and because of the early involvement of engineers and others from the government simulator procurement activity (to ensure proper documentation of parameters used for the PTTs), cost and schedule risk for the delivered production training devices should be reduced. There will be some limitations with lack of problem control (i.e., freeze, malfunctions) on contractor R&D engineering simulators, but any action to move simulator engineers up from the "tail end" of the design data stream could help to shorten the multi-year cycle of simulator procurement.

For systems such as PGMs, the cost and schedule benefits accrue from the development of modular PTTs which can be used in several modes: as stand-alone devices; integrated as combined trainers; or attached to WSTs for different aircraft types. These benefits are realized from common PTT development requirements and thereby a reduction of future integration effort. The modular approach should also provide a degree of flexibility to "swap out" PGM PTTs when required. This is an important consideration, as modern PGMs are essentially modular by design, allowing change of weapons load mix to suit individual aircraft missions while preserving the precision guidance capability. PGM systems may also be rotated among units as the overall planning situation dictates, or they may be replaced by even newer PGM systems. The modular PTT, whether it is stand-alone or integrated with another device, should be capable of being swapped out with a training device for another similar class weapon.

Cost savings will also be realized in the life cycle of PTTs since considerations will include designing the training devices for a specific, realistic life (maintenance and logistics). Also, by using engineering design guidance, common core components can be adapted to other requirements as necessary. Conversely, if a PGM system is being integrated into an existing aircraft, the remaining service life of the parent aircraft will obviously be an early consideration. If the parent aircraft has only a short service lifetime remaining, some of the unique simulation tasks requiring complex/high cost engineering solutions will have to be identified and consideration given to finding more simplified, but effective PTT solutions. In some cases, it might be determined to be more cost-effective to complete full-mission training in the aircraft.

Currency of operational, in-use training devices is another area for examination. Important to the update of PTTs, as well as other training devices, is a continuing analysis of training requirements to determine modification needs. This point is frequently overlooked and becomes the loose thread that brings about loss of confidence in existing trainers. When the device no longer matches the actual equipment, both students and instructors immediately recognize the difference and soon resort to using the actual equipment as a trainer. Since most PTTs can usually be updated at reasonable cost (or in many cases replaced), the problem is less noticeable and causes less loss of confidence in the training system.

While we have noted the rapidly advancing technology which is producing modern weapon systems, we should not forget that the same technology can also assist the solution of our training problems. We must look for new and innovative applications of these technologies to provide cost-effective training systems. For example, the gamesmanship designed into current-day video and computer games has surfaced new concepts in presentation of data for training. Stress is increased by timing and saturation, and anxiety is developed through random presentation of unexpected challenges. Such ideas can meld the uses of PTTs into training syllabii as modules of training events that can be integrated into broader training tasks in the simulators. Computer-based instructional systems currently being acquired by the services will provide potential for management of PTT resources, scheduling them into curriculums and documenting their use. Such potential heightens the applicability of small, microcomputer-directed devices as major components of the overall training program.

The students of the 1985-2000 time-frame will enter military training with a high level of exposure to the microcomputer and game-oriented training from school resource centers. We can expect greater acceptance of PTT concepts as building blocks of instruction that can task the student in highly stressed exercises similar to anxious moments of live combat. These applications can serve the transient needs of changing missions and combat scenarios that now drive the tactical and strategic training costs out of sight.

In summary, the payoff comes when effective front-end analysis provides a dissected definition of training requirements delineating the use of various levels of training equipment. By designing PTTs to build operator skill for practice and integration at the next level of training, instructors can control training resources and maximize the use of moderate-cost devices to bring about a higher overall level of skilled readiness, and thereby reducing the requirement for extended training in the WSTs or the mission equipment. This represents a change in training strategies and demands disciplined instructional designs, but is a viable way to maintain high training standards in the future, and ensure better access to current training equipment.

Standardization in engineering design and the modularity concept should facilitate integration where required. We have suggested that innovative approaches in the design and utilization of PTTs will produce cost and schedule savings for a particular set of training tasks. However, the bottom line is that we must be prepared to meet the training requirements of an increasing number of complex and sophisticated weapons systems.

We perceive the part-task trainer as a viable answer to the dilemma of providing timely, cost-effective training.

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ADVANCED GROUND MAPPING RADAR SYSTEMS

A SIMULATION CHALLENGE FOR THE 80's

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ABSTRACT

The role of the airborne ground mapping radar has been dramatically changing over the last several years due to great technological strides in the science of radar design. Great improvements have been made in both the accuracy and resolution of radar systems primarily due to the influence of high speed digital signal processing and the development of synthetic aperature radar design. As a result of the many improvements to both radar system performance and flexibility, the role played by radar systems is also expanding. As advanced radar become part of aircraft avionics systems, the requirement for high fidelity training systems immediately follows. Changes to existing digital radar landmass (DRLMS) specifications will therefore be required. In order to meet the training requirements for advanced high resolution systems both enhanced revisions of current DRLMS systems and alternative technologies may be required.

INTRODUCTION

Digital radar landmass simulation (DRLMS) technology developments over the last ten years have brought the simulated radar system from not much more than a procedural type trainer to a point where world wide mission rehearsal can be accomplished. The current state-of-the-art DRLMS capability permits radar imagery to be generated that, in many cases, is indistinguishable from the actual aircraft radar image. Unfortunately for the simulation community, the state-of-the-art for aircraft radar systems is not static and can be expected to dramatically change over the next ten years. In response to these changes to aircraft radar systems, significant changes and improvements to DRLMS technology will be required.

Advanced aircraft radar systems will become increasingly more capable of generating high resolution imagery. This paper describes the future role of radar systems with particular emphasis on the anticipated changes and additions to DRLMS specification requirements as a result of new aircraft radar system, and upon the potential impact on DRLMS design.

Future Role of Radar

Future radar systems will be called upon to do an increasing number of tasks as the role of combat aircraft expands with new mission requirements while having to contend with more sophisticated enemy defensive capabilities. The following paragraphs examine the new roles and requirements that are currently being identified, and several of the advanced capabilities that are being developed to meet these requirements.

The trend for future advanced radar systems has already been established by the multimode capabilities of the FB-111 and the advanced capability B-52 radar systems. Systems such as these employ not only the basic ground mapping modes used for general navigation but also include special spotlight/offcenter type high resolution modes for weapon delivery as well as terrain avoidance/terrain following modes to permit low level penetration flight. However, performance limitations of older multimode systems are rapidly being reduced on newer systems by virtue of high speed digital signal processors and on-board computer systems which permit a great deal of flexibility to be exercised in terms of how a radar signal can be processed, analyzed, enhanced, and ultimately displayed. As a result of the enhanced flexibility that is inherent to the digital signal processing capability, an advanced radar system need no longer be limited to the basic capabilities for which the system was originally designed. Both new modes and enhancements to existing modes will be possible to add to advanced radar systems without major modifications or redesign. The multimode capability will further be enhanced with the inclusion of the phased array antenna. (1) Antennas of this type will permit rapid changes from one mode to another and precise pointing at desired targets by electronically steering the radar beam without the delays inherent to conventional mechanically scanned antennas. Examples of different capabilities that will be a part of an advanced multimode radar system include conventional real beam ground mapping, enhanced high resolution imagery using doppler beam sharpening, synthetic aperature antenna with signal pulse compression techniques, terrain following, doppler ground speed measurement, air-to-air and air-to-ground target identification, and rendezvous beacon interrogation.

Both existing and future aircraft will be called upon to carry out an increasing number of mission roles and objectives. Bomber type aircraft will be required to accomplish not only the more traditional low altitude penetration and bombing role but also a standoff missile launching role. Although accuracy for weapon delivery has always been a goal, the requirement for high accuracy is continually becoming more critical due to the decreasing vulnerability of many target areas. An inertial navigation system integrated with the aircraft weapon delivery computer is capable of providing the desired accuracy, but only when system initialization and periodic updates have been provided by an accurate sensor source such as radar. A synthetic aperature mode will be capable of providing the desired high resolution input for both direct weapon delivery modes as well as the capability for precise air launched missile programming. These advanced radar modes will also permit accurate position updates to be accomplished at much greater ranges than with conventional radar systems. Accurate position updates will be limited only by the radar line-of-sight and will enhance the stand-off capability and permit greater flexibility for target aiming point selection.

Advanced radar design will be affected by both the natural and artificially induced environment. A hostile enemy environment will place many demands on the radar system that could not be handled with a conventional radar. The flexibility and inherent capabilities of advanced radar systems will permit a realtime analysis of the electromagnetic environment to be accomplished and to initiate the appropriate response. The radar will be required to not only counter active jamming and interference techniques specifically directed toward the aircraft but also analyze the environment and to avoid detection from ever taking place. The inherent characteristic of microwave energy to penetrate weather has long provided aircraft with all weather, day/night operating capability. However, advanced radar systems must also permit penetration of ground foliage. Built-in flexibility will permit advanced radar systems to keep pace with the continuously changing environment of the future.

It is readily apparent, for advanced weapon systems in general, that crew member task loading is of vital concern due to both the complexity of the equipment and the ever increasing number of tasks that the crew member is called upon to do. (2) As a result, the design goal of all advanced radar systems will be to simplify the basic operation and to provide assistance to the crew member. In general, the operation of advanced radar systems will be simplified by virtue of the programmable capabilities of both the navigation computer system and the radar digital signal processor. A terrain following mode when tied into the aircraft flight control and navigation computer systems is one existing way of assisting the pilot. An example for future radar systems will be automatic target acquisition and classification modes for both air-to-ground strikes against both stationary and moving targets, and air-to-air modes for enemy aircraft interception. The inherent high resolution characteristics of synthetic aperature radar (SAR) and doppler beam sharpening (DBS) modes when integrated with the accuracy of navigation and weapon delivery computers also reduces the crew members task load by providing an automatic means of accurately classifying a target or aiming point. This capability is essential in single seat fighter aircraft where the workload is high or in any high speed aircraft operating at low altitudes where the limited radar range results in a short time for the crew member to react to a target.

In summary, the role played by advanced radar systems will continue to include the traditional tasks of general navigation and weapon delivery. However, many enhancements to the basic capabilities and the addition of new specialized modes will permit advanced radar systems to meet the requirements for a high performance sensor capable of operating in a wide variety of environments and capable of reducing the crew member's workload.

DRLMS Requirements for Advanced Radar Systems

The requirements for the simulation of advanced radar systems will be based primarily upon current DRLMS specifications. Although current specifications have evolved since the first DRLMS specification in 1972, experience gained in more recent years, as well as the more demanding requirements of future radar systems, dictates that a number of significant modifications be made. (3)

From the standpoint of the actual radar system being simulated, the most obvious types of changes to current simulator specifications will be the inclusion of the new types of modes and requirements for any system unique characteristics. Characteristics that may be required include such items as the effects of radar platform motion compensation or digital signal processing anomolies on the resulting radar imagery. Analysis of a specific radar system's operation will dictate which unique system requirements will be required. A requirements emphasis will be placed on a DRLMS design approach that will permit expansion when additional modes and capabilities are added to the aircraft radar system. It becomes highly undesirable for a DRLMS system to require a total redesign or possibly have to be replaced if the existing aircraft radar is modified with the addition of a new mode or capability.

Requirements changes that will most likely affect DRLMS processing capability include accuracy and data density. In both cases, an attempt will be made to further definitize and more quantitatively specify the level of performance required. DRLMS accuracy (processing and data transformation) will continue to be specified independently for both terrain elevation and planimetry, as well as independently for each mode of operation. Of great significance, however, will be tighter planimetry positional accuracy requirements for the high resolution modes. Data density processing requirements will need to be modified to consider both real beam conventional modes and synthetic aperature high resolution modes. Conventional real beam mode density requirements will remain relatively stable; however, the high resolution data density processing requirements can be expected to become more stringent. However, when considering both accuracy and density processing requirements, several important factors must be kept in mind. First, data processing times for individual radar frames on actual aircraft SAR modes are typically several seconds long with an update rate that may be even longer. Second, the individual frame location will most likely be fixed without the need to process data in real time as cross hairs are slewed virtually anywhere within the aircraft field of view. Also of concern when considering DRLMS processing capability is the extent to which world wide flight will be required. Recent programs have emphasized the need for mission rehearsal encompassing potentially the entire northern hemisphere. This requirement will have to be reevaluated in terms of training utility and effectiveness - especially when reviewed in light of DRLMS design complexity and demands that will be placed on high resolution data bases.

A goal for future DRLMS specifications will be the addition of as many quantitative requirements in place of areas that are now subjectively defined. This will be especially true in the areas of radar effects and special effects where words as "shall be realistically simulated" predominate. It is also important to note that quantitative requirements will be based upon training effectiveness studies whenever possible. Since it is realized that quantitative performance characteristics can tend to drive both design and production costs of DRLMS, careful attention will be paid to the desired fidelity as a function of training requirements.

The DMA digital landmass system (DLMS) data base has been the primary source of data for the simulation of conventional ground mapping radar systems over the last ten years. (4) However, the DLMS data base possesses certain limitations that will influence both the requirements for DRLMS data bases and the eventual design of advanced DRLMS systems. These limitations are centered around the basic content of DLMS data. DLMS digital feature analysis data (DFAD) is produced to a set of resolution and feature type inclusion criteria which results in a chart like representation of the earth's surface where homogeneous type areas (e.g. soil, trees, desert, water, etc.) are represented; however, a more precise description of how soil is contoured or plowed, or how trees and foliage are distributed in natural vegetation areas is not contained. As a result, Level 1 DFAD, and to a lesser degree Level 2, will be inadequate for meeting the data content requirements for a high resolution SAR mode. As indicated in a prior discussion, areas of high resolution interest for a simulator training mission will be restricted to relatively small areas selected during mission generation. Various methods will, therefore, have to be developed to either enhance the basic DMA data in these areas or to provide an alternate data source for the high resolution modes. One alternative currently under evaluation is the use of synthetically enhanced DMA data. (5) Synthetic breakup is an automated process of replacing large homogeneous DFAD features with smaller, more realistically sized, individual features. (Figure 1) Although very encouraging results have so far been obtained, certain limitations do exist. The data, when broken up, is random in nature and not necessarily representative of what actually exists in the real world. This is a result of the limited number of descriptors assigned to an individual DMA feature (e.g. feature type, surface material, predominant height, etc.). For example, for a residential area digitized as a single feature, the feature descriptors will not provide any indication of what variations to the basic feature type exist in the real world or if there are any unique characteristics. The capability to generate more realistic synthetic breakup should be realized when more descriptive data bases, such as DMAs experimental Level V, becomes an available product. Other alternatives to the need for a more detailed data base are the inclusion of generic models (i.e. small areas hand modeled to the level of desired feature content and fidelity) into areas of high resolution interest and, to go a step further, generate a complete generic data base. Such a generic data base might be based upon the DMA data base (e.g. Level 1, 2, or V) on which extensive synthetic enhancement and generic modeling is added or might be entirely artificial in content - realistic in appearance but not representing any real world area - but tailored to meet a specific training need. In any case, more detailed data bases are the primary reason why data density processing requirements will be higher for the simulation of high resolution radar systems.

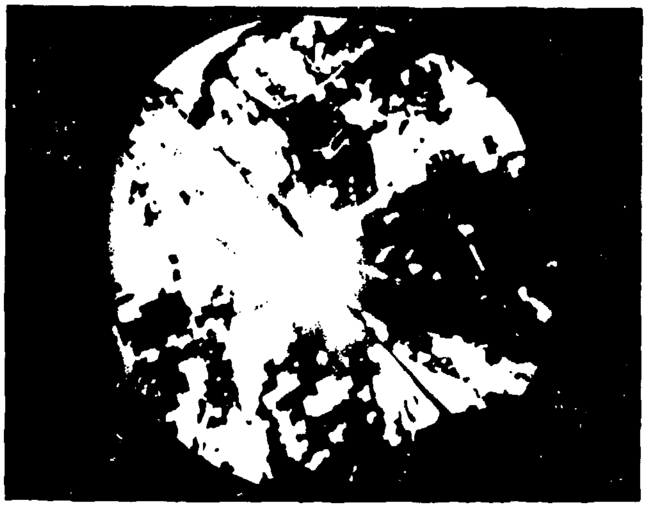
Although not directly related to the requirements for advanced high resolution radar simulation, DRLMS test requirements will also undergo extensive modifications. For the most part, current test requirements are general in nature and a great deal of interpretation is left to the DRLMS system designer. As part of the same effort to quantify the requirements for DRLMS fidelity and processing, DRLMS test requirements will also become more quantitative and more definitive as to how they are to be performed. The goal will be to reduce the subjectivity of DRLMS testing and to achieve the most quantifiable picture of system performance as possible.

In summary, modifications and additions to DRLMS specifications for advanced DRLMS systems as described in the preceding paragraphs are "a goal" to be accomplished in various states during the next five to eight years. It is hoped that certain quantitative performance and test requirements can be added in the next two to three years. However, advanced radar system unique requirements will not be available until an advanced aircraft radar system is fully defined.

DRLMS System Design Impact

One can only speculate as to the total impact advanced radar systems will have on DRLMS design. After looking at the anticipated changes to DRLMS specifications, however, it does appear that the two primary areas of concern for advanced DRLMS will be the data processing capability (i.e. data volume and processing speed) and data base adequacy. It can be anticipated that for conventional ground mapping radar modes, current DRLMS technology will suffice. Current DRLMS technology may also serve as an interim in the near future for high resolution modes; however, several enhancements and several alternatives can be considered.

As discussed in the previous section, synthetic breakup, when fully exploited, is one way of enhancing the data base. One alternative to breaking up the source DMA data base would be to accomplish the breakup of cultural features during realtime processing thereby reducing the amount of on-line storage and data base transformation time. However, careful attention would have to be given to the capability of generating a desired pattern of artificial features and do so in a repeatable manner from scan to scan. Similar to the concept of synthetic breakup would be the realtime generation of texture to be applied to terrain and agricultural areas. Texture patterns should also be selectable and repeatable but would probably be less critical than for cultural features. Generic modeling might also be a means of providing the high data content and detail necessary for high



BEFORE BREAKUP

AFTER BREAKUP

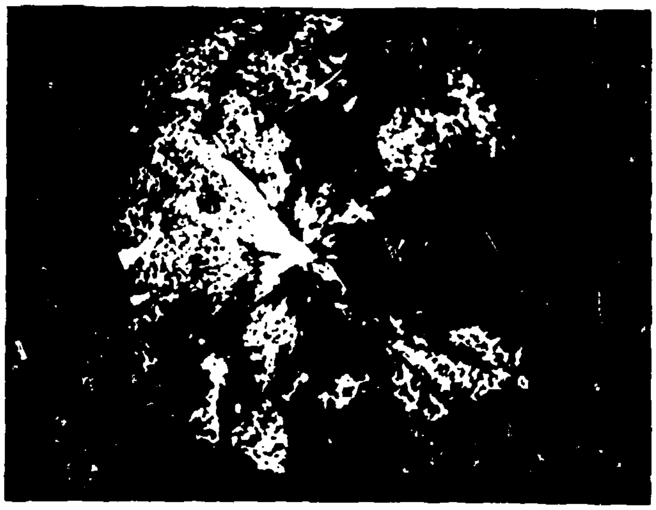


Figure 1. Synthetic Breakup of DMA Data

resolution modes. Generic models of small towns, industrial complexes, residential areas, etc, could be hand modeled as part of a generic library collection to be inserted in the data base either before transformation or during realtime DRLMS processing.

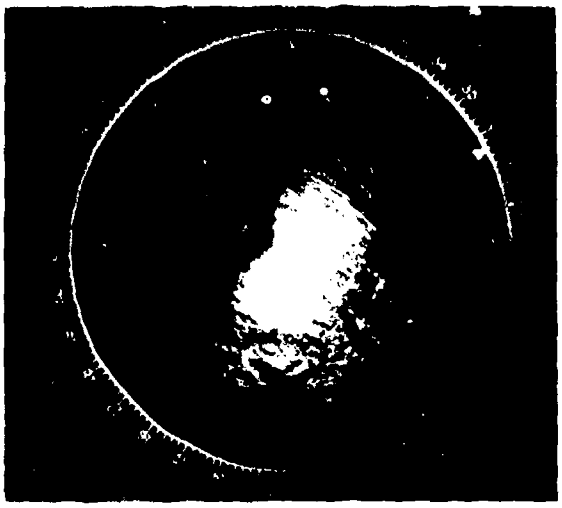
It appears that current DRLMS technology will be adequate for conventional ground mapping radar modes. Figure 2 illustrates a comparison between simulated and actual B-52 radar imagery. In order to accomplish data retrieval and processing for advanced high resolution radar modes, however, either a higher performance DRLMS processor (parallel to the conventional ground mapping channel) or an alternative high fidelity image generation capability would be required. This would then imply that hybrid DRLMS systems may be a solution for the simulation of advanced multimode radar systems. Computer image generation (CIG) techniques, used for out-the-window visual simulation, might be explored. This possibility is appealing from the standpoint that high resolution SAR modes are capable of producing imagery that in many cases contains the same detail and resolution as a visual scene. (Figure 3) In addition, high resolution modes typically utilize digital scan converted video which is output to a raster scan type display. This display format is also utilized for CIG image display.

An alternative to be considered from both a data base and processing standpoint is realtime processing of an array of still photographs. (6) This process, successfully demonstrated for the simulation of airborne forward looking infrared (FLIR) systems, also seems to hold possibilities for high resolution radar modes. High resolution aircraft radar imagery (e.g. synthetic aperture) doppler beam sharpening, side looking, etc.) could be processed in a similar manner as that for a forward looking infrared or visual system, thereby providing a simulation capability with virtually the same level of fidelity as the original aircraft imagery. However, a significant amount of effort would have to be devoted to the questions of dynamic shadow processing, dynamic system controls interaction by an operator, and the processing of radar data base photography at very low grazing angles (i.e. low altitudes and long ranges).

In order to accommodate future growth of DRLMS systems as a result of aircraft radar system modifications, DRLMS system architecture will need to be designed with an understanding of what potential changes may exist in the future. Although it is certainly naive to think that all contingencies can be "designed in" thereby eliminating the chance of DRLMS system redesign, good design planning should help to increase the chances of a more graceful transition to the new capabilities. For example, if additional processing power is required, what level of effort would be required to expand with a parallel processor or, if additional data storage is required, what level of effort would be required to add additional memory? Similar type questions should be asked of the basic radar effects. If aircraft radar performance is increased, how easily can the antenna beam pattern or receiver effects be modified? Just as modern digital radar systems provide growth capability to aircraft radar systems, it is hoped that modern DRLMS systems will also inherit this flexibility.

SUMMARY

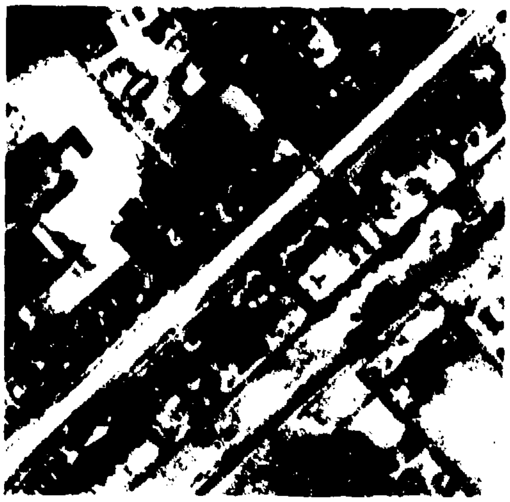
During the next ten years, we will see a quantum jump in the performance of airborne radar systems as compared with the last forty years. As a result, innovative new ideas will be required to advance the state-of-the-art in DRLMS system technology in order to meet the performance requirements for advanced radar simulation training needs. It now appears that either significant improvements to existing DRLMS technology or alternative approaches resulting in hybrid systems will be required as well as a substantial increase to the content and detail of the radar data base. Just as a technical challenge existed in the 1970's to develop digital radar simulation technology to meet the training needs for conventional radar systems, an even greater challenge now exists to meet the training requirements expected for the advanced high resolution radar systems of the 1980's and beyond.



ACTUAL
RADAR
IMAGE

SIMULATED
RADAR
IMAGE

Figure 2. Simulated vs. Actual Radar Imagery



AERIAL
PHOTOGRAPH

SYNTHETIC
APERTURE
RADAR IMAGE

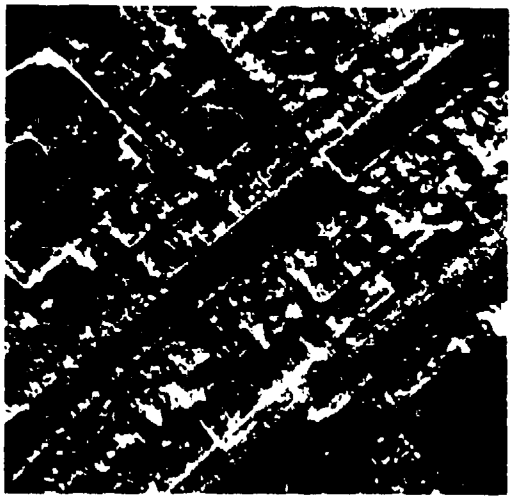


Figure 3. Synthetic Aperture Radar Image

REFERENCES

(1) S.A. Hovanessian, "Radar Detection and Tracking Systems," Massachusetts: 1973, p. 9-14 to 9-29.

(2) "Assessing Pilot Workload," Nuilly-sur-Seine, France, Advisory Group of Aerospace Research and Development, North Atlantic Treaty Organization, AGARD-AG-223, February 1978.

(3) Development Exhibit ENCT 72-104, 3 April 1972.

(4) Defense Mapping Agency Product Specifications for Digital Landmass System (DLMS) Data Base, July 1977.

(5) T.W. Hoog and J.D. Stengel, "Computer Image Generation Using the Defense Mapping Agency Digital Data Base," Proceedings of the 1977 Image Conference, 17-18 May 1977.

(6) J.T. Hooks and V. Devamian, "Simulated FLIR Imagery Using Computer Animated Photographic Terrain Views (CAPTV)," Proceedings of the 1981 Image II Conference, 10-12 June 1981.

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AN EVALUATION OF AN EXTREMELY LOW COST CELESTIAL NAVIGATION TRAINER

OR

(HOW LOW CAN WE GO)

DR. E. RUSSELL PENNINGTON AND MAJOR MARSHALL L. CHRISTENSON

4235 STRATEGIC TRAINING SQUADRON

AND

MR. K. RONALD LAUGHERY, JR.

CALSPAN CORP.

ABSTRACT

This paper will present the results of a study which was conducted on the B-52/KC-135 Celestial Training Device (CTD). The CTD is really nothing more than a moderately equipped microcomputer with special software which was developed in-house by the Strategic Air Command. Total cost of the system is less than $5,000. The CTD is used by B-52 and KC-135 navigators to maintain proficiency in celestial navigation skills. In the study to be reported, twelve measures of navigator celestial navigation performance were examined before and after the CTD training. Findings indicated that even with a 30% reduction in in-flight celestial navigation training, performance on several key variables showed significant improvement after the CTD was delivered. No variables showed a decline in performance. In summary, the findings supported the effectiveness of the CTD beyond the experimenter's initial expectations.

INTRODUCTION

The purpose of this report is to describe the method and results of a study conducted to determine the training effectiveness of the Celestial Training Device (CTD). The CTD is now being used by all operational squadrons of B-52s and KC-135s within Strategic Air Command (SAC) to provide continuation training for navigators in basic celestial navigation. When the CTD was introduced in late 1979, aircraft time for celestial navigation training was being significantly reduced. An immediate question was whether this would adversely affect navigator in-flight performance. The study reported herein seeks to answer this question. The next section will discuss the origin, design, and operation of the CTD. The third section will discuss the training effectiveness study conducted for this device.

BACKGROUND

In early 1978, two KC-135 navigators, stationed with the 384 AREFW, McConnell AFB, KS, developed the concept and software to perform celestial training using a micro-computer. The concept was approved for evaluation by Headquarters, Strategic Air Command (SAC), while the actual feasibility of the concept was determined by the 4235th Strategic Training Squadron (STS) in August 1978. The favorable recommendation from this evaluation resulted in a proposal for the procurement of celestial training devices in January 1979. Final approval for the acquisition of the CTDs was given in February 1979.

The 4235th STS was designated as the command program manager and given the responsibility for program implementation. CTD delivery started in August 1979 and was completed by January 1980.

The Training Device

As presently configured, the CTD is simply a Northstar Horizon micro-computer with a 48K primary memory, a 5 1/4" floppy disk drive, an internal clock, a printer, and the associated software. A picture of the CTD is presented in Figure 1. The program is written in BASIC. Essentially any microcomputer with the required peripherals could be programmed as a CTD with only minor software modifications. The software was designed to enable a navigator to call up the computer program with very simple commands. The

THE CELESTIAL TRAINING DEVICE

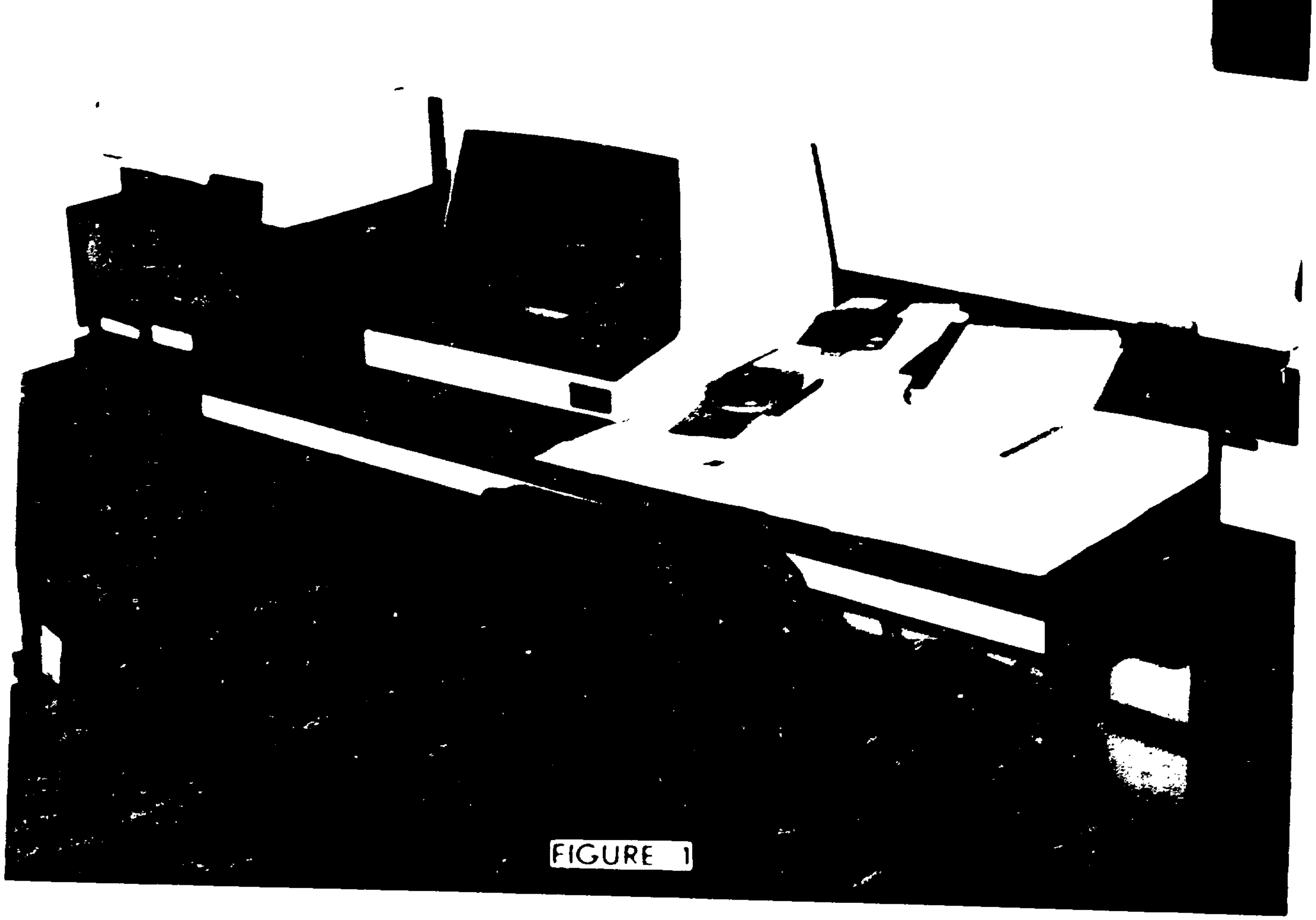


FIGURE 1

computer plays the part of pilot, aircraft, and celestial observer.

The Training Profile

The training profile is similar to actual celestial navigation in the aircraft with some exceptions. The navigator is in a classroom environment that lacks the realism of excessive noise, vibrations and other inconveniences of actual flying. Charts, logs, reference books and required equipment are available to be used simultaneously with the computer. The navigator follows the mission in real time, completing all routine work required on the charts and logs. Instead of coordinating with real people in the pilot and observer stations, he must communicate with the computer via the computer keyboard. Also, the computer has "built-in" errors that will cause the navigation to be in error, thus requiring continuous corrections.

Mission Summary

At the end of the training mission, the computer will provide a print out of the mission actions called the Mission Summary. The Mission Summary provides aircraft position (FIX) for the following positions: (1) Approximately every five minutes of flight time, (2) At each heading change, (3) When the heading mode of operation is changed, (4) At the start and termination of the navigation legs, and (5) At the mid time of each celestial observation.

Each FIX, with the exception of number 5 above, will provide the time, geographic coordinates, true course, wind direction and velocity, drift, true heading, magnetic or grid heading, true airspeed and groundspeed.

The Celestial Star Data portion of the Mission Summary provides the mid-time of each celestial observation, geographic coordinates, average True Course (Track), average Ground Speed (GS), sextant altitude observed (HO), one minute motion correction, True Zenith (ZN) of body at mid-time of the observation, and name of body observed. If the body was not the Sun, Moon, Mars, Jupiter, Saturn, Venus, or one of the 58 navigational stars, the SHA and DEC of the body will be given. If the navigator selects between more than one planet or star in the field of view, they would be listed in the Celestial Star Data printout.

The final portion of the analysis printout provides the time logged on the trainer this mission, time in freeze mode this mission, total time logged on diskette to date, and total time in freeze mode on the diskette to date.

Performance Measurement

At the end of the simulated celestial navigation mission, the student or his instructor can take the Mission Summary data and replot the flight. This replot allows the student to compare his solution of the navigation mission with what the simulated aircraft, the computer, actually flew.

TRAINING EFFECTIVENESS STUDY DESIGN

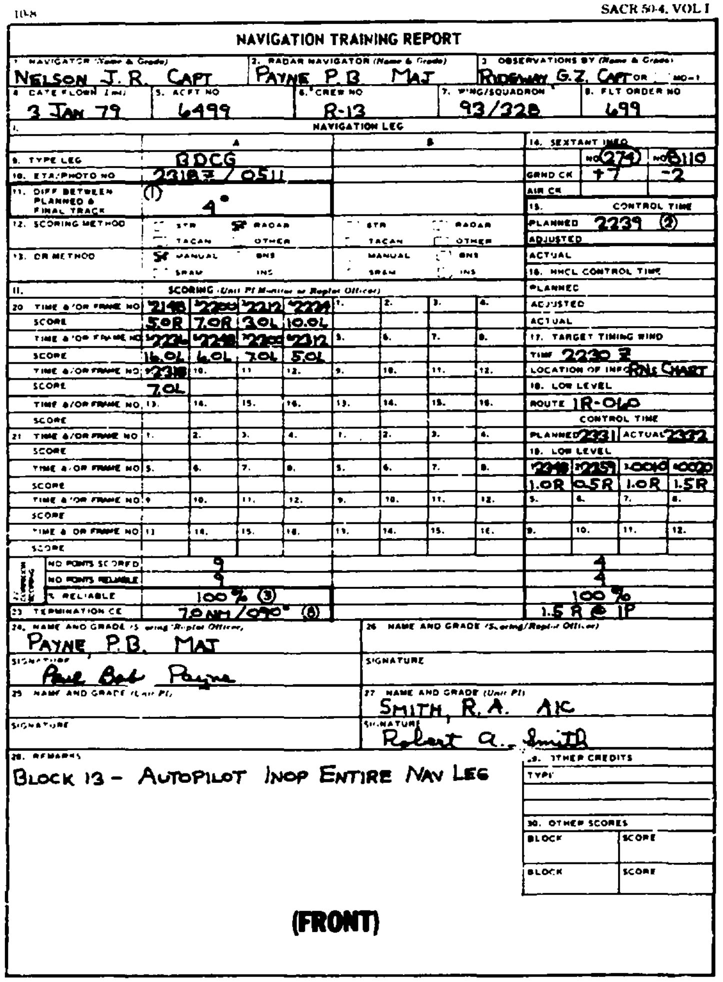
When the celestial training device study was conceived in January 1980, most CTDs had already been delivered to the Air Force units. Due to the shortages of flight crews, aviation fuel, and heavy operational demands, a formalized study was not considered practical. However, the Air Force had objective navigator evaluations in the form of in-flight performance skills on AF Form 157 (see figure 2). It was then determined that a realistic study could be conducted by comparing in-flight navigation skill measurements, as recorded on the AF Form 157s, before CTD practice, with similar skill measurements after the navigators had a chance to practice on the CTD. Also, reductions of in-flight celestial navigation training occurred after the delivery of the CTDs.

The plan called for the flight record office at each base to send copies of all AF Form 157s for flights prior to the beginning of CTD training to the 4235 STS. These forms were reviewed for completeness, and if they met predetermined criteria, they were used in this study.

A single reviewer selected all forms to be included in the CTD study. The predetermined selection guide "Evaluation Procedures for Selecting Qualifying AF Forms 157s for the CTD Study" was used to ensure selection consistency. The control data consisted of the responses from the 19 February 1980 request for all AF Form 157s prior to CTD training. These data yielded over 1,000 Form 157s. Initial review eliminated 700 of these that represented integrated flights, because these flights allowed the navigator to use additional navigation aids such as inertial computers. Since only celestial navigation data is presently available on the Celestial Training Device, it was determined that evaluated flights should be subject to the same restrictions.

The 300 AF Form 157s that remained were reviewed according to the "Evaluation Procedures for Selecting Qualifying AF Form 157s for the Celestial Training Study". Certain omissions of less critical data points were considered acceptable. The data points considered to be less critical were: (1) final heading, the actual direction to destination at the end of the mission; (2) control time, the predetermined estimate of arrival at destination; and, (3) DR Error, errors made in the position plotting on the chart that were also included in computation and plotting error. This was in concurrence with 4235 STS resident subject matter experts. When these omissions were allowed, 121 of the Form 157s qualified for inclusion in the study and were used as control data.

On May 28, 1980, CTDs had been in place long enough to justify acquiring the remaining data for the Celestial Training Device Study. A request went to all SAC squadrons using a CTD to provide the number of basic celestial navigation flights flown from Oct 1979 to May 1980. In addition, they were to send all AF Form 157s for basic navigation legs flown during the months of April and May 1980 to the 4235 STS.



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NAVIGATION TRAINING REPORT

1. NAVIGATOR (Name & Grade): NELSON J.R. CAPT
2. RADAR NAVIGATOR (Name & Grade): PAYNE P.B MAJ
3. OBSERVATIONS BY (Name & Grade): RIDGWAY G.Z. CAPT OR NO-1
4. DATE FLOWN: 3 JAN 79
5. ACFT NO: 6499
6. CREW NO: R-13
7. WING/SQUADRON: 93/328
8. FLT ORDER NO: 699

I. NAVIGATION LEG

	A	B
9. TYPE LEG	BDCG	
10. ETA/PHOTO NO	2318Z / 0511	
11. DIFF BETWEEN PLANNED & FINAL TRACK	(1) 4°	
12. SCORING METHOD	☐ STR ☒ RADAR ☐ TACAN ☐ OTHER	☐ STR ☐ RADAR ☐ TACAN ☐ OTHER
13. DR METHOD	☒ MANUAL ☐ GNS ☐ SRAM ☐ INS	☐ MANUAL ☐ GNS ☐ SRAM ☐ INS

14. SEXTANT INFO

	NO 274	NO 8110
GRND CK	+7	-2
AIR CK		

15. CONTROL TIME
PLANNED 2239 ②
ADJUSTED
ACTUAL

16. HHCL CONTROL TIME
PLANNED
ADJUSTED
ACTUAL

17. TARGET TIMING WIND
TIME 2230 Z
LOCATION OF INFO RNI CHART

18. LOW LEVEL
ROUTE IR-060
CONTROL TIME
PLANNED 2231 ACTUAL 2232

19. LOW LEVEL

2248	2259	0010	0020
1.0R	0.5R	1.0R	1.5R
5.	6.	7.	8.
9.	10.	11.	12.

II. SCORING (Unit PI Monitor or Replot Officer)

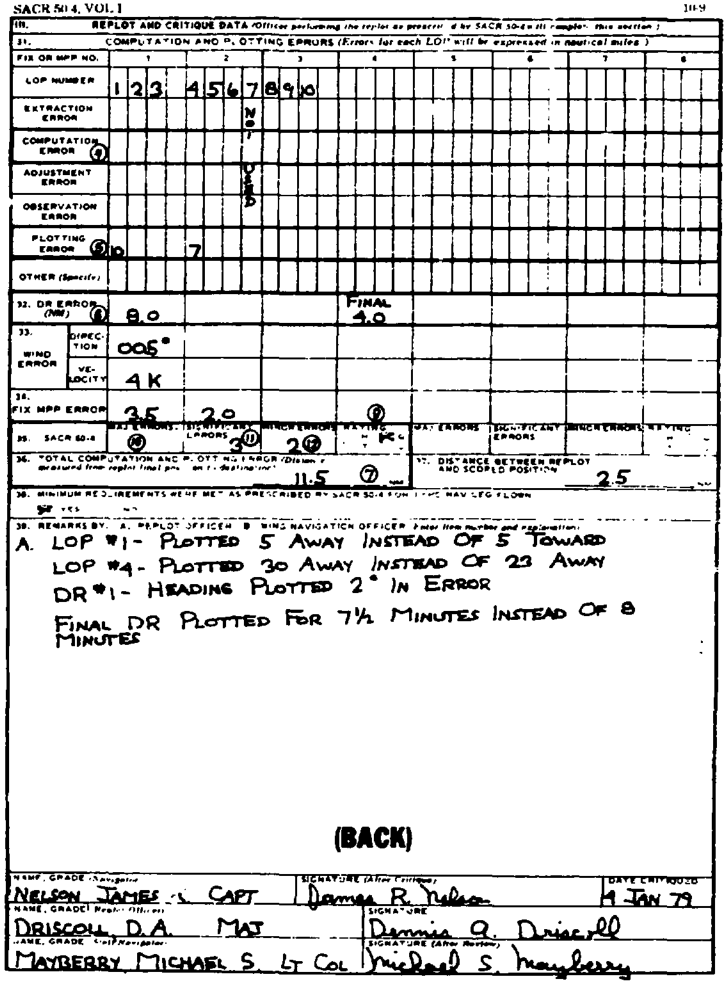
	A				B			
20 TIME &/OR FRAME NO	2148	2200	2212	2224	1.	2.	3.	4.
SCORE	5.0R	7.0R	3.0L	10.0L				
TIME &/OR FRAME NO	2236	2248	2300	2312	5.	6.	7.	8.
SCORE	16.0L	6.0L	7.0L	5.0L				
TIME &/OR FRAME NO	2318	10.	11.	12.	9.	10.	11.	12.
SCORE	7.0L							
TIME &/OR FRAME NO	13.	14.	15.	16.	13.	14.	15.	16.
SCORE								
21 TIME &/OR FRAME NO	1.	2.	3.	4.	1.	2.	3.	4.
SCORE								
TIME &/OR FRAME NO	5.	6.	7.	8.	5.	6.	7.	8.
SCORE								
TIME &/OR FRAME NO	9.	10.	11.	12.	9.	10.	11.	12.
SCORE								
TIME & OR FRAME NO	13.	14.	15.	16.	13.	14.	15.	16.
SCORE								

22.	A	B	LOW LEVEL
NO POINTS SCORED	9		4
NO POINTS RELIABLE	9		4
% RELIABLE	100% ③		100%
23 TERMINATION CE	7.0 NM/090° ⑧		1.5 R @ IP

24. NAME AND GRADE (Scoring/Replot Officer): PAYNE, P.B. MAJ
SIGNATURE: Paul Bob Payne
25. NAME AND GRADE (Unit PI):
SIGNATURE:
26. NAME AND GRADE (Scoring/Replot Officer):
SIGNATURE:
27. NAME AND GRADE (Unit PI): SMITH, R.A. A1C
SIGNATURE: Robert A. Smith
28. REMARKS: BLOCK 13 - AUTOPILOT INOP ENTIRE NAV LEG
29. OTHER CREDITS
TYPE
30. OTHER SCORES
BLOCK SCORE
BLOCK SCORE

(FRONT)

SAC FORM 157 REVISED



SACR 50-4, VOL I 10-9

III. REPLOT AND CRITIQUE DATA (Officer performing the replot as prescribed by SACR 50-4 will complete this section.)

31. COMPUTATION AND PLOTTING ERRORS (Errors for each LOP will be expressed in nautical miles.)

FIX OR MPP NO.	1	2	3	4	5	6	7	8
LOP NUMBER	1 2 3	4 5 6 7	8 9 10					
EXTRACTION ERROR		NOT USED						
COMPUTATION ERROR ④								
ADJUSTMENT ERROR								
OBSERVATION ERROR								
PLOTTING ERROR ⑤	10	7						
OTHER (Specify)								
32. DR ERROR (NM) ⑥	8.0			FINAL 4.0				
33. WIND ERROR DIRECTION	005°							
33. WIND ERROR VELOCITY	4 K							
34. FIX MPP ERROR	3.5	2.0		⑨				

35. SACR 50-4	MAJ ERRORS	SIGNIFICANT ERRORS	MINOR ERRORS	RATING	MAJ ERRORS	SIGNIFICANT ERRORS	MINOR ERRORS	RATING
	⑩	3 ⑪	2 ⑫					

36. TOTAL COMPUTATION AND PLOTTING ERROR (Distance measured from replot final position to destination): 11.5 ⑦ NM
37. DISTANCE BETWEEN REPLOT AND SCOPED POSITION: 2.5 NM
38. MINIMUM REQUIREMENTS WERE MET AS PRESCRIBED BY SACR 50-4 FOR TYPE NAV LEG FLOWN ☒ YES ☐ NO
39. REMARKS BY: A. REPLOT OFFICER B. WING NAVIGATION OFFICER (Enter item number and explanation.)

A. LOP #1 - PLOTTED 5 AWAY INSTEAD OF 5 TOWARD
LOP #4 - PLOTTED 30 AWAY INSTEAD OF 23 AWAY
DR #1 - HEADING PLOTTED 2° IN ERROR
FINAL DR PLOTTED FOR 7½ MINUTES INSTEAD OF 8 MINUTES

(BACK)

NAME, GRADE (Navigator): NELSON JAMES R CAPT
SIGNATURE (After Critique): James R. Nelson
DATE CRITIQUED: 4 JAN 79
NAME, GRADE (Replot Officer): DRISCOLL, D.A. MAJ
SIGNATURE: Dennis A. Driscoll
NAME, GRADE (Wing Navigator): MAYBERRY MICHAEL S LT COL
SIGNATURE (After Review): Michael S. Mayberry

AF FORM 157

FIGURE 2

Since the operational units understood that only basic celestial navigation flights were to be included, only 300 forms were received. These forms were reviewed under the same conditions and by the same person as the control data. Ninety-nine of the AF Form 157s qualified and were used as the experimental data for our celestial training device study.

Figure 2 presents a copy of a completed AF Form 157. A total of twelve performance measures can be obtained from each form (i.e., for each flight). These are as follows:

1. Final Heading: Heading flown to termination point and used to determine the final DR position. Used to determine difference between planned and final TRACK.

2. Celestial Control Time: The difference between the planned and actual celestial observation.

3. Percent Reliability: Percentage score determined by comparing the number of positions scored within the distance tolerance, to the total number of positions scored. Distance tolerance varies according to type of navigation leg flown and equipment authorized.

4. Computation Error: Error incurred in celestial computation of an intercept of azimuth or in pressure pattern computation. Also includes adjustment errors incurred as a result of not recomputing information when actual TRACK and ground speed differ more than ten degrees or 30 knots, respectively, from precomputation information.

5. Plotting Error: Error incurred as a result of misplotting a line of position (LOP) in either range or azimuth.

6. Dead Reckoning (DR) Error: Error incurred as a result of misplotting a dead reckoning DR position, including the final DR, in either range or azimuth. An assumed position error is also considered as a DR error.

7. Computation and Plotting Error: Distance measured from replot final position using correct information computed and plotted cumulatively from the start navigation position to the termination estimated time of arrival (ETA).

8. Cumulative Error: Distance between replot final DR and aircraft scored position.

9. Rating: Grade awarded after using the number of error points and LOPs accomplished to enter the Celestial Error Point Scoring Chart contained in SACR 50-4, Vol I.

10. Major Error: Any error exceeding the criteria of SIGNIFICANT. Failure to plot an air or DR position for each heading change of 20 degrees or more.

11. Significant Error: A celestial computation/plotting or any air/DR/assumed position error of more than 6 but less than 15 NM. A celestial/computation/plotting azimuth error of more than 6 but less than 10 degrees. A wind error more than 10 but less than 30 degrees and/or more than 8 but less than 15 knots.

12. Minor Error: A celestial computation, celestial plotting or any air/DR/assumed position error of 3 through 6 NM. A celestial computation or plotting azimuth error of 3 through 6 degrees. A wind error of 5 through 10 degrees and/or 4 through 8 knots.

ANALYSIS AND RESULTS

Of the twelve variables described earlier, all of the variables except instructor ratings yielded interval data (i.e., data for which an analysis of group means and variances would be appropriate). Instructor ratings were ordinal in nature; therefore, means analyses would not have been appropriate. Consequently, chi-square goodness-of-fit tests were performed on these data.

It was proposed at the outset of the study that data from B-52s and KC-135s should be combined into one group. This was felt to be valid since there is no logical reason to differentiate between navigators of the two aircraft with respect to the celestial navigation task. Procedures and training methods are essentally identical for both aircraft. Also, some of the Form 157s, which were to be included in the study, did not indicate which aircraft was involved. Therefore, a significant proportion of the data would have been excluded if it were necessary to discriminate between aircraft types within the data. To ensure the validity of this commonality assumption, the data for which the aircraft type was known were analyzed for potential differences. This ensured that no performance differences existed which were attributable strictly to aircraft type. Tables 1 and 2 present these comparisons between the pre-CTD and post-CTD groups, respectively, on the instructor ratings.

Chi-square goodness-of-fit tests conducted on these data yielded values of = .771 (p>.5) and = .636 (p>.5) for the data contained in tables 1 and 2, respectively. Table 3 presents this information for the cumulative error score. Two planned independent one-way ANOVAs were conducted to compare B-52 and KC-135 performance on the pre CTD data F(1,52) = .0076 (NS); and on the post CTD-DATA F(1,52) = .34 (NS). The analysis of these two critical measures of performance support the contention that B-52 and KC-135 data could be combined for analysis on an empirical, as well as a logical basis.

Table 4 presents means of the data comparing pre- and post- CTD performance with respect to the first nine variables. From this table, we can see that significant improvements were observed for Percent Reliability and Cumulative Error as a consequence of CTD Training. No measures indicated a deterioration of performance. Table 5 presents the data for a chi-square goodness-of-fit test for the instructor rating data. The test statistic for this table is = 9.4 (p <.025). Table 6 presents the data for the major, significant, and minor errors to determine whether a shift had occurred in the type of errors made (i.e., relatively more minor and fewer major errors). The statistic for this table is = 3.01 (p <.25). However, also of potential interest was whether the mean number of each type of errors made per student had changed with the introduction of the CTD. Table 7 presents these means and indicates the test statistics and associated reliability of differences existing between the means of pre-vs. post-CTD training groups. It appears from Tables 6 and 7 that a reduction in the number of major errors may have occurred, although the effect was only significant at the .25 level.

Table 1

Instructor Ratings - B-52 vs. KC-135, Pre CTD delivery

	Highly Qualified (H)	Qualified (Q)	Qualified with Training (T)	Unqualified (U)
B-52	8 (57.1)	4 (28.6)	1 (7.1)	1 (7.1)
KC-135	28 (70.0)	8 (20.0)	2 (5.0)	2 (5.0)
				$\chi^2 = .771$
				P = NS

Table 2

Instructor Ratings - B-52 vs. KC-135, Post CTD delivery

	Highly Qualified (H)	Qualified (Q)	Qualified with Training (T)	Unqualified
B-52	22 (71.0)	7 (22.6)	2 (6.5)	0 (0)
KC-135	67 (76.0)	18 (20.5)	3 (3.4)	0 (0)
				$\chi^2 = .636$
				P = NS

Table 3

Cumulative Error Score - B-52 vs. KC-135

	B-52	KC-135
Pre CTD	11.5	11.825
Post CTD	8.19	8.97
		F(1,52) = .0076 P = NS
		F(1,52) = .34 P = NS

Another question which had to be answered was how the number of in-flight celestial navigation legs had changed subsequent to the introduction of the CTD. The desirability of the CTD is very much a function of how large these reductions can be. SACR 51-52 and SACR 51-135 were modified so that the required number of celestial navigation legs were reduced. However, to ensure that this reduction had occurred, data were collected pertaining to the number of aircraft celestial navigation legs flown per month at each base. Some months had more flying days available due to the number of weekends and holidays. Consequently, these dates were adjusted to reflect the number of celestial navigation legs flown per available flying day.

Table 8 presents these data. To summarize, there was an average of 10.17 celestial navigation legs flown per available flying day at all of the bases studied during the months of October and November 1979, when the pre-CTD data were collected. There were an average of 7.43 celestial navigation legs flown per available flying day during the months of April and May 1980, when most of the post-CTD data were collected, a reduction of 3.27 celestial navigation legs per flying day. This represents a reduction of 30.6 percent. The number of navigators at these bases remained constant thoughout the period of the study.

Table 4

Pre vs. Post CTD Celestial Navigation

In-flight Performance

Measure	Mean Pre CTD	Mean Post CTD	df	F1,df	Significance Level
Final Heading	6.78	6.05	203	.24	NS
Celestial Control Time	1.66	1.70	104	.01	NS
Percent Reliability	97.57	99.76	207	7.55	<.01
Computation Error	.24	.32	209	.84	NS
Plotting Error	.53	.62	209	.62	NS
Dead Reckoning Error	2.07	2.04	200	.007	NS
Computation and Plotting Error	6.21	4.90	207	1.42	<.25
Cumulative Error	11.24	8.79	209	4.53	<.04

Table 5

Instructor Rating

	Highly Qualified (H)	Qualified (Q)	Qualified with Training (T)	Unqualified	TOTAL
Pre CTD	63 (68.5)	18 (19.6)	4 (4.3)	7(7.6)	92
Post CTD	89 (74.7)	25 (21.0)	5 (4.2)	0 (0)	119

NOTE: Percentages indicated in parentheses. $\chi^2 = 9.4$ P = < .025

Table 6

Error Types

	Maj	Sig	Min	Total
Pre CTD	35 (28)	33 (26)	58 (46)	126
Post CTD	33 (20)	45 (27)	91 (54)	169

NOTE: Percentages in parentheses. $\chi^2 = 3.01$

P = <.25

Table 7

Analysis of Major, Significant and Minor Errors made per Flight

Error Type	Mean-per CTD	Standard Deviation	Mean Post-CTD	Standard Deviation	t	Significance Level
Major	.400	.845	.282	.585	1.14	<.25
Significant	.367	.785	.385	.693	.17	NS
Minor	.644	.928	.744	1.16	.69	NS

Table 8

Number of Available Flying Days and

Celestial Navigation Legs Flown per Day by Month

MONTH	FLYING DAYS	CELESTIAL NAV LEGS	CELESTIAL NAV LEGS/DAY
October 1979	23	267	11.61
November	20	193	9.65
December	16	126	7.88
January 1980	22	167	7.59
February	18	187	10.39
March	21	143	6.81
April	21	172	8.19
May	25	170	6.80

DISCUSSION AND CONCLUSION

There is no doubt that the data obtained during this study support the contention that the CTD provides a highly effective training medium for the maintenance of celestial navigation skills. None of the measures showed a significant degradation of performance and several key measures (percent reliability, cumulative error, and instructor ratings) showed significant improvement at the 95% confidence level. Several other measures (number of major errors per flight, computation and plotting errors, and the distribution of error types) showed significant improvements at the 75% confidence level. The primary question was whether the substitution of the CTD for some inflight training had caused a deterioration of navigator performance. The answer is an unequivocal "No." In fact, we can surmise, with some degree of confidence, that in-flight performance has in some ways improved as a consequence of the CTD.

Because a performance improvement was observed, any estimate of the Transfer Effectiveness Ratio (TER) will probably underestimate the value of the CTD. The Transfer Effectiveness Ratio, as defined by Roscoe (1971), provides a measure of the relative training effectiveness of training device practice as compared to training on the actual equipment. For the purposes of this study, this translates to following formula:

$$\text{TER} = \frac{\begin{array}{c}\text{Number of in-flight celestial}\\ \text{navigation training legs per}\\ \text{unit time prior to CTD delivery}\end{array} - \begin{array}{c}\text{Number of in-flight celestial}\\ \text{navigation training legs per}\\ \text{unit time subsequent to CTD delivery}\end{array}}{\begin{array}{c}\text{Number of CTD celestial navigation}\\ \text{training legs per unit time}\\ \text{subsequent to CTD delivery.}\end{array}}$$

We were unable to obtain precise data on the number of CTD celestial navigation legs "flown" per unit time. However, SAC Regulation 51-52, Volume 7 requires that each navigator fly a minimum of one, and a maximum of three per quarter. If we use the "three per quarter per navigator" figure, we will obtain a conservative estimate of the transfer effectiveness ratio. To allow common units, we must correct the total number of navigators and days per quarter as in the following equation:

$$\text{TER} = \frac{\text{(3 CTD nav legs/quarter/navigator X 300 navigators)/90 days/quarte.}}{\text{10 CTD nav legs/day}}$$

$$\text{TER} = \frac{\text{10.70 celestial nav legs/day} - \text{7.43 celestial nav legs/day}}{\text{10.0 CTD nav legs/day}}$$

$$\text{TEP} = .33$$

This indicates that .33 in-flight celestial navigation legs are equal to one CTD celestial navigation leg in terms of training value. Stated another way, it requires 3 CTD navigation legs to substitute for 1 in-flight celestial navigation leg. As was previously stated, however, this probably underestimates the value of the CTD since this substitution ratio appears to have resulted in better performance. One of the assumptions of this formula is that the pre- and post-training device groups are equal in terms of skill. In our sample, the post-CTD group seems to have performed better. We can probably assume that skill maintenance alone would require even less CTD or in-flight training than is presently required. However, the improved performance may be considered to be beneficial.

It should also be noted that this transfer effectiveness ratio can only be considered valid within a narrow range of utilization practices. If we were to assume that this held true over all levels of utilization, we could eliminate the need entirely for in-flight celestial navigation by substituting three times the current number of in-flight navigation legs with CTD navigation legs. We do not propose this to be the case, and any further reductions in in-flight training should be carefully monitored.

It is also interesting to compare the transfer effectiveness ratio to the operating cost ratio of the CTD to the B-52 and KC-135. This provides us with a measure of the cost effectiveness of the CTD. If we consider the operating costs to include power (i.e., fuel and electricity) and personnel (i.e., 0-3 level navigator) we find the following estimates:

<u>Power costs estimates</u> (per hour)

KC-135 (fuel)=1560 gallons JP-4@ $1.17/gal=$1825.20

B-52H (fuel)=25.75 gallons JP-4@ $1.17/gal=$3012.75

CTD (electricity)=.5 KWH electricity@ $.08/KWH=$.04

Personnel costs (both) Aircraft and CTD
(assume 0-3 level from SACMET)= $15.33

Cost of 1 hour KC-135 = $1825.20+$15.53=$1840.73

Cost of 1 hour B-52H = $3012.75+$15.53=$3028.28

Cost of 1 hour of CTD = $.08+$15.53=$15.61

$$\text{KC-135/CTD Cost Ratio} = \frac{\text{KC-135 cost}}{\text{CTD cost}} = \frac{\$1840.73}{\$15.61} = \underline{117.9}$$

$$\text{B-52/CTD Cost Ratio} = \frac{\text{B-52H cost}}{\text{CTD cost}} = \frac{\$3028.28}{\$15.61} = \underline{194.0}$$

What these numbers indicate is that, from a cost-effectiveness perspective, if less than 117.9 hours of CTD time were required to replace one hour of KC-135 training, the CTD would be cost-effective for KC-135 celestial navigation training. Similarly, if less than 194 hours of CTD training time provided the equivalent of one hour of B-52 H training, the CTD would be cost-effective for B-52H celestial navigation training. We have already estimated that three hours of CTD training is equivalent to one hour of aircraft training. Therefore the CTD is undoubtedly not only a highly cost-effective training device, but also provides an effective training environment. Again, these data only include fuel costs and the navigator's time costs. To be conservative, the other five crewmembers in the B-52 and three crewmembers in the KC-135 were not included. Some may argue that they are receiving other effective training. Also, B-52 fuel cost estimates are for the B-52H aircraft, the most economical model to fly. The B-52D and B-52G models consume 23% and 13% more fuel, respectively.

Recommendations

Based upon these data, we have recommended that SAC consider utilization of the CTD as an effective means of maintaining celestial navigation skills for B-52 and KC-135 navigators. A substitution of three CTD navigation legs for each in-flight celestial navigation leg is recommended. At present, it is proposed that a minimum of two in-flight celestial navigation legs be required per navigator per quarter. However, it is also recommended that a further reduction of in-flight celestial navigation training be considered on an experimental basis to determine whether navigator proficiency can be maintained through greater use of the CTD. The potential for cost savings and/or better use of available in-flight training time is enormous.

On a more general level, these data should again indicate to the training device development community that we should seriously consider low fidelity/low cost training devices. Too often we ignore simple solutions such as a microcomputer with software. We are not yet at the point where <u>minimum</u> fidelity requirements can be specified from a training effectiveness viewpoint. However out data base is expanding, and it seems that less physical fidelity is required than we previously expected. Our design philosophy for part task trainers should be to build the lowest fadelity device which the user will accept. If we do this, we will identify the lower bound of fidelity as well as providing more <u>cost-effective</u> training equipment.

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NEW SIGNAL PROCESSING INTEGRATED CIRCUIT REPRESENTS TECHNOLOGICAL BREAKTHROUGHS FOR REDUCING TRAINER COSTS

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ABSTRACT

New integrated circuit signal processing devices introduced by several manufacturers are usually considered to be for specialized applications. However, it will be shown that these devices are "ideally" suited for the real-time simulation of whole classes of dynamic subsystems. Furthermore, these devices could be used to replace analog components and/or hardware which are subject to aging, drifting and other factors that result in maintenance problems. Since practically all training devices involve placing a trainee in a realistic dynamic environment, these devices could impact the training device industry much like the GP digital computer. The technological techniques required to utilize these new signal processing chips will be presented. Finally, a survey of training devices that could be improved or reduced in cost by using these new devices will be presented.

INTRODUCTION

At present, there are two prominent manufacturers committed to capturing the emerging LSI (including single chip applications) signal processing market. Their alternate approaches to this market are best presented in a tabular form - see Table 1. In brief terms, one has embarked on a fixed point processor approach, whereas the other has chosen a floating point processor design approach. The fixed point approach is easier to implement in terms of current technology, and as such is more mature (approximately two years old). On the other hand the floating point approach shows much more potential in terms of broad-based applications, e.g., compact spectrum measuring devices using FFT chips, statistical analysis devices, array processing etc. As a bonus, the floating point processors do not have the difficult and "pesky" problems associated with scaling fixed-point processors. Several other manufacturers have committed resources to enter this market. Still others should be considered as competitors by virtue of their powerful general purpose microcomputer lines which can be applied to varied and sundry signal processing applications.

TABLE 1. FIXED VS. FLOATING POINT PROCESSORS

Topics	Remarks	
	Fixed Point	Floating Point
1. Math Ops	Fixed Point-scaling problems	Floating Points-no scaling problems
2. Speed	Comparable	Comparable
3. Design	Easy with single chip and software tools	Relatively complex, requiring a complete unique procedure for each application
4. Continuous programmability	Virtually impossible (memory not accessible) except for analog control of center frequency, etc.	Completely achievable but still a rather difficult design problem
5. Evolution	Rather mature	Rather early in development phase
6. Alternatives	Limited to dynamic models and special non-linear subsystems	Most promise for FFT, statistical analysis, array processing, etc. - but accompanied (still) by involved design steps.

When one considers the millions of dollars that manufacturers have committed to manufacturing and marketing of newly emerging signal processing chips (and chip families), one must ask where and how can these technologies be applied to trainers. Hopefully, some of these questions can be answered.

WHAT ARE SIGNAL PROCESSING CHIPS?

It is unfortunate that the words "digital signal processing" or "Processors" and "digital filters" have become the bywords for devices that are more accurately described as real-time digital dynamic simulators or implementations. Traditionally, managers and planners tend to think spectrum shapers or band limiting devices when referring to filters. Similarly, signal processors are thought of as communication pre- and post-signal conditioners. It is important to note that these devices can be used to implement any reasonable size dynamic real-time digital model, such as:

1. Digital controllers for analog servosystems.

Training seminars have been conducted on national and international levels for their sales/ marketing personnel - and then followed up with free (as token costs) seminars in all areas devoted to marketing their signal processing components.

2. Replace whole combinations of analog devices; e.g., circuits, spring-mass systems, motor controllers, etc.

3. Simulate dynamic analog devices of any type in addition to implementing digital filters and signal processors. In fact, these devices show promise for designing inexpensive signal generators, electrical measuring devices, tuneable filters, etc.

Finally, it should be noted that the "general class" of signal processing chips should include special purpose preand post-filters to interface junctures, FFT spectrum analysis chips, high-speed floating point multiply/divide processors, etc. These specialized devices also play a role in processing signals although they are not as prevalent as dynamic subsystem simulators.

TRAINING DEVICE APPLICATIONS

The ability of this device to simulate dynamic models in software, to construct dynamic models in hardware supported by software, and to construct dynamic hardware, has potential payoffs in many areas of training devices. As one example of each of these, consider:

> A war game simulation where many dynamic vehicle situations interact together to produce Monte Carlo type results designed to determine kill ratios, logistics problems, etc. These type problems are highly dependent on software development and clever model formulation.
>
> A flight simulator where countless servos drive motion bases, visual optics, and control loading devices for input control such as rudder pedals. The success of these devices depend on implementing servo systems with carefully designed servo compensators and controllers that permit the simulated device and its environment to be useful for training.
>
> A satellite tracker trainer where dish drive servo velocity limits are far below field units for safety purposes. Then substantial savings are realized by specially designing small scale units that behave like the field units in every respect except for angle rate limits. Hardware redesign is therefore necessary to meet these performance requirements.

In view of the processor's ability to be substituted for the software, interface/hybrid, and hardware elements of the simulation systems, its potential as a high bandwidth adaptive controller becomes apparent.

Simulators are naturally limited in system performance when compared to the real world situations they simulate. The hardware simply does not have, and in cases does not exceed the range and fidelity of the real world. For example, motion platforms cannot generate the complete range of acceleration cue characteristics of a particular aircraft. However, since these requirements are task dependent, the system performance may be optimized as a function of task cue requirements by control of the system hardware/software that adapts (or optimizes) it for the task.

The processor can be programmed and combined with other chips to provide platform drive signal shaping as a function of specific input variables that characterize a task (e.g., carrier landing). For example, it may be desirable to change motion platform gain as a function of slant range to carrier or average stick input deviation from trim to accentuate cueing for small inputs. Since large inputs are less likely as the aircraft approaches the carrier, the platform cueing range is centered around a smaller, localized aircraft acceleration range. This would be accomplished using the processor by implementing filters in the software and modifying the filter gain and bandwidth as a function of slant range.

A SPECIFIC EXAMPLE

Of the many potential applications discussed for use of the "microprocessor on a chip", let's consider a typical state-of-the-art flight controls loading device. This device, which is used in almost all flight simulators generates realistic control stick forces, with extensive use of analog circuit cards for signal shaping functions. All-analog systems are generally preferred because of bandwidth requirements as high as 100 Hertz. Since the fixed point type of signal processor can be operated at sampled data rates of more than 10,000, it is ideally suited for the flight control loader devices.

A typical control loader is illustrated in Figure 1. Analog circuit cards are used for stabilization of the control loops and for generation of the loader forcing functions such as gradient and friction. Typically, several analog cards are required for each control channel.

Figure 2 shows the same loader, except with the "processor on a chip" replacing the analog cards and other analog shaping circuits. Thus, complex analog circuitry with inherent aging, drift, and maintenance considerations are replaced with the predictability and low maintenance qualities of a sampled data system.

In summary, requirements for dynamic systems and their simulations exist throughout the scope of training devices. In view of the previous discussion "What are Signal Processing Chips", it must be concluded that these (typical trainers and training device) areas all represent excellent candidates for signal processor chips. Furthermore, the standard general purpose digital advantages still apply, e.g.:

> EPROM based dynamic models can be redesigned/modified via simple software changes.
>
> Redundant hardware simplifies logistics and maintenance, not to mention capital savings.
>
> System repeatability is assured for training mods and corrections.

SIGNAL PROCESSING TECHNOLOGIES

The technological background that designers must possess to implement systems and subsystem designs based on signal processors fall into two basic categories. First, there is the general area of FFT/Spectrum Analysis applications applied to such problems as Spectrum Signature Analysis or System identification. These problems require engineers/designers trained in noise and communication, FFT algorithms formulation, discrete and continuous signal spectrums, etc. At least some graduate level work is needed for these type problems.

The second category of dynamic system modeling is typically unfamiliar to most engineers, but its level of expertise requirement makes it easy to master, even on a part-time basis, for the dedicated designer. The following areas of study with clarifying comments should serve to place the technologies required for signal processor type designs in perspective.

1. Continuous dynamic system modeling - an area that each engineer should possess by virtue of his differential equations, circuits, linear controls, etc., background.

2. Discrete dynamic modeling - an area missing in many engineer's background. However, this area is usually easily mastered by relating to 1. above and studying difference equations - transforms and discrete models from texts such as DeRusso, Roy and Close, Cadzow's and Kuo's books on sample data control systems (1,4,5,6).

3. Discrete and continuous system relations - an area best mastered by studying digital filters. Here the best approach is to review continuous filters; (such as Butterworth, Chebyshev, Elliptic, etc.) and then study the digital filter impulse invariant, step invariant, bilinear transform, and other methods of digital filter designs, which are topics in standard digital filter texts such as Oppenheim's or Antinov's (7,8).

NOTE: Again "digital filters" may be misleading. The goal and result here is to master dynamic discrete modeling (on digital computers of real-world continuous dynamic models which represent the environment of trainers).

4. Digital hardware implementation - an area almost all engineers have some background in. Assuming areas 1. through 3. above were mastered and a discrete H(Z) discrete model was frozen, then the steps of design for the chip would be:

(a) Code the H(Z) model in assembly language (9).

(b) Using a development system, evoke the assembler and generate an assembly file.

(c) With the software, obtain an object file of the H(Z) model.

(d) Evoke the simulator software and verify the design by input/output test function runs (10).

(e) Using the support software and a PROM burner, program the EPROM with the H(Z) object code.

(f) Test and evaluate the final design.

Thus, because of the rather broad technological background required for signal processing design, the area has been slow to develop. Even so, approximately six months of part-time study with one or two short courses can bring most engineers up to speed. This has been typically reduced to three months (one quarter course) for those with microcomputer system design background.

CONCLUSIONS

It has been postulated that signal processing LSI technological developments will impact the training device industry primarily because economic savings can be realized through:

1. Reduced capital costs

2. Reduced maintenance costs

3. Reduced modification and review costs (via software design)

Other benefits include:

4. Repeatability

5. Immunity to aging

6. Reduced size, weight, accuracy, etc.

7. General purpose hardware - quantity prices.

In view of these potential payoffs, the following conclusions are appropriate:

1. Steps should be taken to utilize signal processor LSI technology throughout applicable trainer designs. Considering the millions of dollars committed by manufacturers to real-time integrated circuits signal processor design, it is obvious that manufacturer market research has identified a multi-billion dollar application area with substantial advancement in technology, as well as alternate design approaches to "old" problems with substantial economic savings (companies are sinking millions into hardware development and marketing). For example, some conduct "running" nationwide seminars and are introducing new chips and support chips. "Inside info" indicates "new version" integrated circuits masks have gone to production.

2. Industry, Academia, and Government agency engineers and scientists must be educated and prepared to take advantage of the new signal processing - or discrete system and/or simulation design hardware. To do so requires preplanning and training of the related work forces.

3. Although the fixed point approach has encountered some difficulties with early production chips, it seems these problems will subside in view of new designs on the horizon. The maturity of this technology indicates immediate utilization.

4. The new floating point processing support chip families are moving a little slower. At this time it is probably prudent to prepare for their use through training measures - but hold off a little longer on real designs. Small special purpose designs may be appropriate to undertake now.

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APPENDIX

In late 1979 the electronic hardware industry was surprised when the first totally self-contained single chip signal processor was introduced. The digital portion of the processor has architecture specifically adapted for high speed real-time signal processing. As an example, one of the fixed point signal processors has the following characteristics:

4 Analog inputs (9 bits)

8 Analog outputs (9 bits)

Provisions for limited digital interface

192 24 bit instructions

Sample rates of 12 KHz (and even higher for simpler models)

24 bit fixed point internal precision

H(Z) models up to 10th to 14th order

Specialized instructions allow very short simple program implementations of signal generators, VCOs, phase-lock synchronizers, etc., - a multitude of applications. Later versions of their architecture promise even more flexibilities. Finally, it should be noted that early version chips still have design bugs that should subside with the perfection of manufacturing techniques (12).

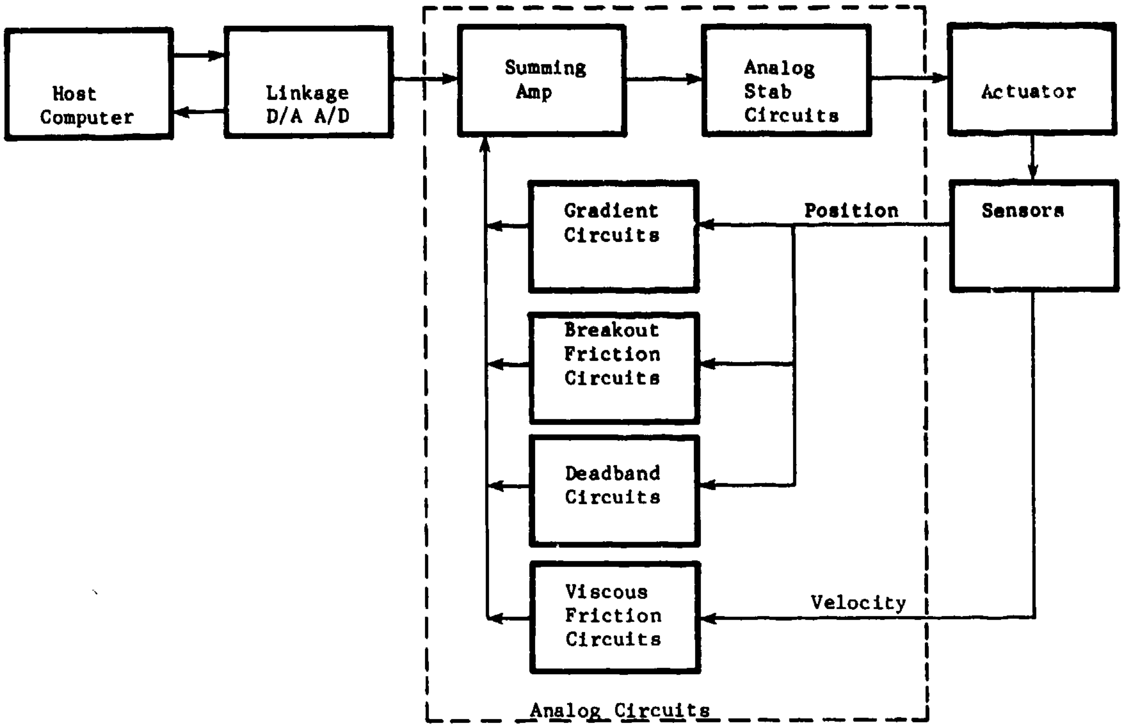

Figure 1. Analog Based Loader

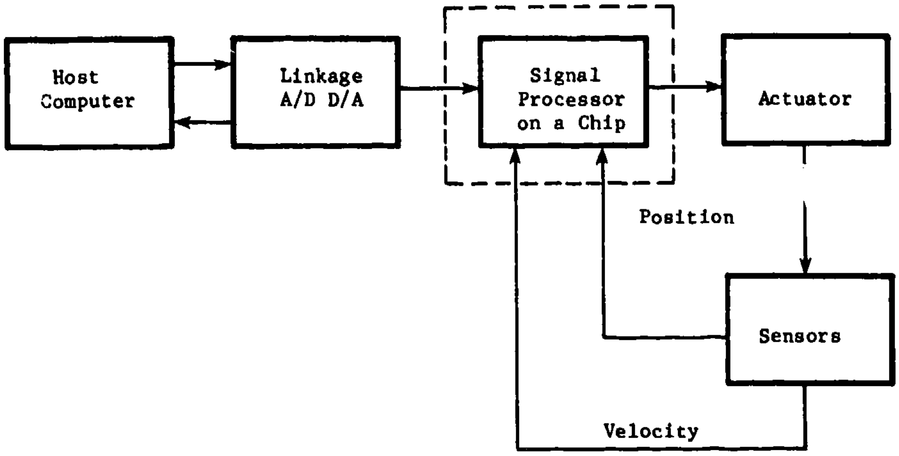

Figure 2. Signal Processor (2920) Based Loader

C-5A/C-141B AERIAL REFUELING SIMULATOR TRAINING EFFECTIVENESS - CONCLUSIONS FROM PRACTICAL EXPERIENCE

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ABSTRACT

Since 1976, more than 400 USAF/MAC pilots have started their aerial refueling training in a multipurpose engineering development simulator at Boeing. The initial simulator capability provided B-52 flight characteristics, a generalized transport cockpit, and a 45°v x 60°h FOV projected image of a K-707 Tanker. The training program was improved through the use of the simulator from the very beginning. Higher student flying performance was achieved with enhanced safety. Within six months, flying hours for training were reduced fifteen percent. Numerous simulator modifications have been made over the past several years, including improved flight characteristics, visual scene fidelity, and training features. This opportunity to train operational pilots in an environment of evolving simulator configurations has afforded a new understanding of the cost/benefit of different levels of simulation sophistication. Practical experience conclusions concerning the training effectiveness of a broad range of simulation features are discussed.

INTRODUCTION

To begin with, this paper is presented with some trepidation as it could be construed as taking a step backwards in simulation technology rather than moving forward in pushing the state of the art. Pragmatically, however, it should be viewed as a description of impressions of a highly cost effective approach to an immediate operational training need. These impressions have come from a program that grew by necessity and serendipity rather than from plan and design. The impressions and conclusions described are primarily subjective, based on five years of experience and observation, not from the preferred, rigorous scientific study.

The training of Military Airlift Command C-5A and last year, C-141B, aircraft commanders began in 1976 with a routine tour of the Boeing Visual Flight Simulation Laboratory by the Commander of MAC. This research and engineering facility had an aerial refueling simulation capability for both the receiver aircraft pilot as well as the tanker boom operator. The receiver pilot simulation capability was recognized as having potential application to an operational MAC training need.

The strategic concept of airlift operations is to deliver a payload anywhere in the world on short notice. Conflict in the Mid-East pointed out the need for enroute aerial refueling of the C-5A transport to achieve this objective (Figure 1). The immediate aerial refueling qualification of a large number of pilots, coupled with the economics of aircraft flying hours, fuel, and tanker availability, posed a training problem of significant proportions.

There were some strong technical questions on the part of both Boeing and MAC training personnel concerning the applicability of the aerial refueling engineering development simulation at Boeing to the training of C-5A pilots. At the time, the simulation provided only B-52 aerodynamics to be "flown" from a YC-14 engineering development cockpit. K-707 and K-747 tanker images were generated using T.V. camera/model techniques and displayed with a 45°v x 60°h FOV by direct projection on a hemispherical screen 15 feet in front of the cockpit. The functional elements of the simulator are depicted in Figure 2. Obviously direct application of the simulation situation to C-5A aerial refueling was open to question. The training need, however, transcended the questions and the decision was made to proceed with an attempt to use the simulator for training.

THREEFOLD TRAINING PROBLEM: OVERCOME ANXIETY, RECOGNIZE VISUAL CUES, AND DEVELOP FLIGHT CONTROL SKILLS

The flying of large transport aircraft is relatively straightforward - takeoff, climbout, enroute, approach, and land. Certainly these flight phases require solid piloting skills and techniques; however, the old characterization that transport flight encompasses hours and hours of boredom interrupted by an occasional moment of stark terror is probably a reasonable description.

Now enter the task of aerial refueling. Find that fuel-giving tanker in thousands of cubic miles of airspace. Current pilot capabilities coupled with onboard navigation systems can put the tanker in visual contact with relative ease. The problem begins several hundred feet behind the tanker. The closer you get the harder it becomes.

The first training problem is to begin to move the receiver aircraft close enough to the tanker to make a non-destructive fuel transferring contact. The flight manual points out that "...flying two airplanes in close vertical proximity is not safe." All pilot training reinforces the emotional notion that touching another aircraft in-flight is dangerous. This attitude, coupled with the transport pilot's concept that close formation flight means thousand foot separations, forms the basis for a strong fear of flying close. The pilot must overcome this natural anxiety and realize that he can develop the close trail formation flying skills necessary to safely perform the refueling task.

Figure 1. C-5A Transport being Aerial Refueled by a KC-135 Tanker

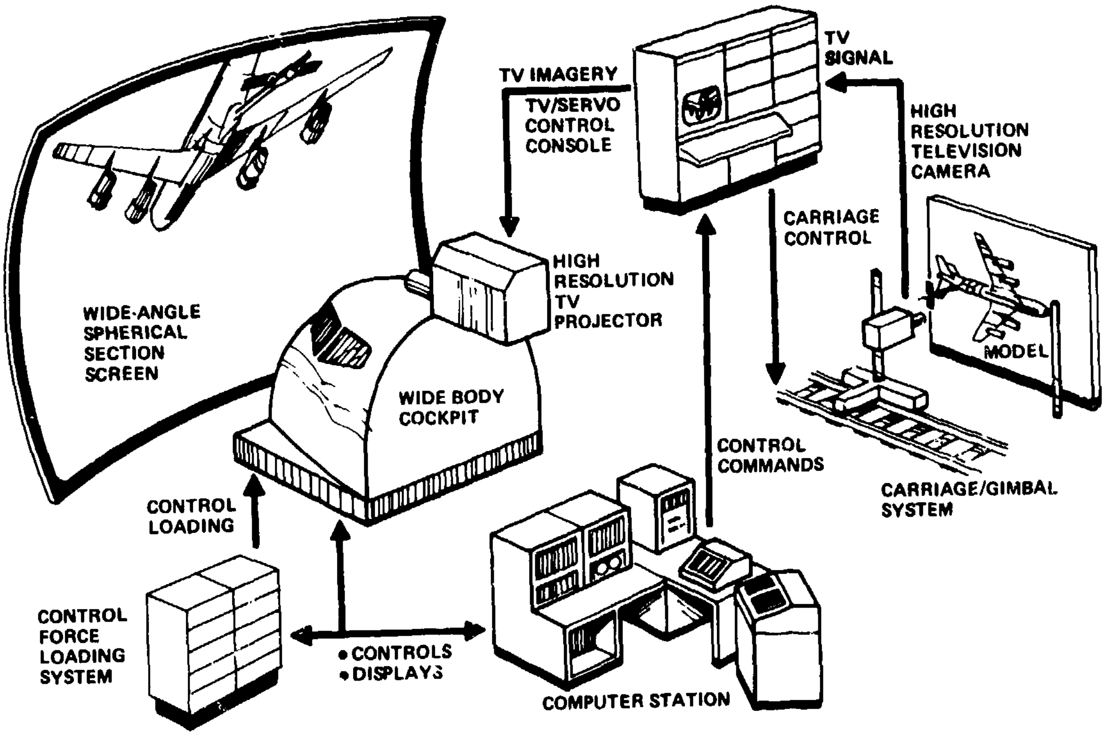

Figure 2. Boeing Aerial Refueling Simulator

Figure 3. Aerial Refueling Pre-Contact Position Behind a KC-135 Tanker

As the pilot gets close to the tanker he can see a myriad of detailed features that were undiscernable from a distance. These features include antennas, drains, access doors, lights, seams, lumps, and bumps. The second training problem is to identify and learn how and when to use these tanker features in the visual crosscheck as cues for detecting and maintaining the proper close trail formation position behind the tanker.

For example, the receiver director lights, while giving vertical and fore/aft position information, are often referred to as "too late lights", telling the pilot where he is but not where he is going. In daylight, observation of the UHF antenna as it lines up with a painted line on a row of rivets provides not only an excellent vertical position cue but also provides early direction and rate of movement information. Similarly, the KC-135 No. 4 engine nacelle can be seen as intersecting with the C-5A center windscreen post to provide fore/aft position and movement information to the receiver pilot.

Recognizing that aerial refueling is primarily a visual task, it is easy to understand that the tanker aircraft, framed in the receiver pilot's window, becomes simultaneously the source of attitude, altitude, and airspeed information (Figure 3). Where the tanker goes during refueling, so must the receiver go. The third training task, then, is to develop the precise control skills and responses to the tanker cues which will maintain the receiver aircraft in the small refueling envelope behind the tanker.

Development of a smooth pilot technique is necessary for safe and successful aerial refueling. Overcontrol or rough usage of the controls on the part of the pilot will cause a chain reaction with progressively larger and larger corrections required to maintain position. Because of the magnitude of interrelated aerodynamic effects between the tanker and receiver, large and rapid control movements may cause the two aircraft to be drawn together or thrown apart, further compounding the pilot's control problem and potentially causing an extremely unsafe condition. With the great mass and inertia associated with transport refueling, the pilot must learn to make very small and very early control corrections in order to remain in position and to keep the situation from getting out of hand.

For initial aerial refueling skill acquisition, the training problem, then, is threefold: build confidence in the pilot that he can safely fly close enough to the tanker to refuel; establish the meaning and use of tanker cues for identification of position and movement; and refine the precision and smoothness of flight control.

AERIAL REFUELING SIMULATION TRAINING PROGRAM

Initial Feasibility Test

Before committing to a major simulation training program, a few highly experienced C-5A aerial refueling instructor pilots and flight examiners subjectively evaluated the simulator performance. Based on their recommendations, the next group of C-5A pilots scheduled to enter aerial refueling training were selected for a simulation training feasibility test. Four pilots underwent training in the simulator before receiving the formal school training and four pilots went directly to the school. The same instructors were responsible for training both groups to qualification.

Comparison of the two groups' performance was primarily subjective instructor assessment supported by measurement of refueling contact time and number of inadvertant disconnects during the training flights. The group that had the opportunity to train in the simulator was judged by the instructors to be more stable on the first training flight and was able to stay in the refueling position longer with fewer inadvertant disconnects. The general assessment was that the first flight performance of simulator trained pilots was equal to the second flight performance of non-simulator trained pilots.

Reduced Flying Training Program Established

The original C-5A pilot aerial refueling qualification course at Altus AFB included ground school instruction, flight simulator training for rendezvous, aerial refueling procedures, and crew coordination/communications, six aerial refueling training flights, and was completed with a seventh flight for a qualification evaluation. Based upon the results of the feasibility test a new training program was developed with training in the simulator substituting for the first of the six training flights. Each pilot would first undergo aerial refueling simulator training in Seattle prior to reporting to the school at Altus AFB. At Altus he would receive the same training curriculum as in the original program but with one less training flight in the aircraft.

The simulator training, conducted by qualified USAF instructor pilots, covered the essential elements of the first flight: closure to pre-contact, recognition of tanker cues, demonstration of the refueling envelope, stabilizing aircraft movement, and closure to contact. Figure 4 depicts the simulated view of the tanker in the pre-contact and contact positions. Each pilot received approximately five hours of simulator training spread over two days to minimize fatigue. This training approach has been followed for the past five years without significant change.

Evaluation of Simulator Effectiveness

The initial evaluation of aerial refueling simulator training effectiveness was primarily subjective, but nonetheless, dramatic. Prior to using the simulator, apprehension or fear, undeveloped pilot motor skills, coupled with new and strange procedures, all combined to produce very little stabilization behind the tanker, much less any significant refueling, on the first training flight. For all practical purposes, the first training flight was seldom productive in terms of developing pilot technique. Improvement in confidence, pilot skills, and technique were immediately apparent after addition of the simulator to the training program.

The great interest generated by the program required that some formal assessment of the improvement in training effectiveness be obtained. A controlled experiment using typical measures of pilot performance to compare different treatment groups was not practical. The squadron of operational aircraft used for aerial refueling training could not be instrumented to measure pilot performance inflight and economics dictated that all future pilots would be trained using the simulator.

Figure 4. Simulation in Pre-Contact and Contact Positions as Viewed from the Right of the Pilot's Head

Fortunately there was one practical and meaningful measure of aerial refueling performance that had been recorded for those pilots who had previously undergone training without the use of the simulator. Aerial refueling contact time (boom time) achieved by each pilot had been recorded on each training flight and check ride by the flight engineer. The same data was recorded for each of the pilots who were trained during the first 5 months of the new training program using the simulator.

Pilots in the two groups were all experienced C-5A aircraft commanders undergoing aerial refueling qualification training. The non-simulator trained group was composed of 56 pilots who had received six training flights plus an evaluation check flight for a total seven mission syllabus. The simulator trained group was composed of 47 pilots who received five training flights plus an evaluation check flight for a total six mission training syllabus.

The early subjective assessment of the effectiveness of the simulator was totally supported by comparison of contact time performance. On the first aerial refueling training flight the simulator trained pilots achieved an average of 18.6 minutes of contact time compared to an average of 10.3 minutes achieved by the non-simulator trained pilots. This amounted to a dramatic 81 percent improvement in first flight performance. The simulator trained pilots continued to achieve consistently more contact time on each succeeding flight. Upon completion of training with the evaluation check ride the simulator trained pilots had averaged a total of 148.5 minutes of contact time during their six aerial refueling missions in the C-5A. The non-simulator trained pilots averaged 149.7 minutes of total contact time during their seven flights.

Clearly, use of the aerial refueling simulator was shown to be an effective substitute for one aerial refueling training mission. Furthermore, it was recognized that the greater flight stability under the tanker and fewer inadvertent disconnects displayed by the simulator trained pilots directly resulted in enhanced flight safety.

The MAC objective was to train a large number of pilots per year, conserve aircraft flying hours, and reduce operating costs; while at the same time, to maintain or improve pilot proficiency achieved during training. These objectives have been realized and the cost benefits of the improved training effectiveness afforded by the simulator have been significant. Aerial refueling training sorties have been reduced by 15 percent, making more flying hours available for operational missions and reducing the demand for KC-135 tanker support. This reduction in training flights for more than 400 pilots trained to date has saved over 1000 receiver aircraft flying hours. After accounting for simulator and TDY costs, estimated current annual savings exceed $2 million, or well over $12,000 per pilot trained. Perhaps even more significant is the total program savings of over 5 million gallons of fuel.

OBSERVATIONS OF THE EVOLUTION OF THE SIMULATOR CONFIGURATION

The original engineering simulation configuration for aerial refueling has undergone considerable modification over the past five years. Starting with a B-52 receiver flown from a YC-14 cockpit against K-747 and K-707 tankers, the simulation has evolved to aerodynamically accurate C-5A and C-141B receivers flying against a KC-135 tanker with interference flow field, down wash, and bow wave effects. In approximately one year, the YC-14 cockpit will be replaced with a C-141B cockpit in the simulator.

The opportunity to operationally train C-5A, and now C-141B, pilots in an environment of evolving simulator configurations has afforded some interesting insights and observations of the cost/benefit of different levels of simulation sophistication. What began as a self evident truth that the fidelity of the training environment must match the operational world has been opened to question. While perhaps all flight simulations can be opened to the same questions, it is important to recognize that the observations reported here are intended to be specific to the aerial refueling training situation only.

Cockpit Fidelity

A relatively simple general purpose engineering development cockpit has been in use for aerial refueling simulation research and training for the past 10 years. Flight controls, throttle quadrants, instruments and seats, not to mention general cockpit size, configuration, and layout, have borne little resemblance to the aircraft being simulated for aerial refueling. However, it has been used successfully for training, starting with B-52 pilots in the early 1970's, followed by 747 cargo/tanker and E-4A pilots, then with C-5A aircraft commanders continuously trained since 1976, and for the past year, C-141B aircraft commanders.

An explanation of this success may be derived by looking at the part-task nature of aerial refueling. Once visual contact with the tanker is made, the pilot gradually transitions from the visual world of his cockpit and instruments to a focus on the tanker. By the time the receiver reaches the pre-contact position, the pilot's whole visual world is solely and completely the tanker framed in his windscreen. His only relationship to the cockpit environment is the touch of the controls.

This rationale and the actual operational training experience to date suggests that a single, multipurpose cockpit configuration is suitable for aerial refueling simulation of a number of large, multi-engine jet aircraft. Specific cockpit interior details and instrument panels are relatively unimportant. In fact, in the current simulation training program, flight instruments are no longer being used, having been turned off by the instructor pilots in the first few months as unnecessary.

The physical size, shape, and location of the flight controls is probably of some importance. The controls in current use are significantly different than those in the C-5A and C-141B and require the pilots to spend a few moments to adapt to the new feel. While completely foreign controls in the aerial refueling situation do not appear to produce any measurable negative training, they don't add to the efficiency of the training. It appears feasible, however, that a common set of controls with the general physical feel and approximate location can be cost effectively used for multiple aircraft applications.

Probably most important is the representation of the window size and shape. It is the frame of reference through which the tanker is viewed. Even here, the precise replication of the window configuration is open to question. The currently used YC-14 cockpit window is not the same as the C-5A or the C-141B, however the top edge and center post are somewhat close, and do provide very similar reference points on the fuselage and No. 4 engine of the tanker. It would appear that as long as the window frame reference points are close to those in the operational aircraft, and can be appropriately used by the pilot, a single general purpose window configuration can be cost/effectively accepted for aerial refueling training. For major deviations, a single multipurpose cockpit should still be highly acceptable if equipped with replaceable window frames.

Simulation Gaming Area

The aerial refueling mission begins many miles beyond where the tanker can be visually sighted. During that time, rendezvous procedures are initiated and specific altitude, airspeed, and distance control points are achieved. As has been previously stated, however, the significant part of aerial refueling begins after the tanker comes into view. For cost/effective training, then, the question becomes how far behind the tanker should the simulation training begin? Is it at the first visual contact, three miles, one-half mile, one thousand feet, or one hundred feet? Tail chasing a tanker, even in a simulator, is not a particularly effective use of training time.

In the early days of the simulation training program the instructor pilots could begin with the receiver aircraft several thousand feet behind the tanker. With the exception of a few "gee-whiz" starts at this distance, the gap between tanker and receiver was rapidly reduced to the no more than the 300 feet and normally the 150 feet in use today. Up to that distance behind the tanker, even the inexperienced refueling pilot has little trouble maintaining a controlled closure.

The maximum vertical separation between tanker and receiver required in the simulation was similarly narrowed very early in the program to no more than 200 feet. Most typically vertical separations have not exceeded 100 feet below the tanker.

The lateral airspace used by the beginning pilot behind the tanker can be relatively large initially, particularly as he gets into the usual wild oscillations from KC-135 tanker wing tip to wing tip on the first flight. When this occurs, safe practice dictates that he back away from the tanker and stabilize. In the simulator, standard instructor pilot practice is to reset to a stabilized position behind the tanker whenever the student flies beyond the KC-135 wing tips. This eliminates non-productive thrashing about and makes for more efficient use of simulator time.

For all practical purposes, a realistic gaming area for aerial refueling simulation can be quite limited while providing very effective training. The tanker centered in the front of a gaming area 200 feet wide, 200 feet high, and 200 to 500 feet deep can open the doors to a broad spectrum of cost/effective visual simulation approaches.

Aerodynamics/Handling Qualities

The precise pilot control techniques that must be developed for aerial refueling would intuitively dictate that the simulated receiver aircraft aerodynamics and handling qualities along with the interference flow field and bow wave effects should be completely and accurately modeled. Recognition of control lag and correction of under and over control are key elements in aerial refueling training. Once again, a question may be asked: how accurately must the flight characteristics be modeled for effective training, and, at what cost?

Refueling simulation training for the C-5A began using relatively simply modeled B-52 aerodynamics, control, propulsion, and environmental effects models. The handling characteristics were nothing like the C-5A, but, during the first six months of the program the pilots were able to fly the simulation, learn, and transfer their newly acquired skills to the C-5A in flight. The often heard words "it doesn't fly anything like the C-5A" did not prevent the successful development of the piloting technique that permitted the reduction of one training flight from the syllabus.

Over the next several years the B-52 characteristics were modified to somewhat approximate the C-5A, particularly in roll and power response. This was accomplished by the time honored tradition of "tweaking" the mathematical coefficients based on experienced pilot comments. While the handling characteristics were still not the same as the C-5A, the pilots were more confident in the simulation. Perhaps this attitude was the most important aspect of the modification because there did not appear to be any discernable effect on training performance.

When the requirement to train C-141B pilots in aerial refueling was established, a complete and proper modeling of the receiver aircraft seemed appropriate. Extensive aircraft design and test data were obtained and detailed aerodynamic, flight control, and propulsion models were developed to produce an excellent simulation of the C-141B. This new simulation model permitted refueling at variable altitudes, gross weights, and c.g.'s, and included effects of tanker downwash, tanker/receiver interference flow field and bow wave effects. Upon completion of the C-141B simulation, a similar effort was accomplished for the C-5A.

Instructor and student pilot response to the new aircraft models was immediate and excellent. They had a simulation that was easily recognized as "their" airplane. Interestingly, however, when in the past the pilots knew they were not flying a simulation of their airplane, they were extremely tolerant of gross differences in handling qualities between simulator and airplane. With the new simulation models, the most insignificant variance was brought into sharp focus.

Based on past observations, there was no expectation that the new simulation models would result in a dramatic improvement in effectiveness for initial qualification training. With only limited training experience to date on the new models, that appears to be the case. There are some trim and handling quality improvements; however, that might prove very significant if future simulator continuation training is considered to maintain experienced pilot proficiency.

Obviously the goal should be to produce the best representation of the aircraft possible, not only for pilot acceptance but to ensure training effectiveness. This refueling simulation experience does suggest, however, that a generic model for large, multi-engine jet aircraft may be an acceptable and cost/effective approach for part-task training.

Instructional Features

Since the aerial refueling simulation was implemented in an engineering development simulator facility, virtually unlimited control over simulation parameters and pilot performance measurement was inherently available. Any aircraft position, attitude, or speed behind the tanker could be selected by the instructor, and aerodynamic effects could be selectively added or deleted. The instructor could start, freeze/hold, and stop/reset the simulation at will as well as to record and playback any simulation flight. Typical performance measurement included both analog and digital recording of all aircraft flight parameters and control inputs on a continuous or instantaneous basis, in raw data form, integrated, or statistically reported.

Most of this extensive capability has been paired back over the years to a level of useful practicality. Selective addition and deletion of aerodynamics effects and aircraft characteristics have been found helpful in building the inexperienced pilot's confidence and skill as he progresses through the learning process. Instructors now use the record/playback feature solely for an initial demonstration of what closure to contact should look like and how to recognize the limits of the refueling envelope. Occasionally, instructors will select a new starting position behind the tanker, most often to a stabilized pre-contact position which eliminates non-productive tail chasing as the pilots become more proficient.

Of all the possible performance measures only a few are currently being recorded by the instructors. Periodically the students fly a ten minute evaluation flight with total contact time and number of inadvertent disconnects recorded. This is practical and meaningful data that can be used by the instructor to monitor progress just as is done on the actual aircraft refueling mission. In addition, it is more economical in terms of reducing performance measurement and recording equipment and eliminating recordings of data that were never used.

Visual Image Quality and Field of View

One of the most significant elements in aerial refueling is the pilot's view of the tanker aircraft. The tanker becomes the receiver pilot's total visual world during his approach to the contact position. The pilot must learn what the tanker looks like, and how to use the tanker features as cues to judge distance, movement, and rate of change. This highly visual nature of the aerial refueling task places great demands on the quality of the visual simulation.

Pilots had great difficulty in achieving and maintaining a contact position during some of the very early aerial refueling simulation research and development at Boeing. Even though the physical models of the tanker aircraft were accurately shaped, it became rapidly apparent that the visual cues were insufficient. Prominent features such as doors, control surfaces, and windows were added to the tanker models. These features made the simulated refueling task easier to perform. Additional features such as antennas, drains, and seam lines were then added with a further apparent improvement in pilot performance under the tanker. While no objective performance measurements were obtained, improvement in pilot performance was obvious. By the time the C-5A simulation training began, all that remained to be added was the row of rivets in front of the VHF antenna, a cue specifically taught in the operational training program.

The importance of adequate tanker feature representation for aerial refueling simulation, though subjective, was none-the-less dramatic. The task could be accomplished only with difficulty without the presence of these tanker features. After the C-5A simulation training began, the K-707 tanker was replaced by a KC-135 tanker without the fan engines and with longer engine struts, but with all the other tanker features essentially the same (Figure 4). This change in tanker configuration resulted in no noticeable difference in pilot performance.

It would appear that it is the tanker feature detail that provides the distance, movement, and rate of change cues to the pilot. A conclusion based on practical experience and observation is that aerial refueling simulation image quality should be expressed in terms of the representation of tanker features that are consciously or unconsciously used as perceptual cues by the aerial refueling pilot.

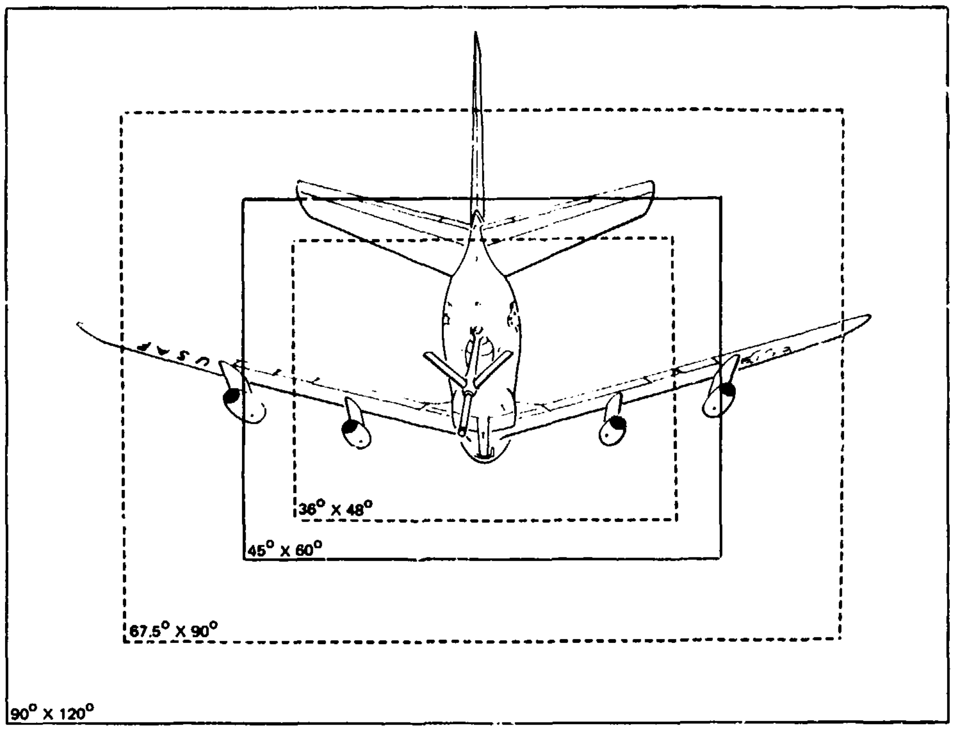

Figure 5. KC-135 Tanker Image Provided by Various Simulator Display Fields of View

Any discussion of image quality must logically include an assessment of the field of view of the tanker image in which the cues are represented. Obviously, the quality of the visual simulation is impaired if important perceptual cues fall outside of the simulated field of view. The portion of the tanker image available to the pilot in the contact position is depicted in Figure 5 for several display fields of view. Some portions of the image will be occluded by the cockpit window frame and of course the boom would not be seen as the pilot's head is forward of the nozzle when in the contact position.

As can be seen in Figure 5, the horizontal dimension is effected most by the different fields of view. The C-5A and C-141B simulation training program has used both the 120° horizontal (h) FOV and the currently used 60°h FOV. Other refueling simulations have used a 48°h FOV.

Analytically, one can show that a field of view which includes the tanker aircraft wingtips is most desirable. An uncorrected difference in bank angle between the tanker and receiver will cause divergent flight paths and eventual loss of the contact position. The receiver pilot must be able to rapidly detect the onset and direction of the apparent roll motion in order to make the early aileron corrections necessary to maintain a stable position under the tanker. When a divergence in bank angle occurs, the physical displacement of the wing at the outboard engine is approximately 70 percent of that at the wing tip. At the inboard engine the displacement is about 40 percent of that at the wing tip.

Not only would the larger displacements be more rapidly detected by the eye, but vision research has found that short duration (less than 1 second) motion sensitivity is greater and longer duration motion velocity thresholds are achieved more rapidly in the periphery of the visual field. This means that even while the pilot focuses on details along the tanker body, his motion sensitive peripheral vision is detecting roll cues out toward the wing tip.

The outboard engine provides significant fore and aft cues as has already been mentioned. Some pilots develop a technique of using the engine nacelle as it is bisected by the window post, others use the tail cone of the engine. When the receiver aircraft is centered in the refueling envelope, the 60°h FOV provides a view of most of the outboard engine to the pilot. This view of the engine is diminished as the receiver aircraft moves toward the inner limits of the envelope. The 60°h FOV has provided an acceptable, although marginal, view of the important outboard engine cue.

Both the presently used 60°h FOV and a 120°h FOV have been used in the aerial refueling simulation at Boeing. Very early in the program the 120°h FOV was tested to determine if adequate cue resolution could be maintained with the wider field of view which incorporated the tanker wing tips. The wide field of view provides only about one-half the resolution of the tanker features used as refueling cues, and as might be expected, this loss in cue resolution was not an acceptable trade for the added roll cue afforded by being able to see the tanker wing tips.

The high resolution T.V. camera, T.V. projector, and video electronics have been replaced in the simulation since the time of the field of view test. An approximate 25 percent increase in displayed T.V. resolution has been achieved with this state-of-the-art T.V. and solid state video electronics. This new equipment has noticeably enhanced the tanker image quality at 60°h FOV, however, while no tests have been conducted, it is still not expected to provide sufficient resolution at 120°h FOV.

A "quick and dirty" evaluation of a color T.V. system was accomplished in the spring of 1981. The color camera was manually positioned behind the tanker model and the static tanker image was projected on the screen in front of the cockpit. This visual impression was extremely dramatic. With approximately one half the T.V. line resolution of the existing monochrome system, the tanker features were much more discernable. Experienced refueling pilots were convinced of the significantly improved image quality and usefulness of the tanker cues. Based on this short test, it is apparent that some measure beyond that found in current visual system specifications is needed to define image quality reqirements. Unfortunately for the refueling simulation, the physical size of the color T.V. camera precludes incorporation in the simulation system without major redesign.

Experience and observation over the past five years suggest that a number of image quality conclusions for aerial refueling simulation are reasonable. First, image quality should be defined in terms of the training cues that must be provided. These cues include not only the specific tanker features but how much of the tanker (FOV) must be included. Because of the interaction between cue resolution and field of view, the elements comprising image quality should be prioritzed. Second, it is readily apparent that current 60°h FOVs provide acceptable image quality. The potential for inclusion of more tanker features/cues through futher expansion of the field of view appears possible with existing camera/model techniques. The field of view certainly can include the entire outboard engine without resulting in unacceptable image quality; expansion of the field of view to as much as 90°h may even be possible without resorting to a two channel visual system with its higher associated costs.

SUMMARY AND CONCLUSION

Five years of evolving aerial refueling simulation training experience has provided a relatively unique opportunity to observe the effects of simulator design and fidelity on training effectiveness. Just because a simulator design does not make use of the latest technology, or provide the utmost in fidelity, does not mean that it is not an effective approach for training. The state of the art of a simulator may be measured more by the training provided than by the technology employed.

For aerial refueling training, a fixed base, generic cockpit simulator, with a wide field of view visual display, using the "old" camera/model image generation approach has been found to provide extremely effective training for a range of different aircraft types. In many areas, the traditional notion that better fidelity means better training has been opened to question, particularly in terms of the cockpit and instruments, and perhaps in terms of handling qualities. The costly provisioning of a multitude of instructional features can be questioned and cost/effectively limited to what the instructor can practically use in day to day training. The training gaming area should be looked at in terms of what is needed for effective training rather that the too often used "nice to have". The implications for creative and cost/effective design approaches are significant when the training need is understood. Even when seemingly contradictory requirements of image quality and field of view are considered, the state-of-the-art answer may well be better satisfied by an old design approach than by the latest technology achievements.

What is required is more and better training, at a lower cost. Where advanced technology supports this objective, it should be used; where application of existing technology is more cost/effective, the choice is clear. The real answer may be found in understanding the training requirements, limiting the scope of simulator design to meet the training need, and then applying all available design approaches to the cost/effectiveness test. If this tailoring of technology to the training application results in an apparent backward step in technology advancement, perhaps it still can be considered innovative in terms of training productivity.

ABOUT THE AUTHOR

Dr. Thomas E. Sitterley is Manager of Training Equipment Programs for Product Support of the Boeing Aerospace Company. He has over 15 years experience in human performance and training research, instructional system design, and simulator development since receiving his Ph.D. from the University of Arizona.

COMPETITIVE CONTRACTING OF NON-PERSONAL SUPPORT SERVICES FOR FLIGHT SIMULATORS

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ABSTRACT

This paper describes a useful management tool for helping program managers determine the cost-effectiveness of competing maintenance, engineering support, and other types of service contracts. The underlying analytical framework is based upon cost improvement (learning) curve theory and incorporates the effects of competition on this process. Supporting data are discussed. The original research was performed by the authors at The Analytic Sciences Corporation (TASC) for the Air Force Human Resource Laboratory's (AFHRL) Advanced Simulator for Pilot Training (ASPT), Williams AFB, but is applicable to other simulator maintenance and support contracts where the work is of a repetitive, technical, and somewhat complex nature.

INTRODUCTION

Numerous studies have examined the impact of competition on acquisition costs. Several of these analyses have developed useful models and predicted acquisition costs for military hardware with some highly sophisticated efforts recently prepared. Few research efforts have analyzed the effects of competition on service-type contracts. Most studies concerning competition for service contracts are qualitative discussions with little or no attempt to develop an analytical framework or a supporting data base.

Questions which program management must often encounter and whose answers benefit from the use of a predictive framework include the following:

- What are likely future program costs of continuing to use a sole-source contractor?
- What are expected costs from competing the service contract?
- Does the accumulated experience and knowledge of the original sole-source firm provide too great an obstacle for a potential competitor to overcome?
- Are new firms able to effectively compete with the original contractor?
- Are potential savings from competition large enough to recover the up-front or nonrecurring costs of competing a contract (e.g., costs of technology transfer to potential competitors)?
- Will contractor performance deteriorate from intense competition and affect successful attainment of program goals?

While performing research for the Air Force Business Research Management Center (AFBRMC) and the Air Force Human Resource Lab (AFHRL), the authors have developed a framework for analyzing cost-performance trade-offs and predicting costs of service contracts. In addition, the authors have incorporated the effects of competition into the framework and have developed a supporting data base and computer model.

The authors' original research in this area was performed and applied for an analysis of flight simulator maintenance and support contracts. Although specific examples are from the flight simulator case, the concepts which are discussed apply to service contracts in general.

DEVELOPING THE ANALYTICAL FRAMEWORK

In analyzing the underlying theoretical concepts of competitive service contracting, the authors found several concepts which were similar to those incorporated into some of the previous hardware acquisition studies. Principal among these were learning or cost improvement curves. Since some of the services which the authors initially examined were highly complex (often state-of-the-art) support functions, it intuitively made sense that workers, supervisors, and management would improve their efficiency as familiarity with, and knowledge of, the system grew.

This paper begins with a brief general discussion of cost improvement (learning) curve theory and then illustrates important differences in unique application of the theory to service contracts.

COST IMPROVEMENT CURVE THEORY

A cost improvement curve reflects the relationship between the unit cost (or unit price) of an item and the quantity of the item produced. An "80 percent" curve is one in which a doubling of output drives unit cost down to 80 percent of its initial value. That is, the cost of the 2Nth unit is 20 percent less than the cost of the Nth unit.

Simply stated, the cost improvement curve represents the decreasing costs of accomplishing any repetitive operation as the operation is continued. As any technically complex process is repeated, whether it is production of missiles or maintenance of simulators, employee and supervisory familiarity should grow, technical methods should improve, and managerial efficiency should increase.

Cost Improvement Curve in Standard Form

Graphically displayed in Figure 1 is a cost improvement curve in standard form. The curve shows the recurring cost of each unit of production as a function of total quantity produced. The area under the curve is the total recurring cost of a given production run.

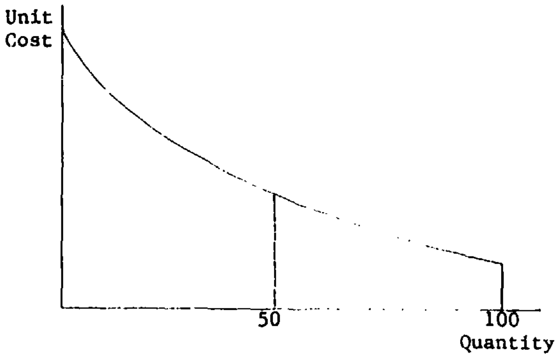

Figure 1 Cost Improvement Curve

It is important to note the rapid cost improvement which is incurred early in the performance period. Each horizontal increment of progress yields a smaller absolute reduction in cost than the previous increment. As the curve grows increasingly flatter, larger amounts of production or work are required in order to further reduce cost until the cost improvement curve ceases to function as a useful tool. Producers and suppliers of relatively limited production quantities, or state-of-the-art engineering services (e.g., simulator maintenance), are rarely found on the flat end of the curve.

SERVICE COST IMPROVEMENT CURVES

Cost improvement analysis has been applied almost exclusively to production studies (e.g., missiles, aircraft, new consumer products) with little application to services. The theory fits service contract analysis, but requires modifications from production or hardware application.

Not all services, just as not all production situations, are suitable for cost improvement curve analysis. As for production studies, the cost improvement curve effects for services are most notable for relatively new or complex situations. For example, the cost improvement curve for custodial services, after a small and rapid period of cost improvement, is probably extremely flat. Most janitorial companies, or individuals, are well established on the flat part of the cost improvement curve. But for services where techniques used, skills required, and equipment serviced, are relatively new, complex, changing or diverse in nature, cost improvement analysis provides a useful analytical tool.

The authors have identified several major features of cost improvement curve theory which are applicable to service contracts. A discussion of those features follows.

Definition of an Increment of Progress

One immediate need for applying this type of analysis to service contracts is definition of an increment of progress (i.e., a unit of production) along the cost improvement curve. Some period of performance is obviously the most convenient way to measure quantity (see Figure 2). The unit period of performance chosen should best reflect the repetitive nature of the work and is determined analytically. For flight simulator maintenance, the choice of a suitable increment of progress is not easily identifiable.

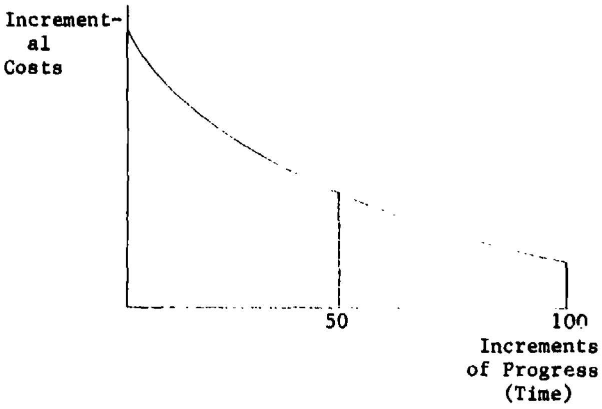

Figure 2 Service Cost Improvement Curves

Although set daily routines exist, (training, repairs, data analysis, preventive maintenance, etc.), the same problems do not arise each day, indicating that the best incremental measure of progress is longer than a day. With a period of performance measured along the horizontal axis, the vertical axis will now reflect the cost of service for each successive period (i.e., incremental cost).

For example, to define a suitable increment of progress for a flight simulator case, the authors have calculated actual cost improvement curve rates using various increments of progress. The results are presented in Table 1 and are based on contract data obtained from the Simulator for Air-to-Air Combat (SAAC) Program Office at Luke AFB. As the increments become smaller, the effect which they have upon the cost improvement rate becomes less significant. The cost improvement rate varies little with increments of one month or less. Consequently, the authors selected one month as the increment of progress for analysis purposes.

Table 1
SAAC Cost Improvement Curve Rates

Increment of Progress	Cost Improvement Curve Rate
Fiscal Year	.84
Month	.895
Week	.902
Day	.904
Hour	.905

Using a month as an acceptable increment of progress, the authors have calculated cost improvement rates (Table 2) for a number of flight simulator maintenance and support contracts. The average rate is 90 percent.

Table 2
Cost Improvement Curve Rates for Flight Simulator Maintenance and Support

System	Rate
F-4E/A-7D AAFTS	86.2
C-5/C-141	91.8
F-15	90.8
E-3A	95.3
F-111A-F	86.5
SAAC	89.5
ASPT	90.0
Average	90.0

Acceptable increments of progress can be determined for other types of service contracts and will vary from case to case.

Level of Effort, the Cost Improvement Forces, and Contractor Performance

For many service contracts, a specified level of effort (manpower) is required. In these cases, the contractor is required to provide a total number of manhours of service during the contract period. The contractor may be required to provide a fixed daily level of manpower or he may only have the total manpower level fixed, remaining free to choose his allocation (e.g., resources during a major system failure). Cost improvement effects are not eliminated by this requirement, but simply emerge in a different manner than the usual cost improvement process.

With daily (or monthly) manpower levels fixed, employees will learn, technical skills will develop, and managerial efficiency will increase. These forces produce an improvement in contractor performance over the length of the contract. If manpower and skills are allocated to meet required performance standards at the beginning of the contract period and remain fixed throughout the contract, then the contractor's performance levels will increasingly exceed the required standards as time passes and as contractor experience grows. The improved contractor performance represents the learning process within a contract period.* This effort has been observed for several level of effort contracts.

During a contract period, the government will be unable to benefit from the cost improvement process in terms of reduced cost, but will receive an increase in performance beyond that required. The emergence of performance levels which

*This analysis assumes that employee idle time does not increase. If the increased efficiency and learning emerge as an increase in idle time, then performance levels will remain relatively stable.

exceed those required by the government indicates that the government can reduce specified manpower and skill levels and realize a cost reduction for the next contract. This process is graphically represented in the stairstep manner illustrated in Figure 3.

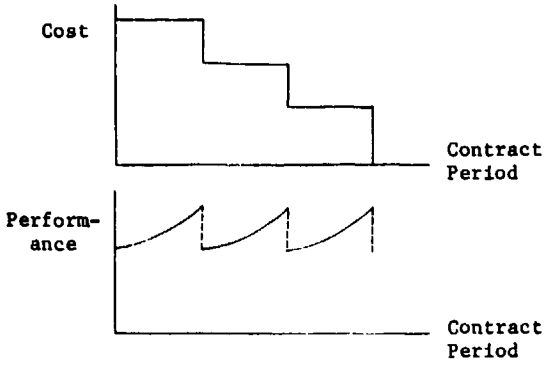

Figure 3 Fixed Level of Effort

Cost improvement forces for level of effort contracts might emerge in a different manner than the performance improvement case described above. Assume a contractor is obligated to provide a specified number of manhours of service for the contract period, but is not required to allocate those manhours equally over the length of the contract. He may allocate his contractually required manpower and resources in a manner that reflects the actual cost improvement process. In this situation, relatively larger amounts of resources are used in providing service at the beginning of the contract period than are used in providing service near the end of the contract. If the specified level of effort for a contract period is set too high and the contractor allocates his manpower and costs by following the actual cost improvement curve, then performance will remain stable, but at a rate in excess of the contractually required level. The level of stairstep cost reduction possible between contracts is still driven by the underlying cost improvement forces. Figure 4 illustrates this situation.

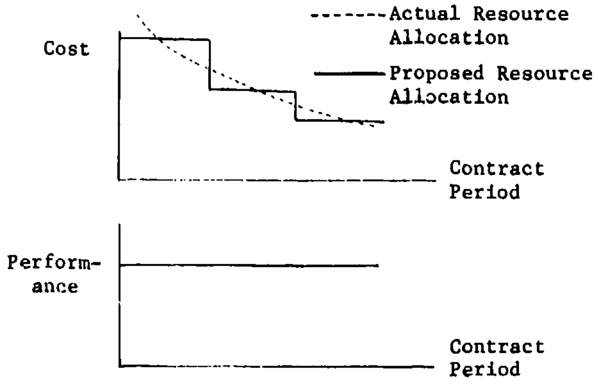

Figure 4 Decreasing Level of Effort

The solid line (steps) represents the cost and manpower level which was negotiated with the contractor. In reality, the contractor may allocate manpower and skill levels according to the descending pattern of the dotted line.

In the health care field, one of the first service areas where the authors' research revealed cost-improvement curve forces at work, the performance-cost trade-off is easily identifiable. Analysis of two Medicaid claims processing contracts,* one sole source and one competitive, illustrates the trade-off. The cost per unit (claim processed) of the sole source contract showed no cost improvement present. However, contractor performance (error rate) continually improved until it reached an eventual level far in excess of contract requirements. In the case of the competitively bid contract, cost per unit followed a cost improvement curve and steadily declined over time. Performance levels in this case stayed essentially constant. (The effects of competition for service contracts are examined in more detail later in this paper.)

Two performance-cost situations for level of effort contracts have been discussed. The first, where the level of manpower resources is held constant during a contract period, results in increasing performance levels. The second, where manpower follows a decreasing pattern with time, provides relatively stable performance levels at less cost. A combination of these two effects may also occur. A contractor may allocate his manpower in a decreasing manner which does not entirely reflect all of the cost improvement forces. Performance levels will then increase, but at a slower pace than if resources were equally distributed over the entire contract period. Figure 5 illustrates the combination effect.

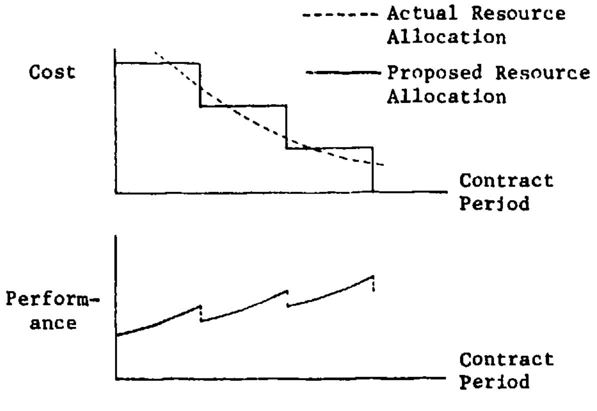

Figure 5 Combined Effect

*Preliminary Performance Profiles of Contractors Operating Under Experimental Contracts, Health Care Financing Administration.

The observation of performance-cost trade-offs on cost improvement curves is unique to service contract analysis. In the production of hardware, a similar relationship may exist, but may require years before the quality or performance tradeoff is known. With many service type contracts, the performance level is usually quickly and easily measurable and can serve as a useful tool in acquisition planning for follow-on contracts or for changing current contracts.

SUMMARY: ANALYTICAL FRAMEWORK

Cost improvement curve theory, although emerging in a somewhat different manner than in previous applications, proves applicable and useful for performing service contract cost analysis. Few government officials actively use the cost improvement process to project future costs when negotiating service contracts. When contracting officers recognize a significant improvement in contractor performance during the most recent contract period, they will negotiate to reduce costs for the next contract. This type of passive use of the cost improvement process delays any possible cost reduction by at least one contract period. A more active use of this type of analysis includes projecting costs, performance, and requirements with the use of cost improvement theory. Reduced costs and improved performance are reflected in the contract and captured as they occur. An active use of the cost improvement process projects future costs and assesses contracting options based on these projections.

EFFECTS OF COMPETITION

Attention is now focused on the effects of competition on the cost improvement process. The benefits of competition, the relative cost positions of potential competitors, and several unique aspects of service contract competition are discussed.

BENEFITS OF COMPETITION

The authors have identified two distinct effects on the cost improvement curve due to the introduction of competition:

- A downward shift of the cost improvement curve (i.e., a reduction in costs and profits)
- A downward rotation of the cost improvement curve (i.e., a faster rate of improvement).

These two effects are graphically displayed in Figure 6. (In Figure 6, the standard cost improvement curve has been transformed into a logarithmic version. This transformation produces a linear relationship which is convenient for displaying and describing the analytical results.) It is assumed that contracts were initially sole source. The curve's parallel downward shift from A to C results from both a reduction in profit and a reduction in costs.

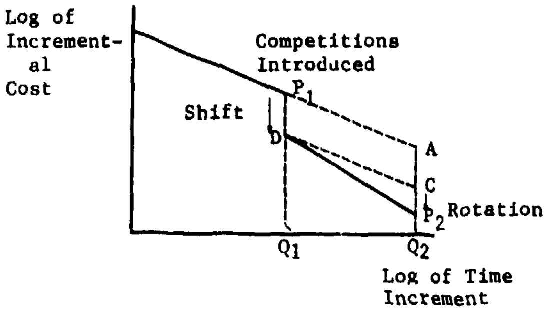

Figure 6 Benefits of Competition

The final reduction from C to P_2 represents a reduction based upon the firm developing, under competition, a steeper cost improvement curve (i.e., a faster rate of cost improvement). The line DP_2 reflects the steeper slope.

Without the pressures of competition, the contractor would have continued along his projected sole source cost improvement curve, P_1 to A. The total area in $P_1AQ_2Q_1$ represents what the total costs would have been if the government had remained with a sole source producer. The area $DP_2Q_2Q_1$ represents the actual costs obtained under competition. The area P_1AP_2D represents the amount of potential savings due to competition.

It is important to recognize that training or skill substitution can produce an improved cost improvement rate represented by the area DCP_2. If such cost improvement changes are ignored, the entire change AP_2 is likely to be anticipated for all future buys. However, it is clear from Figure 6 that the size of CP_2 critically depends upon the total number of periods for which service is provided. If the combined profit and cost savings due to competition (the downward shift of the cost improvement curve) can be established at a given level, these savings can be retained for all future periods of service. However, the savings from the downward rotation of the cost improvement curve (at point D) increase as the number or periods of service increase.

The potential advantage to the government from competing a previously sole source procured service was illustrated by Figure 6. In that figure, the cost to the government of purchasing the service is easily identifiable and represented by the area under the cost improvement curve. Even if the new competitor wins the competition, the cost benefits of competition to the government are still present and represented by the shift and rotation of the cost improvement curve. Regardless of which competitor wins, the benefits of competition to the government emerge in the same fashion. Not only does an initial cost and profit reduction apply to all future periods of service affected by the competition, but the cost improvement process occurs at an improved rate. Thus, there are both immediate and lasting effects of competition.

UNDERLYING COST TO THE SECOND FIRM

When faced with a competitive situation for a service previously procured from a sole source firm, the second firm faces an underlying cost schedule as depicted in Figure 7.

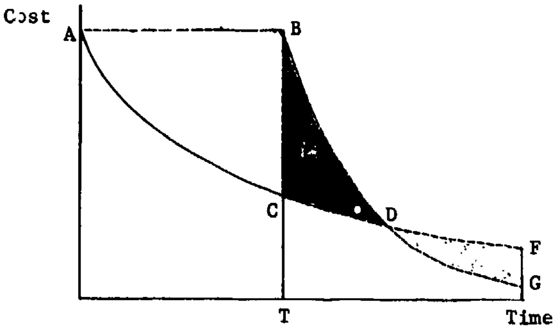

Figure 7 Underlying Cost to the Second Firm

Competition is conducted at time period T. Because of its lack of experience, the second firm must plan on beginning service for an increment of time, at some price B, which is in excess of the prevailing sole source price C. If the second firm's cost improvement rate is steeper than that for the sole source firm, cost parity will be achieved at some point D. If, after reaching Point D, the second firm were to move down the projected single source curve to point F, his total cost would exceed the projected single source total cost by the amount BCD. This is the experience cost for the second firm. If this was the basis of the second firm's bid, the original sole source firm would then win the competition by simply proposing a cost reflecting a move from point C to point F on its cost improvement curve. He would not feel any competitive pressure and would not have to reduce costs, profits, or improve his cost improvement curve rate to stay competitive (i.e., he would not have to shift and rotate his cost improvement curve).

The second firm, in an attempt to win the competition, must continue down a curve, after reaching point D, which is steeper than the projected sole source curve, such as from D to G. The total amount of potential competitive savings over the projected single source cost in this case is equal to the area DFG minus the area BCD for the contract period. When area DFG is greater than area BCD, the second firm is able to overcome his "experience" cost and offer service to the government at a lower cost than what would have prevailed from continuation of the sole source situation.

The sole source firm, in order to win the competition, must produce a lower cost than what he estimates his competitor will bid. This lowering of cost by the sole source firm is evidenced by a shift and rotation (as earlier discussed) in the sole source cost improvement curve. If the sole source firm miscalculates and his bid does not reflect a large enough shift and rotation to overtake his competitor's proposed cost, the second firm will win the competition. In either event, the government benefits from the competition.

Several factors will help the second firm obtain a competitive cost position. These factors include the following:

- Immediate competitive pressure
- Contract length
- Performance-cost trade-offs
- System modifications.

Immediate Competitive Pressure

In contrast to the sole source firm, the second firm would begin providing service at costs which were competitively bid and responsive to pressures of competition. The shift and rotation of his underlying cost schedule are reflected for his first period of service. Figure 8 below, which is similar but not identical to Figure 7, helps to illustrate this point. Figure 7 is drawn with point B, the cost of the second firm's initial period of service, lower than point A, the cost of the sole source contractor's initial period of service. Since the new firm is immediately faced with a competitive situation, he will logically begin,

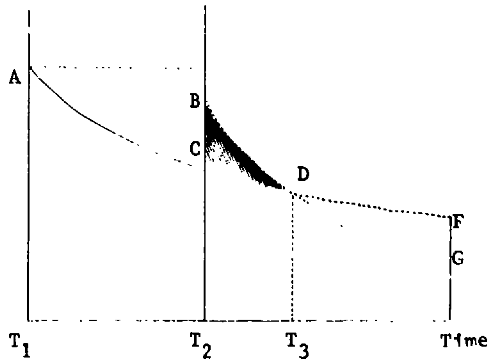

Figure 8 Immediate Competitive Pressure on the Second Firm

or bid to begin, providing service at a lower cost level and with a more rapid improvement rate than that which prevailed at the sole source determined point A. This reduction in the initial cost is caused by factors such as reduction in profit, technology transfer, and skill substitution. Additionally, the second firm's cost improvement curve is more steeply sloped than the sole source curve, with the intersection of the curves (cost parity) occuring at point D. Factors such as improved processes or more experienced employees will accelerate the cost improvement rate.

If point B is placed at a cost level reflecting a 10% downward shift from point A, and if a 4 percentage point rotation is used for the second firm's cost improvement rate (values which are well within the range of observed data cases), then the period of time from T_2 to T_3 (the time required for the second firm to move from point B to point D and achieve cost parity) is equal to approximately 5% of the period of time from T_1 to T_3 (the time required for the sole source firm to move from point A to point D). Simply stated, with the above assumptions, the second firm requires only 5% of the service experience that the sole source contractor needed (assuming a 90% sole source cost improvement curve) in arriving at the cost level represented by point D. For example, if the sole source firm has five years of sole source experience, the second firm would need less than four months to obtain cost parity.

Although these numbers are only an example, they help illustrate the magnitude of the competitive pressures on the original sole source contractor. When shift and rotation parameters consistent with observed data on competitive procurements are applied to a new competitor's underlying cost improvement curve at the initial period of service, the original contractor's cost advantage, projected by the sole source curve, is rapidly overcome.

It is important to note, that unlike a microeconomic analysis, inefficiency and waste are assumed to exist for the sole source situation. In a microeconomic analysis, when faced with the pressures of the market, the firm operates with the most efficient combination of resources possible. This situation is not true for some federal contracts, where the market forces are either absent or hidden under a totally unique buyer-seller relationship. The sole source firm, although increasing his efficiency as his experience grows (i.e., follows a cost improvement curve), is not following the most efficient (optimal) cost improvement path. The pressures of competition are required to move the sole source firm toward the optimal curve.

When a new competitor bids on the contract, since he is immediately faced with a competitive situation, his bid for the initial cost of work will not reflect the initial sole source cost but will be based upon an improved level of efficiency. Even if the new competitor bid to operate on his optimal curve, the sole source firm would still retain some amount of cost advantage (assuming the sole source firm bid to operate on or near his optimal curve) because of his initial sole source experience. In industries where new technical knowledge disseminates relatively rapidly among firms, this advantage may prove insignificant. In this case, the new firm and the sole source firm would face approximately equal "optimal" cost improvement paths. For example, in the electronics industry, when one firm achieves a technological breakthrough, the new knowledge spreads rapidly throughout the industry. As a sole source firm gains its initial experience, word of the techniques developed and knowledge acquired easily spreads to other firms.

For a case where the sole source firm has closely guarded technological and procedural developments, its advantage is much more significant. In this latter case, the initial sole source firm should win the competition by moving close enough to its optimal cost improvement curve so that its "learning" or "experience" advantage cannot be overcome by a new and inexperienced competitor. If both firms bid to provide service at their optimal levels, the sole source firm will win, providing it has an initial advantage from prior experience with the system. Of course, since the sole source firm improves its efficiency, the government will realize a savings. If the sole source firm misjudges its competition and bids too high, the more efficient new firm will win the competition and still produce the savings to the government.

Whether or not the experience and knowledge of the sole source firm provides a significant obstacle for a new competitor is dependent on the nature of the industry, the type of service provided, and the availability of technical data. (Implicit in this analysis is that rights to unique technical and procedural data are invaluable items to write into a contract.) Careful analysis of these factors is required to determine and quantify the likely cost improvement curve of the new firm.

Contract Length

Contract length is crucial to a potential second source in many service contract situations. With a lengthy contract horizon and an accelerated rate of cost improvement, a second firm not only has ample time to achieve cost parity, but also acquires sufficient cost reduction (learning) to overcome the experience cost of achieving parity and produce a substantial savings to the government.

During a recent competition for a flight simulator maintenance and support contract, the second firm won the award over the original sole source firm for a five-year period. The second firm's costs were based on providing support at the same average monthly cost (constant year dollars) for the entire five years. With a firm-fixed price (FFP) contract and performance rather than level of effort requirements, the winning firm will likely follow a cost improvement curve as depicted in Figure 9. As the firm's experience grows, the cost improvement forces drive the monthly cost of service below the average monthly cost for the five-year period of performance.

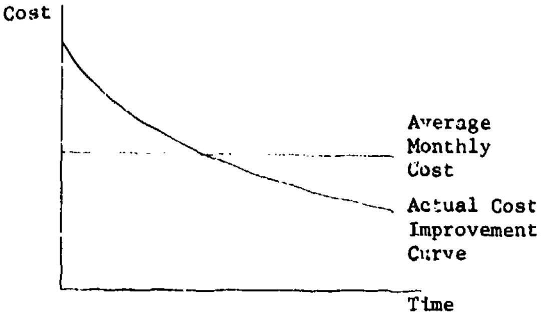

Figure 9 Actual Versus Monthly Average Cost

The actual cost curve of the winning firm must also intersect the projected sole source cost improvement curve (as seen earlier in Figure 7). With a five-year service horizon and an accelerated rate of cost improvement, the winning firm had ample time not only to achieve cost parity but also to overcome the experience cost of achieving parity and produce a substantial (40%) savings to the government over projected sole source costs.

Cost-Performance Trade-Offs

As discussed earlier, when contract performance standards are steadily exceeded by substantial amounts, cost savings are made possible by employing less resources (or less costly resources) and lowering unnecessarily high performance levels. This situation often exists for flight simulator support. The contractor's performance levels often exceed the minimum standards set by the government. A new competitor can bid to provide support service at a reduced cost with lower resultant performance levels, but still meet required performance standards.

For example, on one USAF simulator, the sole source contractor has steadily maintained an availability rate substantially in excess of the required 90%. On recent monthly performance reports, the average availability rate approximates 97%, with several months displaying a 99% rate. This situation indicates that a new competitor has sufficient room to reduce costs and still provide service at a level which meets performance requirements. If we assume that the relationship between cost and availability rate is similar to Figure 10, then the government is spending a disproportionately large amount of funds for the excess performance.

The curve depicted in Figure 10 resembles a total product curve for labor. Since labor is the primary input for a support service contract, this comparison appears both appropriate and useful. The slope of the curve, which represents the marginal product of labor, reflects the diminishing returns to scale of labor as additional amounts of that input are supplied. Additional gains in availability become relatively more expensive in terms of manpower.

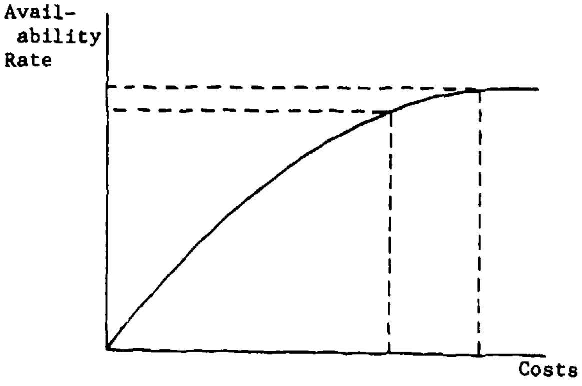

Figure 10 Potential Savings From a Reduction in Availability Rate

This relationship indicates that substantial savings are possible by providing service at a slightly lower availability rate. A potential competitor may lessen the sole source firm's cost advantage by submitting a bid which is based on providing service at a 90 percent availability rate. The difference (in cost) between the sole source position on his cost improvement curve and the level at which a new competitor will begin service is substantially reduced if the sole source firm bids on the basis of a 98% availability level and the new competitor bids on the basis of the required 90% level. As Figure 10 shows, a slight reduction in availability produces a more than proportionate reduction in cost. Any move by the sole source firm to adjust his bid downward on the basis of a lower availability rate shifts his costs below the projected sole source costs and is a direct savings to the government.

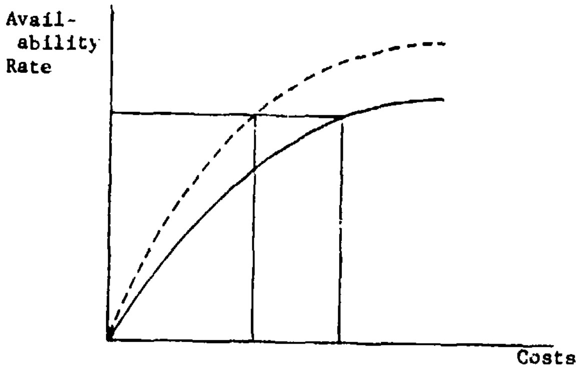

Figure 11 Competition and the Availability Rate

One theory states that competition produces improved performance at a reduced cost. As Figure 11 shows, this theory is not inconsistent with the performance-cost relationship theory. An increase in efficiency (e.g., improved processes, more qualified supervisors, more skilled employees) will shift the marginal curve upward. It now becomes possible to sustain a given level of performance (availability rate) at less cost than on the original curve. The performance-cost relationship is still applicable, but occurs at an improved level of efficiency.

System Modifications

Finally, modifications to the system for which the sole source contractor is providing support help to enhance the new firm's competitive position by partially under-cutting the sole source cost advantage.

Cost improvement curve theory implies continual improvement at repetitious work. If the nature of the work were to change, then the shape of the curve would also change. If the system being maintained on an engineering services contract were modified, then the nature of the work will change. Additional maintenance checks are required, additional workers are often hired, spares are replaced. The effect of this type of change is illustrated by the modified cost improvement curve in Figure 12.

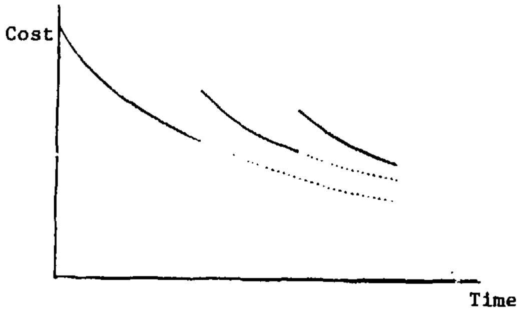

Figure 12 Effects of Modification and Changes in the Scope of Work

After each shift upward due to modifications, the cost improvement process continues, but a higher level of costs. For small changes (i.e., relatively minor system modifications), the upward shift is negligible and will represent only a small portion of the total cost. Major system modifications which drastically alter the nature of the support service are graphically displayed as large upward shifts of the cost improvement curve and virtually represent a new curve with significant cost reductions during the first few periods of service.

To understand how this process helps bring the second firm into cost parity with the single source, the cost improvement curve is viewed as a combination of smaller cost improvement curves. Theoretically, the cost improvement curves for each modification and the cost improvement curves for these parts of the original system which are still intact will sum to the total support cost for the entire system. If the modifications are recent, the sole source firm has not moved very far down the modification cost improvement curve and his cost advantage is reduced.

Although the effect of system modifications is difficult to measure based on available data, it is important to consider its possible impact when examining the original cost disadvantage of the second firm.

SUMMARY: EFFECTS OF COMPETITION

The authors' research and analysis of competition has produced the following results:

- Competition produces two distinct effects on the cost improvement curve
  - A downward shift of the curve
  - A downward rotation of the curve

  The magnitude of these effects determine the amount of the potential savings due to competition
- A new competitor is faced with an underlying cost disadvantage because of the experience of the sole source firm. The new competitor must rapidly overcome this disadvantage, or appear to the original source that he can, if the government is to realize substantial savings from competition
- Several factors exist which help the second firm in obtaining a competitive cost position

-- Immediate competitive pressure on the second firm reduces his initial cost of providing service and hastens his rate of cost improvement over what would prevail in a sole source situation

-- Sufficient contract length provides a potential new firm, who follows a more rapid rate of cost reduction than the sole source firm, ample experience for achieving a competitive position

-- A performance-cost trade-off allows the second firm to reduce his cost by providing service with lower performance levels than those provided by the sole source firm, but performance levels which still meet government requirements

-- System modifications result in a new cost improvement situation for both firms.

POTENTIAL APPLICATIONS

The authors have developed a unique framework in which some basic principles of service contracting were analyzed and the effects of competition were examined. The central feature of the authors' work is a shift and rotation of the sole source cost improvement curve in the presence of competition. This phenomenon represents an immediate reduction in the current level of costs (shift) and an acceleration in the rate of cost improvement (rotation) which applies to future periods of performance. The magnitude of these parameters depends upon the amount of competitive pressure which a second firm applies on the sole source firm.

When transformed into a computer-based model and used along with an accompanying data base, the framework is applicable to specific service programs for the purposes of forecasting savings (losses) from competition. The model provides a useful tool for program management and supplies information which helps managers determine the future costs of their program, the cost-effectiveness of competition, and the requirements for a successful competition. Sensitivity analyses can be performed on key factors such as the timing of competition, performance requirements, and the cost improvement rate.

Each application of the model is individually constructed. The nature and background of the specific program are researched. Data are gathered on similar programs and a probable range of parameter values are determined for key variables such as the sole source cost improvement rate, and the shift and rotation of the sole source curve.

Information and data which is collected and analyzed prior to application of the model includes, the following:

- Cost, contract, and general history of the program
- Past and future changes in the scope of the work
- Contractor performance reports
- Cost, contract, and performance reports on similar programs
- Technical data requirements (e.g., cost of a data package)
- The nature of the industry providing the service.

It is important to note that continual development of this analytical framework is occurring. Each application provides new insights and additional data which are used in further construction and refinement of the model for the purposes of helping managers recognize and capture potential cost savings on their service programs.

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COST-EFFECTIVENESS OF MAINTENANCE SIMULATORS FOR MILITARY TRAINING

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ABSTRACT

The cost-effectiveness of maintenance simulators is compared to that of actual equipment trainers for training military maintenance technicians. Maintenance simulators are as effective as actual equipment trainers when measured by student achievement at school; there is no difference in the job performance of students trained either way, according to supervisors' ratings (based on one study). The acquisition cost of maintenance simulators is less than that of actual equipment trainers; they cost less than 60 percent as much if development costs are included and less than 20 percent as much if only unit fabricating costs are considered. Acquisition and use of a maintenance simulator over a 15-year period would cost 38 percent as much as an actual equipment trainer (according to one life-cycle cost comparison). Since maintenance simulators and actual equipment trainers are equally effective and since maintenance simulators cost less, it is concluded that maintenance simulators are more cost-effective than actual equipment trainers. This finding is qualified because it comes from a limited number of comparisons, because effectiveness is based primarily on school achievement rather than on-the-job performance and because it is based primarily on acquisition rather than on life-cycle costs.

INTRODUCTION

This paper compares the cost-effectiveness of maintenance training simulators and actual equipment trainers for use in training military personnel how to maintain operational equipment. Both types of equipment have been used for training personnel to perform corrective and preventive maintenance at organizational and intermediate levels (Orlansky and String 1981).

Actual equipment trainers have long been used in technical training schools for two significant reasons: (1) they can be acquired simply by ordering additional units of operational equipment already being procured as components of weapon and support systems; and (2) they provide realistic training on the equipment to be maintained after leaving school. Operational equipment can be modified for training by, for example, placing it on a stand and adding power supplies, input signals and controls needed to make it operate in a classroom. In recent years, there has been a trend to use maintenance training simulators rather than actual equipment for training purposes. Maintenance simulators are said to have advantages for use in training such as lower cost, ability to demonstrate a wider variety of malfunctions and more freedom from breakdown in the classroom.

MAGNITUDE OF THE PROBLEM

Maintenance is a critical aspect of defense planning and operations and costs $18-20 billion each year, including the costs of spare parts, supplies and modifications (Turke 1977, p. 5). According to the General Accounting Office, the Army spends 25 percent ($7 billion in FY 1978) of its annual budget on maintenance; over 200,000 mechanics and equipment operators in the Army have specific unit-level maintenance responsibilities (GAO 1978, p. 1). In the Air Force, maintenance requires about 28 percent of the work force (military and civilian) and costs between $5 and $7 billion annually (Townsend 1980). Labor for repairs is estimated to account for 39 percent of the cost of recurring logistical support of the Air Force A-7D aircraft (Fiorello 1975). Specialized skill training at military schools will cost about $3.4 billion or 33 percent of the cost of individual training in fiscal year 1982 (Department of Defense, Military Manpower Training Report for FY 1982, p.6); the portion attributed solely to maintenance training is not known. The cost of on-the-job training, that follows school training, is also not known.

The three services spent over $5 million in FY 1979 for research and development on maintenance simulators. About $3.7 million (68 percent) of these funds (category 6.4 funds) were for the development and procurement of prototype training equipment. About 30 different maintenance simulators were either under contract or planned for development, as of February 1981.

There are now about 3600 different types of maintenance training devices in the Air Force to support aircraft systems. The Air Force Air Training Command estimates that the current inventory of all maintenance training devices cost $500 million, of which $350 million is for aircraft maintenance alone (Aeronautical Systems Division, 1978). The procurement of maintenance simulators for the F-16 aircraft is estimated to cost about $32 million, including some units to be delivered to NATO countries.

One large industrial contractor has estimated that the Department of Defense will spend over $600 million for maintenance trainers from 1977 to 1985; annual procurements are estimated to reach about $120 million per year by 1984 (Figure 1). The distribution of this procurement, according to type of simulator, is shown in Figure 2. Outside the United States, the procurement of maintenance simulators is estimated to be about $5.5 million per year.

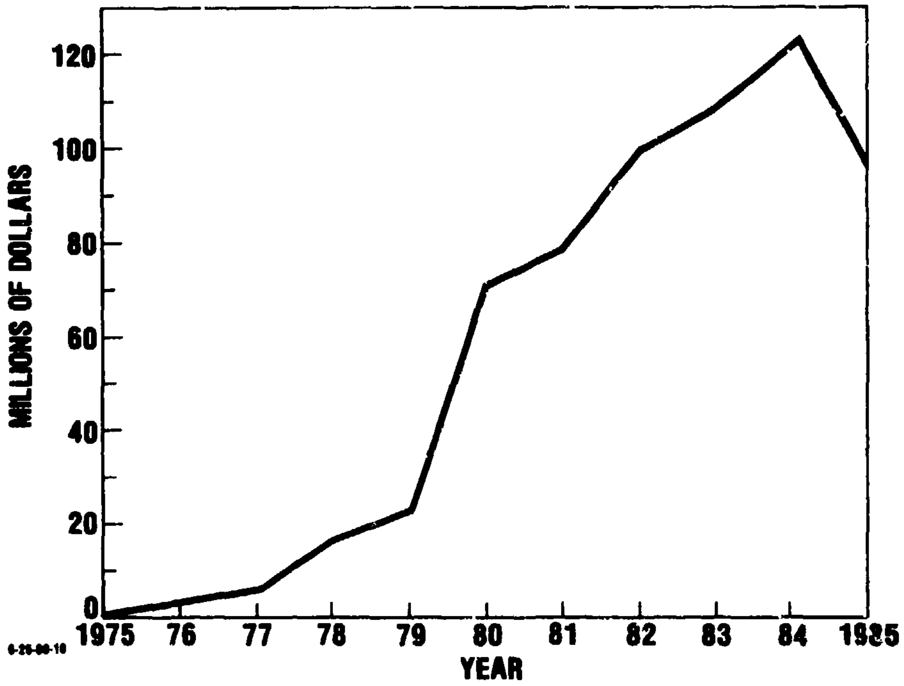


FIGURE 1. Estimated Procurement of Maintenance Trainers by the Department of Defense, 1975-1985 (as of November 1979)

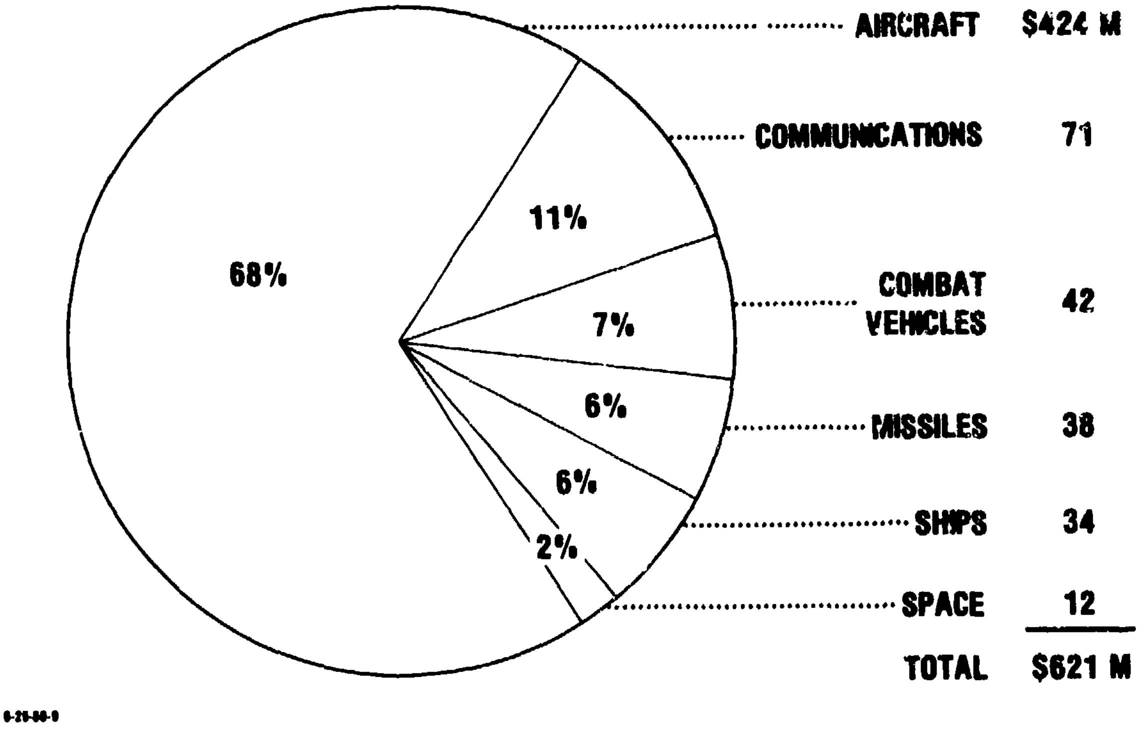


FIGURE 2. Predicted Procurement of Maintenance Trainers by the Department of Defense, According to Type of Application, 1977-1985 (Estimate made in November 1979)

The "Electronics-X" study, conducted in 1974, was a major effort to determine the cost and reliability of military electronic equipment (Gates, Gourary, Deitchman, Rowan and Weimer, 1974). Four methods were used to estimate the cost of maintaining electronics equipment each year. The results ranged from $3.4 billion to $6.8 billion with an average of $5.4 billion per year (Gates, Gourary, Deitchman et al., 1974, Vol. II, p. 374). The estimate of $5.4 billion per year for maintenance is about equal to the cost of procuring electronic equipment each year (Gates, Gourary, Deitchman et al., 1974, Vol. I, p. 52). Note that procurement costs relate to acquiring current technology; the maintenance costs relate to systems whose average age is about ten years.

The costs for manpower were estimated by the Defense Science Board Task Force on Electronics Management to account for perhaps as much as 75 percent of the costs of maintaining military electronics equipment; actual costs are unknown due to limitations in the cost allocation system (DSB, 1974, p. 14).

CHARACTERISTICS OF MAINTENANCE SIMULATORS

Maintenance simulators now under development differ notably in their resemblance to actual equipment, their ability to provide instructional services, and in their complexity and cost. These simulators are often characterized as 2-D or 3-D devices, i.e., as being two- or three-dimensional in their physical form; some simulators contain both 2-D and 3-D components.

The manufacturers of 2-D simulators have developed software packages, computer and support equipment that can be used in a number of different simulations. This has led us to distinguish between, what we call later in discussing costs, "standard" and "non-standard" maintenance simulator systems. Standard systems, whether they are 2-D or 3-D simulators, are likely to cost less than non-standard systems. A 3-D simulator permits "hands on" practice in manual maintenance skills not possible on many 2-D simulators; it also has greater physical similarity to the actual equipment. Whether or not greater physical similarity increases the effectiveness of training is a proper question.

Advantages of Maintenance Simulators

The advantages of simulators for training maintenance personnel have been recognized for many years (e.g., R.B. Miller 1954, Gagne 1962, Lumsdaine 1960, Valverde 1968, Kinkade and Wheaton 1972, G.G. Miller 1974, Montemerlo 1977, and Fink and Shriver 1978). The major advantage of a maintenance simulator is that, as a training device, it can be designed to provide facilities important for instructing students; in contrast, actual equipment is designed to perform some military function and is not intended to be a training device.

Maintenance simulators can be designed to demonstrate a large variety of malfunctions with which maintenance personnel should be familiar, including those that cannot be demonstrated conveniently on actual equipment trainers or that occur rarely in real life. All modern maintenance simulators incorporate some type of computer support. Thus, the symptoms of many types of complex faults can be stored in the computer and selected simply by a control setting on the instructor's console. Computer-supported equipment can also record what the student does, thereby reducing the need for constant observation by the instructor. The instructor can use information collected by the computer to guide each student; a computer can also assist the student without an instructor's intervention. Records of student performance and achievement can be maintained automatically. Simulators can be made rugged enough to sustain the damage or abuse encountered from students. Thus, they can provide greater reliability and availability in the classroom than is often often possible with actual equipment. Training that would be avoided because of safety reasons, e.g., exposure of students to dangerous electrical currents or hydraulic pressures, can be undertaken with little risk with a simulator. If students using such equipment complete their training in less time, as has often been found with computer-based methods of instruction, there are potential cost benefits due to savings in student time, increased throughput of students and reduced need for instructors and support personnel.

A simulator need not contain all the components found in the actual equipment. Thus, it is often possible to build a simulator that has greater flexibility and capacity for training and costs less than an actual equipment trainer.

Disadvantages of Maintenance Simulators

There are some disadvantages to the use of simulators. The procurement of maintenance simulators necessarily involves costs to design and build this special equipment, to develop course materials, maintenance procedures, support and documentation. The types of training provided by simulators may not provide the student with all the skills needed to maintain operational equipment, an outcome that seems assured when actual equipment is used for training. A simulator may not be ready when needed for training the initial cadres of a new weapon system because its design and development requires some effort in addition to or at least parallel to that needed for the actual equipment which is already being produced for the new system; modifications in the design of the actual equipment for a new system may also require modifications in the simulator and delay its delivery. If there are many and frequent modifications to the system, the original simulator may have to be redesigned totally at some additional cost, in order to be useful for training.

Data on the effectiveness and cost of maintenance simulators and actual equipment trainers are considered next.

THE EFFECTIVENESS OF MAINTENANCE SIMULATORS

The purpose of maintenance training, whether with simulators or actual equipment trainers, is to qualify technicians to maintain equipment in the field. In fact, however, the effectiveness of maintenance simulators for training technicians has been compared to that of actual equipment trainers only on the basis of student performance at school and not on the job; there is one exception to this general statement (Cicchinelli, Harmon, Keller and Kottenstette, 1980). The lack of job performance data to validate training applies generally to all types of military training rather than to maintenance training alone.

Effectiveness of Maintenance Simulators at Schools

We found 12 studies, conducted over the period of 1967 to 1980, that compare the effectiveness of maintenance simulators and actual equipment trainers for training in a variety of courses at military training schools; these are summarized in Figure 3.

Most of the maintenance simulators apply to electronics and aviation, e.g., radar, propellers, engines, flight controls, FM tuner, test equipment; one, the Hagen Automatic Boiler Control, involves an electro-mechanical system for ships. The training segments or courses in which they were used varied in length from 3 hours to 5 weeks (median 4.7 days, N = 12 courses); the number of subjects trained with simulators in these courses varied from 6 to 56 (median 16, N = 14 groups); a grand total of 267 students was involved in all of these studies.

Student Achievement

Effectiveness was evaluated by comparing the scores, in end-of-course tests, of students who used simulators with those who used actual equipment trainers. There are 13 comparisons; in 12 of these, students trained with simulators achieved the same or better test scores than those trained with actual equipment; in one case, scores were lower. The differences, though statistically significant, were small.

Cicchinelli, Harmon, Keller and Kottenstette (1980) compared supervisors' ratings on the job performance of technicians trained either with a maintenance simulator (the 6883 Test Station 3-D Simulator) or an actual equipment trainer. Field surveys provided data on the job performance of course graduates (some twice), some of whom were on the job as long as 32 weeks. The supervisors did not know how the students had been trained. Their ratings showed no noticeable difference between the performance of technicians trained with the simulator or the actual equipment trainer. The abilities of the technicians in both groups increased with amount of time on the job.

Time Savings

The automated and individualized method of instruction that is an inherent characteristic of modern maintenance simulators should be expected to save some of the time students need to complete the same course when given by conventional instruction (Orlansky and String 1979). Such time savings are reported in three of these studies (Parker and DePauli, 1967, Rigney, Towne, King and Moran, 1978 and Swezey, 1979); compared to the use of actual equipment trainers, maintenance simulators saved 22, 50 and 50 percent, respectively, of the time students needed to complete these courses. Although no explanations are offered for these time savings, one could surmise that they are due to such factors as that brighter students can complete a self-paced course faster than one given by conventional, group-paced instruction, that maintenance simulators generally have greater reliability in the classroom than do actual equipment trainers and that instructors need less time to set up training problems and/or to insert malfunctions in simulators than in actual equipment trainers.

Attitudes

Based on questionnaires administered at the completion of the courses, students favor the use of simulators in 9 of 10 cases and are neutral in one. Instructors are equally divided (about one-third in each category of response) in being favorable, neutral or unfavorable to the use of simulators.

Relevant Data from Computer-Based Instruction

Modern maintenance simulators can provide individualized instruction on a series of prescribed lessons. They can also measure student performance and see that the student does not go to a new lesson until he has mastered the preceding ones. The instructional strategies employed in these simulators are derived from widely used methods of instruction called computer-assisted and computer-managed instruction; both are individualized and self-paced in nature and use computers to monitor student progress. In computer-assisted instruction (CAI), all the instructional material is stored in a computer and presented to the student in a controlled manner via, e.g., a cathode ray tube or a visual projection device with random access to a large reservoir of slides. The student responds to this material by touching portions of the screen sensitive to touch or by using a keyboard or teletypewriter. In computer-managed instruction (CMI), the lessons are performed away from the computer in a learning carrel or on a laboratory bench

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	COMPARISONS: SIMULATOR TO ACTUAL EQUIPMENT							REFERENCE
			NO. OF SUBJECTS(3)	EFFECTIVENESS(1)				ATTITUDE TO SIMULATORS(2)		
				POORER	SAME	BETTER	TIME SAVINGS	STUDENTS	INSTR.	
Generalized sonar Maintenance Trainer	Sonar maintenance (special course)	4 days(3)	9		●		22%(4)	Students favorable		Parker and DePauli, 1967
	Intermediate General Electronics	4 weeks	20		●					DePauli and Parker, 1969
EC II	APQ-126 Radar		17					+		Spangenburg, 1974
	Mohawk Propeller System	3 hrs	33			●				Darst, 1974
	Hydraulic and Flight Control	32 hrs	13		●	●		+	–	Wright and Campbell, 1975
	Engine, Power Plants and Fuel	24 hrs	13	●	●			+	–	Wright and Campbell, 1975
	Environmental/Utility System	32 hrs	9		●●			+	–	Wright and Campbell, 1975
	APQ-126 Radar	60 hrs	15		●●			0/+	0/+	McGuirk, Pieper, and Miller, 1975
										Platt, 1976
								+	+	Biersner, 1975
	Pilot Familiarization, T-2C	18 hrs	6						+	Biersner, 1976
	Flight Office: Familiarization, TA-4C	11 hrs	30						+	Biersner, 1976
Automated Electronics Maintenance Trainer	FM Tuner									Modrick, Kanarick, Daniel, and Gardner, 1975
	Power Control for ALM-64 Test Equip									Modrick, Kanarick, Daniel, and Gardner, 1975
	ALM-106B Test Set									Modrick, Kanarick, Daniel, and Gardner, 1975
	Visual Target-Acquisition System									Modrick, Kanarick, Daniel, and Gardner, 1975
Generalized Maintenance Training System	SRC-20 UHF Voice Command System		20				ABOUT 50%	+		Rigney, Towne, King, and Moran, 1978
	SPA-61 Radar Repeater	16 hrs	10					+		Rigney, Towne, Moran, et al., 1978
Fault Identification Simulator	Hagen Automatic Boiler	5 wks	16		●		ABOUT 50%			Swezey (in Kinkade 1979)
6883 Converter/ Flight Control Systems Test Station	F-111 Avionics Maintenance	6 days(5)	56		●			+	0/+	Cicchinelli, Harmon, Keller, et al, 1980

(1) Some studies provide more than one comparison.

(2) favorable. 0 neutral. negative; 0/ + neutral to mildly favorable

(3) Simulator only.

(4) Average of five maintenance tasks in final test.

(5) Training with 6883 takes 2 days in a 23-week course; 6 days in this special test.

11-18-80-11

FIGURE 3. Summary of Studies on the Effectiveness of Maintenance Simulators, 1967-1980

setup. The student takes a test at the completion of each lesson; the answers, on a sheet, are scored by the computer via an optical reader, which then directs the student to a new lesson or to additional practice on the current one.

CAI and CMI systems are not maintenance simulators but they have been used to provide certain aspects of maintenance training, e.g., knowledge of operating principles, troubleshooting procedures, fault identification, and the knowledge aspects of remove and replace actions (i.e., what the technician should do after a fault is identified rather than perform the task with actual parts). Knowledge about maintenance procedures can be acquired on a CAI and CMI system but this is accomplished with less fidelity and with little of the hands-on experience than can be provided by a maintenance simulator, particularly of the 3-D variety. Some of the new maintenance simulators are essentially CAI systems.

Student Achievement

In a previous study, the authors examined the cost-effectiveness of computer-based instruction in military training (Orlansky and String 1979). Some of the courses on which effectiveness data were available involved instruction similar to that provided on maintenance simulators, i.e., basic electronics, vehicle repair, fire control system maintenance, precision measuring equipment and weapons mechanic. Data on student achievement in these courses are presented in Figure 4; there are 28 comparisons of conventional instruction with CAI and two with CMI. Student achievement in these courses at school with CAI or CMI was the same as or superior to that provided by conventional instruction; the amount of superior performance, when present, was small. This is consistent with what we found for maintenance simulators.

Time Savings

Data on the amount of student time saved by CAI and CMI in these courses, compared to conventional instruction, are shown in Figure 5; there are 30 comparisons. The amount of time saved by computer-based instruction varied from -32 to 59 percent with a median value of 28 percent.

THE COST OF MAINTENANCE SIMULATORS

Many people believe that the cost of a maintenance simulator is a function of the fact that it is a two-dimensional or three-dimensional device. There is a certain plausibility to this point of view which relates the physical characteristics and complexity of a simulator to its cost. But another important cost factor concerns the number of units that are procured and, thus, the average cost of each unit. In order to deal with the issue of costs, we divided simulators into three classes called standard, non-standard and CAI-like systems.

Standard Systems

This class of maintenance simulators is based on standardization of the physical configuration. Such simulators consist of two elements: one element, called here the "general simulation system" constitutes a generalized and adaptable (but incomplete) simulation capability that can satisfy a wide range of specific training applications. The second element, that tailors the general simulation system to a particular training application, is typically limited to courseware and pictorial or other representations (i.e., the simulation model) of the particular equipment being simulated. Standard systems were the earliest type to be used for maintenance training and are the only class to achieve extensive use. Compared with the other classes of simulators, the standard systems are generally low in cost and limited in terms of the complexity of processes that can be simulated. About 650 units of standard simulators have been procured for about 200 different training applications (most produced by ECC, Burtek, Ridgeway, and Lockheed).

Non-Standard Systems

The outstanding characteristic of non-standard systems is diversity, encompassing different contractors and types of contracts, program purpose, numbers of devices manufactured, physical characteristics, complexity, and cost.

The physical characteristics of the non-standard simulators are diverse and include two- and three-dimensional trainers. There is wide variability in the software. Further, since most non-standard systems typically simulate only one operational system, there is no definitive separation between software and courseware functions. There are now about 17 non-standard maintenance simulator programs that will produce 687 units of 47 unique maintenance simulators, e.g., the Mk 92 Fire Control System, Close-In Weapon System, F-16, MA-3 and 6883 Test Bench. Producers of these simulators include Honeywell, Vought, Applimation, Grumman and RCA.

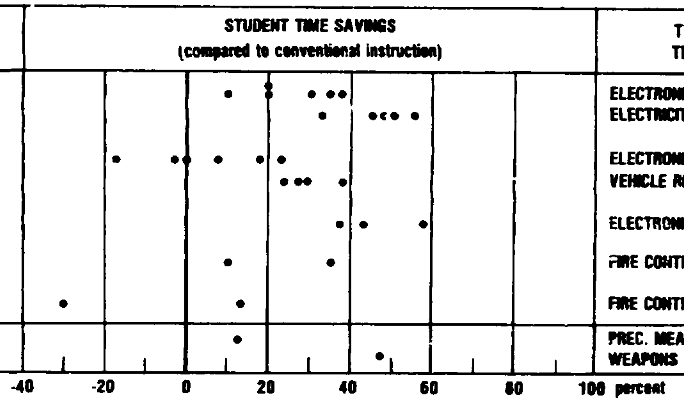
CAI-Like Systems

A CAI-like maintenance simulator is a computer-assisted instruction (CAI) system with courseware designed specifically to train maintenance skills. A typical CAI system uses a two-dimensional display (cathode ray tube and/or random access slide or microfiche projector) to present lesson materials (pictures of equipment and the like) under control of a computer that also monitors student progress, prescribes lessons, and scores tests. When

METHOD OF INSTRUCTION	SYSTEM	SERVICE	LOCATION	STUDENT ACHIEVEMENT AT SCHOOL (compared to conventional instruction)			TYPE OF TRAINING	REFERENCES
				INFERIOR	SAME	SUPERIOR		
CAI	IBM 1500	A	SIGNAL C&S		● ● ● ●	● ●	ELECTRONICS	IBM (1968), Longo (1969, 1972) Giunti and Longo (1971)
		N	SAN DIEGO			● ● ● ● ●	ELECTRICITY	Ford & Slough (1970), Hurlock & Lahey (1971, 1972), Ford, Slough *et al* (1972)
	PLATO IV	N	SAN DIEGO		● ●	● ● ● ●	ELECTRONICS	Stern (1975), Lahey, Crawford *et al.* (1976), Slough and Coady (unpubl.)
		AF	CHANUTE		● ● ● ●		VEHICLE REPAIR	Dallman, De Leo *et al* (1977)
	LTS-3	AF	KEESLER		● ●	●	ELECTRONICS	Harris, Grossberg *et al* (1972), Keesler AFB (1972, 1973)
	IDIOM	N	DAM NECK	●	●		FIRE CONTROL TECHNICIAN	General Electric Ordnance Systems (1975), Radsken and Grossen (1975)
	PLATO IV	N	DAM NECK		● ●		FIRE CONTROL TECHNICIAN	General Electric Ordnance Systems (1975), Radsken and Grossen (1975)
				TOTAL 1	15	12		
CMI	AIS	AF	LOWRY		●		PREC. MEASURING EQPT.	Briefing (1978)
		AF	LOWRY		●		WEAPONS MECHANIC	Briefing (1978)
				TOTAL 0	2	0		

Source: Orlansky and String (1979)
8-27-80-3

FIGURE 4. Student Achievement at School in Courses Relevant to Maintenance, CAI and CMI Compared to Conventional Instruction



METHOD OF INSTRUCTION	SYSTEM	SERVICE	LOCATION	STUDENT TIME SAVINGS (compared to conventional instruction)	TYPE OF TRAINING	REFERENCES
CAI	IBM 1500	A	SIGNAL C&S		ELECTRONICS	IBM (1968), Longo (1969, 1972) Giunti and Longo (1971 a&b)
		N	SAN DIEGO		ELECTRICITY	Ford & Slough (1970), Hurlock & Lahey (1971, 1972), Ford, Slough *et al* (1972)
	PLATO IV	N	SAN DIEGO		ELECTRONICS	Stern (1975), Lahey, Crawford *et al* (1976), Slough and Coady (unpubl.)
		AF	CHANUTE		VEHICLE REPAIR	Dallman, DeLeo *et al* (1977)
	LTS-3	AF	KEESLER		ELECTRONICS	Harris, Grossberg *et al* (1972), Keesler AFB (1972, 1973)
	IDIOM	N	DAM NECK		FIRE CONTROL TECHNICIAN	General Electric Ordnance Systems (1975), Radsken and Grossen (1975)
	PLATO IV	N	DAM NECK		FIRE CONTROL TECHNICIAN	General Electric Ordnance Systems (1975), Radsken and Grossen (1975)
CMI	AIS	AF	LOWRY		PREC. MEASURING EQPT.	Briefing (1978)
		AF	LOWRY		WEAPONS MECHANIC	Briefing (1978)

Source: Orlansky and String (1979).
8-27-80-2

FIGURE 5. Amount of Student Time Saved in Courses Relevant to Maintenance, CAI and CMI Compared to Conventional Instruction

adapted to maintenance training, the CAI features are retained, and the trainer may also employ three-dimensional versions of equipment. Examples of such systems are the Navy Electronic Equipment Maintenance Trainer and the Army Maintenance Training and Evaluation Simulation System. Insufficient cost data were available on CAI-like maintenance simulators and they are not discussed further.

Costs of Maintenance Training Simulators

We learned, to our regret, that the data now available on standard systems are insufficient to analyze their elements of cost and to relate these cost elements to the physical and performance characteristics of the trainers. In effect, it is now difficult or impossible to identify the major cost distinctions (e.g., between recurring and non-recurring costs, between development and fabrication, between hardware and software) that allow characteristics of the simulator to be related to the total cost of the simulator program.

Data from nine contracts for standard simulators were reviewed, and the information they contain is shown in Figure 6. These contracts involve the development of 67 different models of simulators and the delivery of a total of 444 units. The figure shows average contract cost per delivery (total contract value divided by the number of trainers procured) vs the number of trainers procured in each contract. These simulators ranged in unit

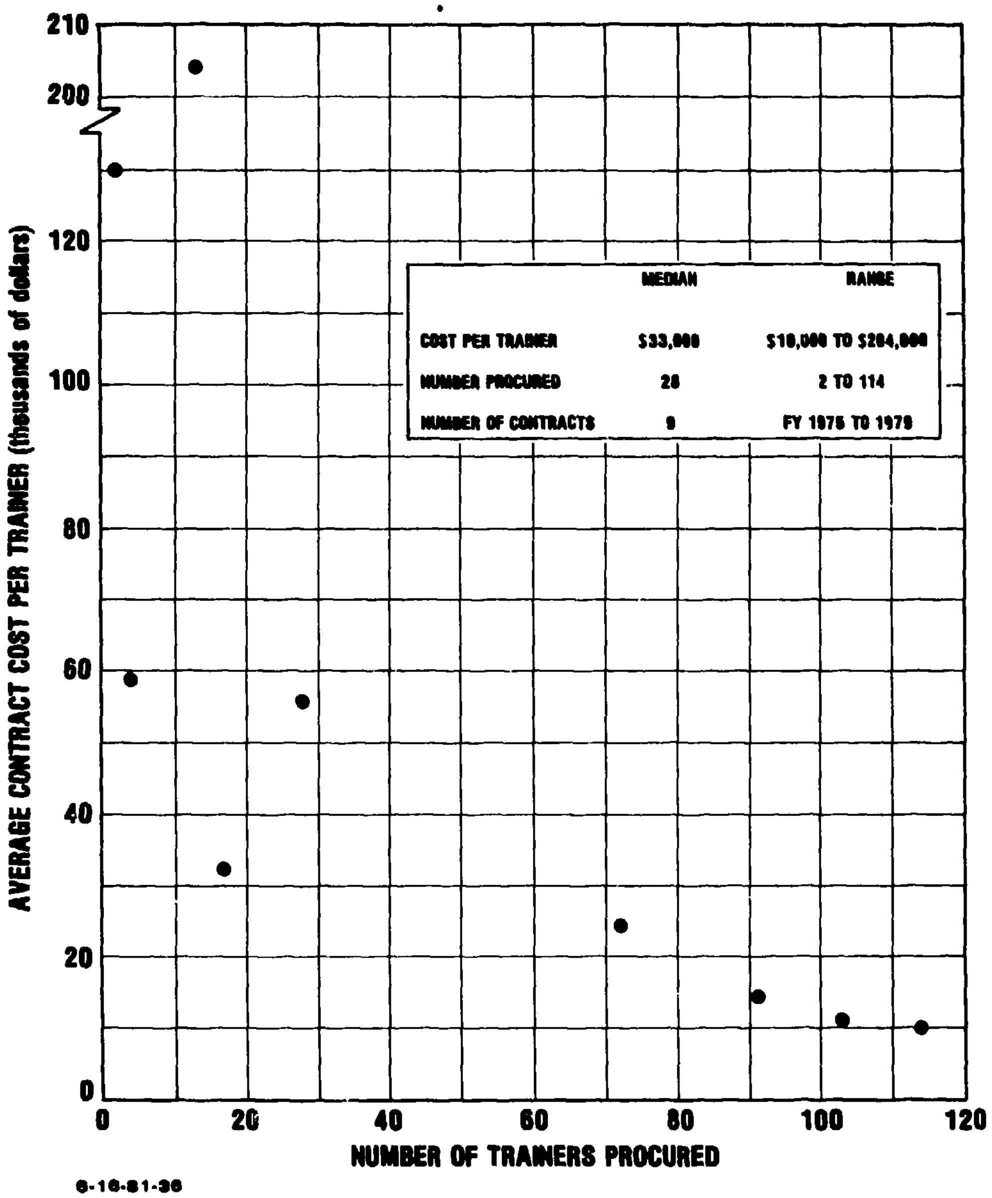


FIGURE 6. "Standard" Maintenance Simulators: Average Cost Per Trainer vs. Number of Trainers Procured

cost from about $10 thousand to $204 thousand each, with a median cost of about $33,000. As we would expect, the unit cost is reduced as the number of units in each contract increases. However, these simulators are not a homogenous sample; they vary in their complexity, physical and performance characteristics. Therefore, caution is advised in using the data in this figure.

The cost of 13 non-standard maintenance simulators is shown in Figure 7. The estimates are normalized to show recurring production costs adjusted to reflect a production quantity of one; costs of development and test are not included. These simulators range in cost from $100 thousand to $4.5 million; the median value is $900 thousand.

The non-recurring costs account for a large portion of the total program costs of non-standard maintenance simulators--over 70 percent when only unit is fabricated and about 50 percent when five or six are fabricated (Figure 8). Software and courseware account for 10 to 45 percent of total program costs (Figure 9).

COST-EFFECTIVENESS OF MAINTENANCE SIMULATORS

We found that student achievement at school is about the same whether students are trained with maintenance simulators or with actual equipment trainers. Therefore, the relative cost-effectiveness of maintenance simulators and actual equipment trainers depends on how much each costs.

We have just shown what maintenance simulators cost; next, we must compare the costs of simulators and of actual equipment trainers. But note that the data on maintenance simulators refer only to procurement costs. These data do not include the costs of using these simulators, such as for instructors, student pay, support and travel, maintenance of the training equipment and management of the school. There is one life-cycle cost comparison that we will consider separately. The cost comparison that follows is incomplete because it is based only on acquisition costs.

The cost of an actual equipment trainer is the production cost of one unit of equipment under procurement for some military system; this value does not include the costs of research, development, test and evaluation (RDT&E). Adapting a component of an operational system for use in training, such as by adding power, special inputs and controls, may require some additional costs attributable to training.

We were able to get relatively complete data, useful for comparative purposes, on both maintenance simulators and actual equipment trainers, for only 11 cases; comparisons were not possible for some recently developed maintenance simulators where actual equipment trainers had not been used previously for training. Some of the simulators are prototypes, rather than production units; data on these simulators include the costs of research and development. The costs of research and development should be removed

Trainer	Cost $(000)
AN/TPS-43 Ground Radar	100
Trident Air Conditioner	135
Trident High Pressure Air Compressor	140
F-111D Avionics Test Bench (2-D 6883)	395
A-6E TRAM	475
MA-3 Generator/Constant Speed Drive Test Stand	525
AWACS Radar System	900
F-111D Avionics Test Bench (3-D 6883)	920
A-7E Heads-Up Display Test Bench	1295
F-4J/N (AT Trainer)	1540
AWACS Navigation/Guidance System	2460
Trident Integrated Radio Room - Maintenance Trainer	2625
Trident Integrated Radio Room - Operator/ Maintenance Trainer	4465

FIGURE 7. Acquisition Costs of 13 Non-Standard Maintenance Simulators (Normalized to Include Recurring Costs for a Production Quantity of 1)

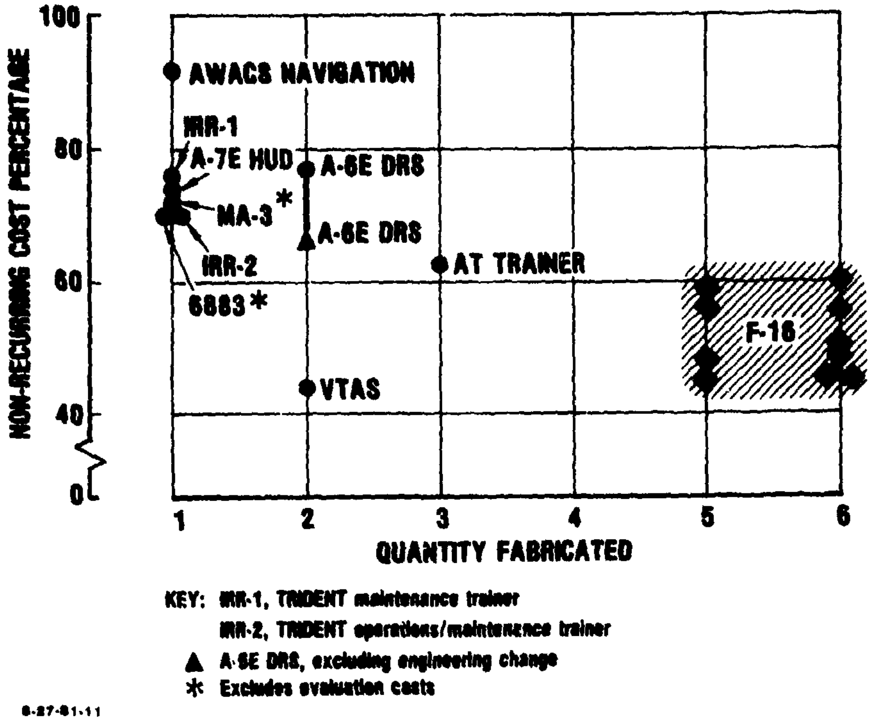


FIGURE 8. Non-Recurring Cost as a Percent of Program Total Cost According to Quantity Fabricated

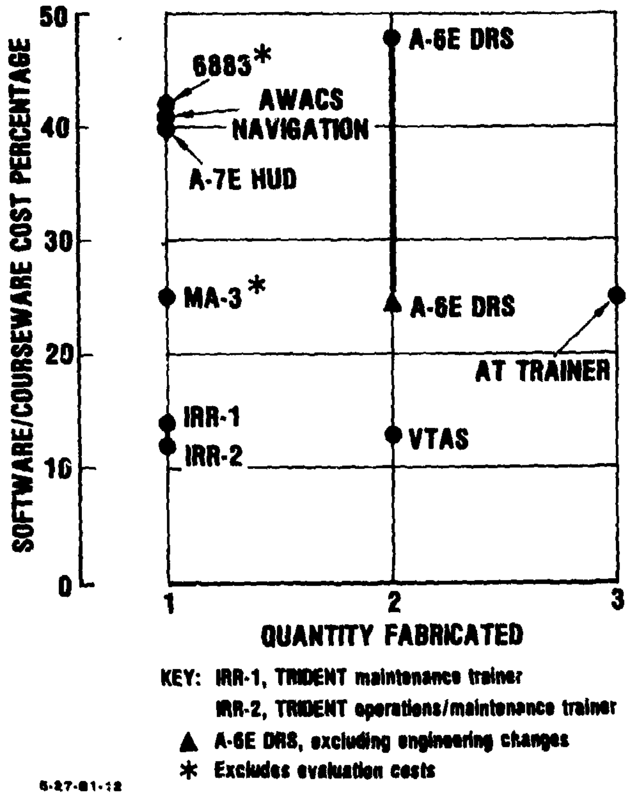


FIGURE 9. Software/Courseware Cost as a Percent of Program Total Cost, According to Quantity Fabricated

in order to make a fair comparison of maintenance simulators with actual equipment trainers which, as noted above, are production items and exclude such costs. The number of maintenance simulators procured could also influence the cost of a single unit; this varied from 1 to 36.

We decided to use estimates which would bracket the cost of one maintenance simulator within high and low limits. These were:

> High cost estimate: Total production costs adjusted to reflect a production quantity of one; this includes the costs of research and development but not of test and evaluation. We call this the "Simulator Normalized Program Cost".
>
> Low cost estimate: The cost of producing a follow-on maintenance simulator after the costs of RDT&E; prototypes and manufacturing facilities have been accounted for. We call this the "Simulator Unit Recurring Fabrication Cost."

The high cost estimates are shown in Figure 10. The ratio of simulator/actual equipment trainer costs is 0.60 or less for seven cases cases (range 0.25 to 0.55). There are four cases where this ratio varies from 1.60 to 4.00 (VTAS, MA-3, AT Trainer and AWACS). We believe these data are suspect for one or more of the following reasons: the costs of the operational equipments (some of which are relatively old) may have been considerably underestimated; the costs of the simulators, some of which are designed for use in research, may be high because they include capabilities not needed for routine training. For these reasons, we decided to accept 0.60 as an upper limit for the relative cost of a maintenance simulator compared to an actual equipment trainer.

The low cost estimates, based on the recurring cost of these simulators, are shown in Figure 11. Nine of the 11 cases fall at 0.20 or lower; the range is 0.03 to 0.19. The two outlyers (VTAS and MA-3) are regarded as atypical for the reasons set forth above.

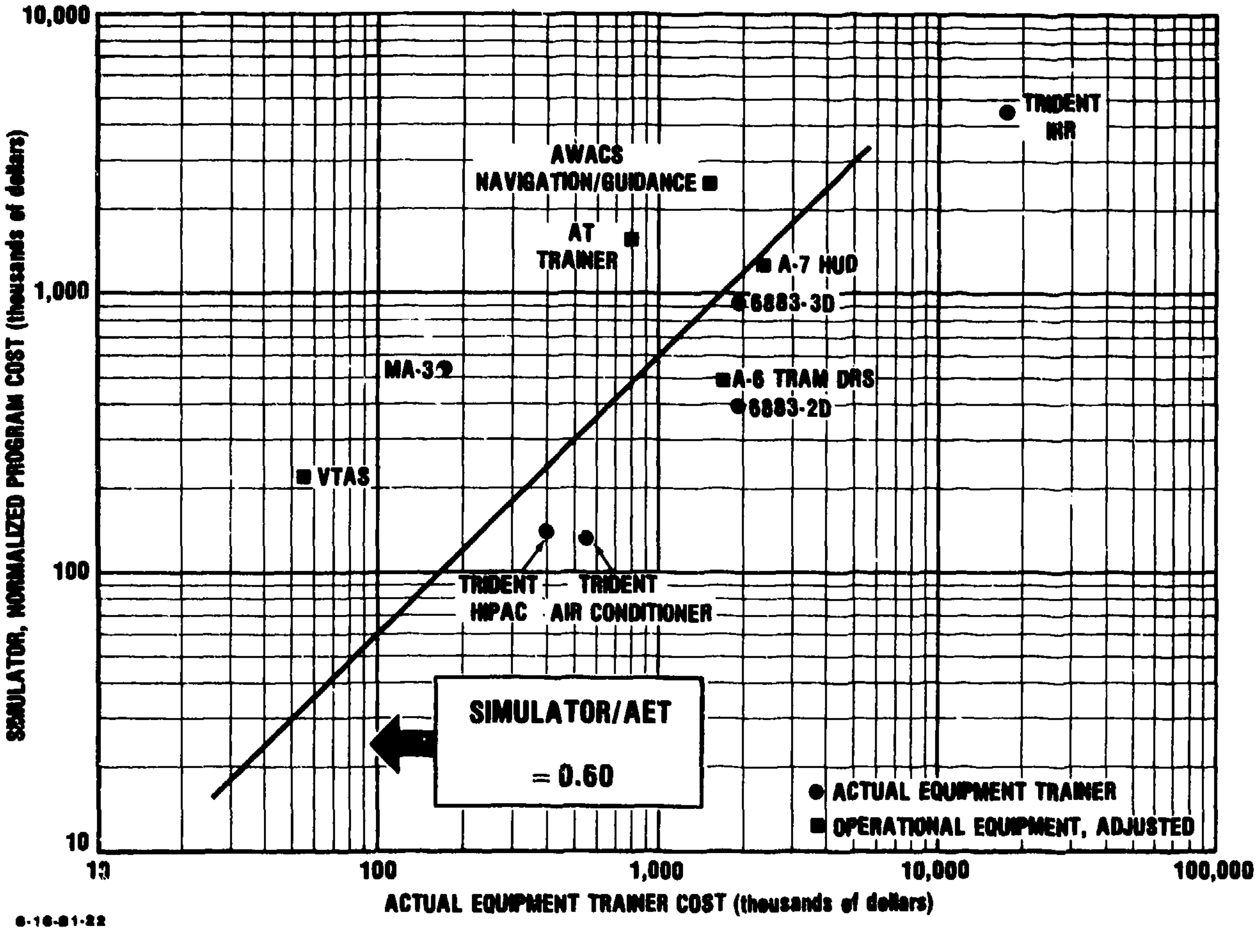


FIGURE 10. Relation Between Actual Equipment Trainer and Simulator Normalized Program Costs

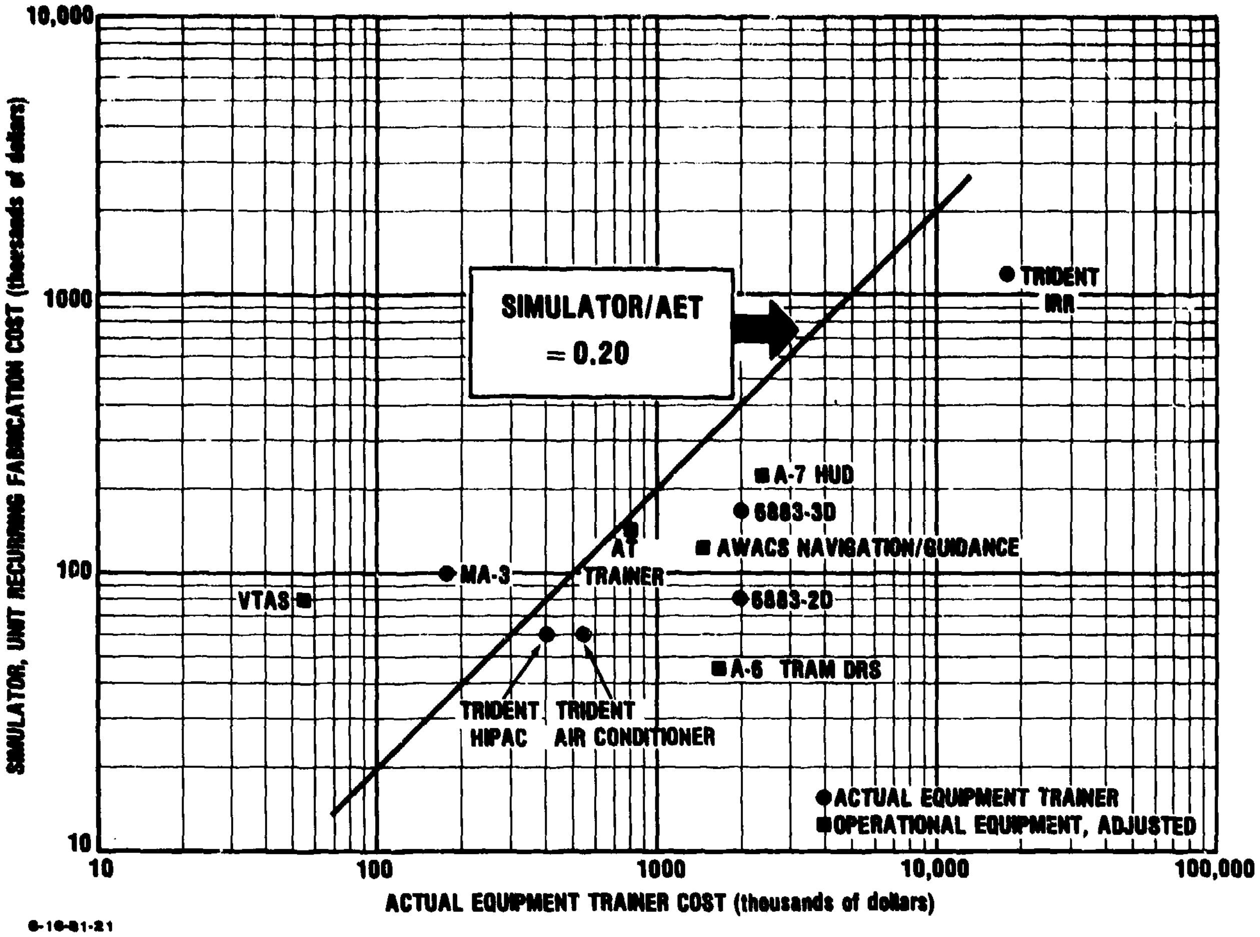


FIGURE 11. Relation Between Actual Equipment Trainer and Simulator Recurring Fabrication Costs

We conclude, therefore, that the acquisition costs of simulators generally fall in the range of 20 to 60 percent that of actual equipment trainers. These are very conservative estimates.

The cost-effectiveness of a maintenance simulator on a life-cycle basis has been evaluated only in one case, that of the Air Force 6883 Test Stand 3-Dimensional Simulator and 6883 Actual Equipment Trainer (Cicchinelli, Harmon, Keller and Kottenstette, 1980). The three-dimensional simulator and actual equipment trainer were equally effective when measured by student achievement at school; supervisors' ratings showed no difference between the job performance of students trained either way for periods up to 32 weeks of experience after leaving school.

The life-cycle cost comparison of simulator and actual equipment trainer is shown in Figure 12. Costs were estimated in constant 1978 dollars over a 15-year period and discounted at 10 percent. The results show that the total cost per student hour was $23 for the simulator and $60 for the actual equipment trainer, i.e., 38 percent as much for the simulator for all costs over a 15-year period. The simulator cost less to procure ($595 thousand vs $2105 thousand, or 28 percent as much) and less to operate ($1588 thousand vs $3367 thousand or 47 percent as much) over a 15-year period.

Therefore, maintenance simulators are more cost-effective than actual equipment trainers.

DISCUSSION

The finding that maintenance simulators are more cost-effective than actual equipment trainers is necessarily qualified by the limited nature of the data from which it is derived. Effectiveness, as used here, is based on performance demonstrated at school rather than on the job. Cost, as used here, refers to the initial costs of acquiring training equipment and does not include the costs associated with the long term use of simulators or of actual equipment for training, e.g., maintenance and upkeep, instructors and support personnel, student pay and support. In the one case where a life-cycle cost comparison

Item	(Thousands of dollars)		Simulator/ AET (%)
	Actual Equipment	Simulator	
Acquisition	2105	595	28
Recurring costs	3367	1588	47
Total	5472	2183	40
Net present value (1978 dollars)	3896	1501	39
Cost per student hour	60	23	38

FIGURE 12. 15-Year Life-Cycle Costs of 6883 Test Stand 3-Dimensional Simulator and Actual Equipment Trainer

was made, total cost per student hour over a 15-year period for the 6883 Test Stand 3-Dimensional Simulator was 38 percent as much as for the actual equipment trainer. Both were equally effective as measured by tests at school and by supervisors' ratings of performance of technicians on the job after leaving school.

The data on the cost and effectiveness of maintenance simulators have not been collected in a systematic manner. Therefore, there is no basis at present for making trade-offs between the effectiveness and cost of different types of maintenance simulators on such issues as two-dimensional vs three-dimensional design, the complexity of maintenance simulators (in such terms as number of malfunctions and instructional procedures), the extent to which simulators should provide a mixture of training in general maintenance procedures applicable to a number of different equipments or for maintaining only specific equipments, and the optimum combination of maintenance simulators and actual equipment trainers for training technicians at school.

There have been too few studies on the amount of student time saved with the use of maintenance simulators. There have been no studies on whether the use of maintenance simulators influences the amount of student attrition at school. There have been no studies to collect objective measures of performance of maintenance technicians on the job after training either with simulators or actual equipment trainers.

Maintenance simulators now under development are only beginning to use recent technological advances such as videodiscs, automated voice input and output, and miniaturization sufficient to make them readily portable. There has been more talk than action about such possibilities. Reductions in size would make it possible, as well as convenient, to use maintenance simulators for refresher training near job sites and for performance evaluation and/or certification of maintenance personnel on an objective basis in operational environments. Extreme reductions in size would make it possible to use maintenance simulators as job aids in performing maintenance on operational equipment, thus assuring a close link, not yet available, between facilities used for training at school and for performance on the job. There is a small but probably insufficient effort along these lines.

CONCLUSIONS

1. Maintenance simulators are as effective as actual equipment trainers for training military personnel, as measured by student achievement at school and, in one case, on the job. The use of maintenance simulators saves some of the time needed by students to complete courses, but data on this point are limited. Students favor the use of maintenance simulators; instructors are favorable, neutral or negative to the use of simulators in about equal amounts.

2. The acquisition cost of maintenance simulators varies from 20 to 60 percent that of actual equipment trainers, for cases where complete cost data were available. The higher value includes the costs of research and development needed to produce one unit; the lower value includes only unit recurring fabrication costs. One life-cycle cost estimate shows that purchase and use of a simulator would cost 38 percent as much over a 15-year period as it would for an actual equipment trainer.

3. Maintenance simulators are as effective as actual equipment trainers for training maintenance personnel. They cost less to acquire. Therefore, maintenance

simulators are cost-effective compared to actual equipment trainers.

4. The conclusions to this paper must be qualified by the fact that they are based on limited and often incomplete data. There is a need for hard data that compare maintenance simulators to actual equipment trainers in the following areas: life-cycle costs, on-the-job performance, and student attrition at school. There is also a need to compare the cost and effectiveness of simulators that vary in complexity of design, e.g., two- and three-dimensional simulators and types of instructional features.

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COMPETITIVE PROTOTYPING DURING FULL SCALE DEVELOPMENT

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ABSTRACT

Competitive prototyping during full-scale development is an innovative concept and has been exercised in various Army programs such as the Division Air Defense System (DIVADS) and Conduct of Fire Trainers (COFT) for tanks and fighting vehicle systems. This technique is expected to be particularly effective when combined with hands-off, "skunk works" type management by the Government. If success is, in fact, achieved, this concept should be considered for use in other projects involving large capital investments.

TRAINER DESCRIPTION

The Conduct of Fire Trainer (COFT) (Figure 1) is a deployable, shelterized gunnery simulator which uses computer-based visual simulation technology to create an environment that is ideal for learning. The COFT produces full-color computer-generated action scenes (Figure 2) in which tank crew members can see and interact with dynamic multiple target situations. Yet, there is no danger to the crew, no fuel is consumed, and no ammunition is expended. In addition to saving fuel and ammunition costs, the COFT has other advantages: it can be used 24 hours per day, every day; weather can be scheduled in the simulator; simulated engagements can be reenacted, and degraded modes of operation can be practiced. The COFT allows more tanks to be kept where they should be: ready for any emergency.

Training Capabilities

By simulating a wide variety of situations and tactical engagements, the COFT system can provide basic gunnery training and keep fully qualified crews proficient. A library of preprogrammed exercises is provided which can be loaded and executed from the instructor station. A training sequence should, typically, progress from identifying a target to setting up the weapons system to aiming the reticle and firing the simulated weapon. The COFT system will simulate different times of day or night, including dawn and dusk. Simulated special effects include rain, smoke, variable fog, and fading to further increase scene realism.

BACKGROUND

Published material dealing with DOD philosophy, past experience and lessons learned with competitive prototyping during full-scale development using the "skunk works" philosophy is virtually non-existent. This paper may, in fact, be the first formal document which addresses this subject and could be used as a baseline for succeeding studies.

In September, 1979, competing contracts were awarded by the Naval Training Equipment Center for research and development of a Conduct of Fire Trainer as described above for the M1 and M60 tanks and subsequently the Fighting Vehicle Systems (FVS). Following delivery of the trainer, a competitive test of the trainers and evaluation of production proposals was scheduled with the winner to be awarded a multi-year, multi-million dollar production contract. The R&D contract awarded to General Electric and to Chrysler Defense, Inc. followed very closely an earlier "skunk works" type contract which the Army had executed for the DIVAD gun.

Competitive prototyping is, of course, not new to the acquisition process. However, it has historically taken place during validation with award of a full-scale development contract to the winning contractor followed by delivery of a complete Tech Data Package, design disclosure and a package for solicitation of a production proposal, as was the the case with the M1 Tank.

"Skunk works" contracting also is not a new initiative in acquisition since it was used as early as 1943 by the Air Force on a contract with Lockheed Aircraft Corporation for the P80*, the first tactical jet fighter aircraft. It was again used for contracting for the U2 spy plane in 1955, and on the SR71 Reconnaissance Aircraft between 1960 and 1975. It has been used a total of eighteen times at Lockheed (sole source) and the procedure is considered by Lockheed to be very successful. The refinements that have been applied to the present efforts are:

1. The competitive prototyping is taking place during full-scale engineering development and is followed by a competitive test resulting in production award to the winning contractor within three years of the development contract award;

2. The "skunk works" is taking place during a competitive phase as opposed to the sole source environment.

For clarity, the philosophy above will be referred to as "skunk works 81" in the remainder of this paper.

SKUNK WORKS 81

What Is It?

It is the technique, as explained above, of utilizing competition and minimum interaction with the Government in achieving the best of both worlds

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* Information was collected via phone conversation with Mr. "Kelly" Johnson, former director of the Advanced Development Products Group at Lockheed Aircraft Corporation and original executor of the "skunk works" philosophy.

by optimizing technical development at minimum cost.

The "skunk works" designation implies industry's achievement of designated goals with little or no Government control. In the case of training devices, contractors have been given the goals of training effectiveness equal to or exceeding that of training on the weapon system and minimum life-cycle cost. Much has been said in the past about the expensive, overly restrictive requirements of Government specifications. With the "skunk works 81" training device philosophy, industry must decide where and in what ways the requirements are overly restrictive in achieving and maintaining the goal of training effectiveness and affordability (low life-cycle cost) and make appropriate trade-offs.

When Is It Used?

The prerequisite is a long production base and a procurement budget large enough to amortize the increased R&D dollars involved in awarding two development contracts. In the case of COFT, the production base was recognized to be at least several hundred million dollars programmed for four years or longer.

How Is It Used?

Award Criteria - It must be made in a fixed price environment. In the case of COFT, it is cost plus with a ceiling which, in effect, achieves the same objective as fixed price. In any other type environment, the development period could easily become a spending contest between the competing contractors.

Monitoring - Generally, in-plant monitoring is limited to that required to keep the Government current as to each contractor's progress. The Government reserves the right of termination in the event that progress is not satisfactory. "Splinter Groups" of Government and contractor personnel are used at Progress Reviews in order to facilitate effective communication and provide a sufficiently detailed and accurate assessment of progress.

Technical Requirements - Intentionally very loose, and generally used as guidelines only. The Government is buying a contractor's "best effort" and insists on only certain basic requirements (e.g., safety, production readiness) and baseline documentation necessary to conduct production proposal evaluation and device testing. The production contract will be awarded to the contractor with an acceptable product that is the most training and cost effective.

Acceptance Criteria - The only criteria necessary for the acceptance of the R&D model by the Government is count, condition and safety. Other factors, however, must be assessed before beginning OT.

Logistics - Obviously, a complete logistics package on both designs would be too costly. Therefore, a modified LSAR has been incorporated which attempts to achieve the best of both worlds; that is, delaying the expensive portion of the process until after selection of one design but assuring that either contractor is ready to furnish logistics data in a timely manner when needed.

Security - Communication is limited to that necessary to satisfactorily assess progress. Statements of non-disclosure have been made by all Government participants.

Contract Data Requirements List (CDRL)

Only those data items necessary to assure that the Government will have appropriate information when necessary are required. For instance, the Configuration Item Development Specification (CIDS) is required and will be used as a baseline for the contractors' initial production proposal. Therefore, this item must be delivered in accordance with the specified requirement. Likewise, the Government acceptance test procedure will be used to verify that the CIDS is an accurate representation of the prototype being tested, so it must also be delivered in accordance with the Government requirement.

Test Planning

An unusual characteristic is that operational test planning must be done in accordance with the goals that were given the contractor by the developer at the onset of the development period, i.e., if training effectiveness was the most important goal then it must assume the most important aspect of the test. However, the role of the operational tester is supposed to be independent of the developer; therefore, the developer must input heavily to the structure of the operational test so that the goals will be adequately tested.

What Are the Pros and Cons?

Industry - Advantages: 1) Contractors are given trade-off authority within the specifications and can follow their own interpretation in achieving the best mix of training effectiveness and affordability; 2) There is an absolute minimum of Government interference; 3) Enthusiasm on the industrial project team. Unique opportunities to "do their own thing" encourages intitative; 4) No extensive design reviews, per se.

Industry - Disadvantages: 1) Without Government specifications, can RAM be achieved to provide low life-cycle cost? (In some cases, author understands that Government specifications were voluntarily used); 2) Competition could force contractors to invest company funds; 3) The idea looks good but can you really keep "big brother" out? 4) In many cases, one individual is watching progress of both contractors. Thus, proprietary design/security must be a consideration.

Government-Advantages: 1) Competition achieves end result (better than aggressive control of a single source); 2) Responsibility for the design not placed on the Government; 3)Fewer data items to monitor, less paper work (however, this may be offset by having data items delivered concurrently by two contractors, thus causing heavy involvement by the reviewing Government team members at possibly critical times), 4) Fewer Requests for Deviation (RFD), Requests for Waiver (RFW), and Engineering Change Proposals (ECP) to process; 5) Competition drives down cost, and at the same time drives technical capability up.

Government Disadvantages: 1) Very large source selection team (two contractors, two production proposals, two sets of test reports to review, etc); 2) Less directionary authority but more effort in keeping current on two designs; less opportunity to gain insight into the design; 3) same security problem as industry concern above; 4) Greater than average risk of protest from losing contractor; 5) No control over design, no knowledge of costs, manhours, etc to apply to production proposal evaluation.

SPECIAL OPERATING PROBLEMS

Monitoring

There is a tendency for upper management to rely completely on the theoretical skunk works (hands-off) philosophy. Given today's competition for people resources within most Government agencies, various managers may have a tendency to view this approach as an opportunity to withdraw the support necessary for detailed attention during the R&D phase. However, it is in the best public interest for the Government to assure that all steps are taken to maintain competition. Therefore, appropriate communications between the Government and the contractors must be maintained while respecting the competitive environment.

Resources

All Government costs increase. Supporting manhours roughly double with the necessity to monitor two designs.

Data

Certain data items cannot be considered under the blanket of "best effort." As discussed earlier, contract data requirements must be formally assembled, delivered and accepted within the terms of the contract.

Logistics Planning

This will be/has been extremely difficult in light of the fact that the majority of the data available will not be delivered until after source selection. This is not timely nor is it in accordance with AR-700-127. Many problems are posed as a result of the lack of design information available early in development. For instance, facilities planning,technical manuals and provisioning all start later in the development/production cycle than the Army logistics system demands it. This will probably drive ownership costs up in the early years until the wholesale logistics system can fully support the equipment.

Source Selection

Competition forces detailed assessment of the Operational Test by the Source Selection Board. The question is not only the traditional, "Will the equipment be accepted into the inventory"? but adds a new dimension, "Which one"? Because of this increased effort, lack of depth in various talent areas forces the Project Manager to seek assistance from other Government offices. This, in turn, forces expenditure of TDY funds and funds to expand facilities, since the evaluation should take place in one area as a security precaution. It is important to identify these resources early.

CONCLUSIONS

"Skunk works 81" has proven to be a viable method of developing training devices. Initial indications are that competition has favorably influenced both technical development and cost.

However, all the returns are not yet in. We have identified, at the upper-management level, the major problems encountered and expected in managing a "skunk works 81" acquisition. To make the maximum use of lessons learned, panels should be developed in order to investigate the problems more thoroughly using logisticians, contracting officers, testers, RAM and design engineers and managers who have experience in this type of acquisition and properly record these lessons learned for future use.

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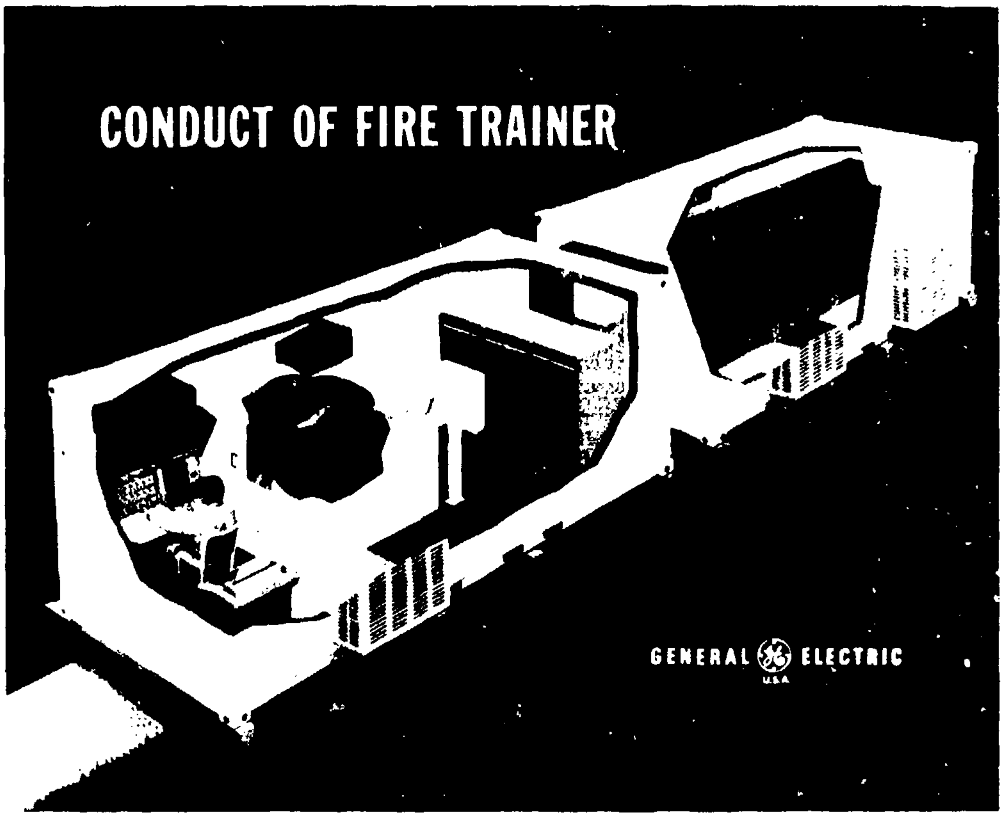
Mr. Stansberry has occupied a variety of Department of the Army civilian positions within the Research and Development community. These have included Project Director at the Army Training Device Agency and Chief of Configuration Management at PM TRADE. He was appointed to his present position of Deputy Product Manager, Armor Training Devices, in 1979.



CONDUCT OF FIRE TRAINER

SCENE FROM COFT

IMPROVING PROGRAM START-UPS

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The current modus operandi for the initiation of large simulator programs is "throttles to the firewall" on the day of contract award. The contractor's program management team doesn't have time to effectively plan the program due to an immediate and continuous barrage of customer visibility data items and reviews. This inability to develop accurate and workable plans impacts program costs and schedules by means of false starts and premature commitment of resources. Likewise the government program office incurs unneeded travel and workload commitments during the initial stages of their organizing and planning effort. This problem is caused by an attempt to achieve the earliest possible Ready for Training date through rapid start-up and close monitoring of progress. The solution lies in a joint Government/Contractor front end planning effort which allows the contractor time to plan and also provides the government with sufficient visibility during the start-up period.

Over the past few years a common approach for the start-up of large simulator programs has developed which is in essence "throttles to the firewall" on the day of contract award. Current RFP requirements clutter the critical early months of these programs with a continuous barrage of premature, and in some cases unnecessary, reviews and data item submittals. The shear magnitude of these "square-filling" requirements has a detrimental effect on the program management team's ability to plan effectively. This inability to develop comprehensive and workable plans has a definite impact on program costs and schedules since inadequate planning leads to false starts and premature commitment of resources. Also, the premature submittal of data and the conduct of poorly timed reviews detract from the value of these requirements, which are most effective when properly time phased.

The existence of this problem presents both a challenge and an opportunity to government and industry managers. The challenge is to develop an approach to program start-up which optimizes the needs of both industry and government. The opportunity is to reap the benefits to be gained from comprehensive front end planning and proper time phasing of requirements.

The scope of the problem at hand can best be illustrated via a current example. An RFP for an operational flight trainer released within the last few months requires the following data items to be submitted within the first 120 days after contract award.

- Operation and Support Cost Trade Studies
- Firmware Development Plan
- Computer Program Development Plan
- Program Milestones
- Contract Work Breakdown Structure
- Monthly Activity Reports
- Support Equipment Plan
- Configuration Management Plan
- Parts Control Program Plan
- Cost Performance Report
- Training and Training Equipment Plan
- Integrated Support Plan
- Maintainability Plan
- Reliability Program Plan
- Facility Design Criteria
- Support Equipment Recommendations Data
- Systems Engineering Management Plan
- Logistics Support Analysis Record Data
- Logistics Support Analysis Plan

In addition, the program management team must schedule, prepare for, conduct and submit minutes for the following reviews during this same 120 day period.

- Post Award Conference
- System Requirements Review
- Engineering Design Review
- Computer Program System Documentation Guidance Conference
- 2 Program Management Reviews
- Project Planning Review

Obviously, these requirements constitute a substantial workload for the Program Manager and his staff which significantly impacts their priorities and effectiveness during a very critical phase of the program.

Admittedly, these data items and reviews are germain to overall program planning and control and provide the customer with needed visibility. However, they are not all needed at this early stage of the program.

There is no single cause on which we can place the blame for this problem. However, the main driving factor influencing government RFP writers is the very real need to achieve the earliest possible RFT and begin realizing the very tangible cost savings provided by modern trainers. The RFP writers have assumed, quite correctly, that one of the best ways to insure program success is to plan well and maintain visibility as to progress against that plan. Unfortunately, the schedules for completing planning requirements in current RFP's have been compressed by a desire to demonstrate immediate results and progress to the chain of command. Also, the RFP requirements have grown more extensive and complicated due to the influence of popular paneceas or DOD crusades such as getting control of software by planning, documenting, and reviewing it to death. In addition, there is now and always has been the problem of the use of strawmen in writing RFP's and treating the Acquisition Management Systems and Data Requirement Control List (DOD 5000.19-L) as a data item shopping list. As a result, each RFP or CDRL has all the requirements specified in the last RFP plus any new ones which have been directed from above or created from within the procuring agency.

Finally, industry has a share in the blame for the current start-up procedures. In some cases, contractors have been known to delay putting sufficient resources on a low visibility program in order to show progress on a high visibility effort. Hence, the government manager believes that his only recourse is to insure that his contract requires data and reviews sufficient to keep the pressure on and reveal any lack of contractor emphasis before his program is affected.

The impact of all these reviews and data submittals on the industry is dramatic. For instance in the example cited above there are seven reviews required during the first 120 days of the program. According to the Statement of Work contained in that RFP, each of these will last at least three days. Allowing two days for internal dry runs, two days for preparing presentations and one day for preparing the minutes of each of their reviews, we see that a total of 56 days could be consumed in satisfying these requirements. That accounts for over 46% of the first 120 days. Add to this the time required for the data items and it becomes obvious that the program management cadre will not be able to effectively plan their manpower requirements or develop comprehensive schedules and time phased budgets during this same period.

What usually happens is that a lot of additional manpower is applied to the program much earlier than the real job of building a trainer requires. This additional manpower cranks out vugraphs and creates plans which are, to a large extent, eyewash and boilerplate. This procedure often generates unrealistic plans and schedules which cause more work later when they must be revised and the revisions justified. The real danger, however, lies in the potential for false starts made in an attempt to show early progress. This results in the expenditure of resources which cannot be recovered.

For example, the requirements for a Computer Program Development Plan are so extensive and detailed that they cannot be totally satisfied until the system is complete and tested. Such details as module and subroutine definitions and completion schedules are not not available during the first few months. However, the requirement for a plan with detailed schedules exists and must be satisfied. In attempting to define these items prematurely, the contractor often makes assumptions which are sometimes totally wrong. Nevertheless, the die is cast and the government has a plan against which to monitor progress. In order to show progress, the contractor starts to work on the assumed module/subroutine structures. If, as usually happens during development, the assumptions prove wrong, significant resources have been wasted.

On the government's side, the impact is equally dramatic. The 56 days of formal reviews normally entail 56 days of travel time for large numbers of government employees. This imposes a substantial drain on available travel funds early in the program and usually forces cutbacks in travel later on when the benefits would perhaps be greater. Also, the mass of data being generated and delivered must be reviewed and in most cases approved by the system program office staff which is being reorganized and expanded to administer the contract. Both of these requirements place a tremendous workload on personnel who are just coming on board and need time to acclimate to new jobs and responsibilities.

For example, another recent simulator program required the delivery of extensive documentation 30 days prior to PDR which was scheduled to last for one week. The documentation was delivered as scheduled and consisted of approximately 7,000 pages of technical data. The government then had thirty days to review that data and five days to discuss it with the contractor.

Finally, the strawman/shopping list approach to preparing RFP's often leads to the purchase of expensive documents which serve little useful purpose in the life of the program. This fact was recognized and addressed by the AF in the early 70's. At that time the then Brigadier General, Alton B. Slay, headed up a Data Reduction Action Group (DRAG) which reviewed the data requirements of major Air Force procurements. This review indicated that large portions of the data being procured was not in any way being used to manage the programs. As a result substantial reductions in data requirements were made to subsequent AF RFP's. However, it now appears that the DRAG has faded into history and data procurement is again getting out of hand.

From the government's viewpoint the solution to the problem would be for the contractor to have done such an excellent job in preparing his proposal that all plans and schedules are ready to go immediately after contract award. This is not possible because the time allocated for proposal preparation and the page limitations imposed effectively limit the detail which can be provided. Even if such accurate and detailed plans were provided in the proposal, they would be largely negated by the fact that the actual contract award is in most cases much later than that projected in the RFP. This lag allows conditions to change relative to the amount and type of resources available to the program.

From the contractor's viewpoint the solution would be for the government to award the contract then go away for about six months while top level system design and plans for completing the program can be formulated. At the end of this period the government would be provided with a program plan and schedule. Clearly, this approach is not possible because of the large sums of money being committed and the importance of the programs to the national defense.

Therefore, the optimum solution must lie somewhere between these two extremes. It must allow the RFP to require and obtain pricing for the reviews and data that the procuring activity needs while at the same time providing the contractor the time and flexibility to plan properly. To accomplish this objective the RFP should specify the reviews and data which, after careful consideration and appropriate justification, will be required to manage the particular program at hand. Instead of specifying data delivery or Program review dates, the contractor should be tasked to provide his front end plan for the program. This plan should be complete not later than 90 days after contract award and should provide schedules for management and design reviews. It should also contain the contract work breakdown structure (CWBS) and specify when schedules for each element of the CWBS will be completed.

This 90 day period is a critical period for the government management team during which they must make sure the program is getting off the ground. Therefore, they should participate in the front end planning process to provide required visibility and to help develop an acceptable plan. This participation should be limited to a few key people and consist of a "work with" rather than a "watch over" effort. The government project engineer, a software expert, someone from the program control function and someone with extensive operational experience with the system being simulated would be ideal.

As part of this effort, delivery dates for all required data should be time phased with key program events such as PDR and CDR, and the degree of completeness of the data appropriate to those events should be clearly specified. Again using the Computer Program Development Plan as an example, the portions and level detail to be submitted at PDR and CDR should be established.

Finally, the plan should show how progress will be measured against the plan and how status will be reported to the procuring agency. For instance, the milestones to be used in tracking computer program development should be jointly defined between the government and the contractor as well as the criteria which must be met before the milestone is considered complete. This will alleviate much confusion usually generated by different definitions of milestones and what their completion means.

The first management review with the full government management team should then occur approximately 120 days after contract award. This review would be a modification of the currently popular Program Planning Review. However, instead of presenting a re-hash of the RFP, the contractor will be revealing his approach to planning and control which is applicable to the program in question, and is based on conditions which exist at that point in time. This review should be conducted as a working meeting with the objective of reaching an understanding of the program plan, defining and agreeing to revisions to the plan needed to meet government requirements and achieving a mutual agreement relative to objectives to be achieved and measures of accomplishment.

At the conclusion of the Program Planning Review the front end plan is approved by the procuring agency and used to measure progress until all elements of the CWBS are completely planned.

This approach will provide the contractor with enough time to effectively plan the program. He can use his initial staff of experienced manpower to formulate the overall concepts for the program and establish realistic goals and checkpoints. It will enable him to generate more realistic schedules by allowing him to defer the preparation of schedules for downstream efforts until he has sufficient data to accurately scope these efforts. In turn, this will help prevent false starts caused by the initiation of efforts which are not adequately defined. Finally, it will give the contractor's upper management the opportunity to review the Program Manager's concepts before significant resources are committed to the program.

To the government's benefit, early visibility will be provided by the participation in the front end planning process, the Program Progress Review and subsequent statusing of the front end plan. Travel funds will be conserved until properly time phased reviews have been defined. The system program office will be given enough time to complete its organization and indoctrination of newly assigned personnel. Also, the improved accuracy of the resulting schedules for the CWBS elements will increase the credibility of program status as measured against those schedules.

One final, and possibly the most important, benefit offered to both parties by the proposed front end planning effort is the fostering of a team spirit among the contractor and procuring agency personnel. The fact that both parties have participated in the definition of objectives improves the probability that they will succeed in meeting those objectives and achieve the earliest possible RFT date.

In conclusion, it is apparent that improvements can be made in our procedures for initiating large simulator programs and that those improvements will require the combined efforts of industry and government to achieve. Perhaps the American Defense Preparedness Association offers the base of talent from which a joint interservice/industry working group could be established to review this problem and recommend a course of action.

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TRAINING DEVICE ACQUISITION
MANAGEMENT MODEL
(TDAMM)

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ABSTRACT

In October 1980 PM TRADE developed a Training Device Acquisition Management Model (TDAMM) which outlines the specific events that must be accomplished in the development and production of training devices. This paper will explain how the DoD Acquisition Model was tailored to accommodate training devices to include the responsibilities of the Developer, the Users and the role of major commands in the acquisition cycle. The advantages of using the model will be mentioned along with the elimination of events which are not applicable and/or are not necessary in the development of training devices; the benefits to the User by reducing development time and minimizing costs. Moreover, an explanation will be included to demonstrate its use in assisting the Project Directors in accomplishing their key events in a methodical manner, and tailoring new developments to the model with an examination of the resultant acquisition strategy.

PM TRADE MISSION/CHARTER

The Project Manager for Army Training Devices (PM TRADE) is responsible to centrally direct, coordinate and support the materiel development and acquisition activities of system devices developed by PM TRADE as agreed upon by the System Project Manager, non-system and non-type classified training devices. This responsibility encompasses the research, development, configuration management, product assurance, developmental testing, procurement, production, distribution, and integrated logistic support for the following categories of assigned training devices:

1. Non-system trainers
2. Non-type classified
3. Synthetic Flight Trainer systems
4. Commercially workable training device

The PM TRADE provides assistance to all Army agencies in the execution of their responsibilities in the area of training devices. Particularly, this is the filling of the training device requirements of the U.S. Army Training and Doctrine Command (TRADOC) and U.S. Army Forces Command (FORSCOM).

Rather than focusing his attention on a single materiel system as do most Project Managers, the PM TRADE must manage a multiplicity of systems, each in various stages of the training device life cycle from concept formulation through production and deployment, as applicable.

COMPLEXITY OF OPERATION

The operations of the Project Manager for Army Training Devices are much like the operations of any other Project Manager. It is the several differences briefly discussed below that cause what initially appears to be a straight foreward project-managed effort to become a highly complex management problem to control and integrate the efforts to manage the Training Device Acquisition process of at least fifty individual training device systems.

Not only must several training device developments be actively pursued, but they are each in different parts of their acquisition process. Some are in the early parts of conceptual development; or perhaps the identified concept is being demonstrated or validated. Others are in various stages of Engineering Development and Production. Finally, some may already be deployed and even nearing obsolescence. Each of the "system" and "non-system" devices, no matter where it is in the acquisition process, must receive management attention and be supported adequately to meet the needs of the user.

Each of the system or non-system training devices has its own inherent technical risks of development from simple or off-the-shelf device to very sophisticated devices requiring advance technological development. In between are varying degrees of complexity from moderate, mostly mechanical devices to complex and software-oriented devices.

In addition to the technology that must be called upon to develop the devices, PM TRADE has the full range of trainers to manage:

1. Trainers for the Corps of Engineers include such devices as the Medium Girder Bridge; highly complex items for Air Defense Artillery such as the ROLAND Air Defense System; the Multiple Integrated Laser Engagement Simulation (MILES) and the Reaction Electronic Equipment Simulator (REES) for the Signal Corps.
2. Armor trainers include the Conduct-of-Fire Trainers for the M1 and M60 series Main Battle Tanks and the new Infantry and Cavalry fighting vehicles.
3. Synthetic Flight Trainer Systems include simulators for the Advanced Attack Helicopters (AAH) and the COBRA.

Finally, the PM TRADE's management challenges are further complicated by not having a supporting research and development facility, a supporting National Inventory Control Point (NICP) nor a National Maintenance Center (NMP) while at the same time having multiple customers and funding sources.

The number of training devices being developed, both system and non-system, the several different technological risks involved, the number of categories of sevices, the number of customers and funding sources all act to compound the very difficult management problems that are the day-to-day environment in which the PM TRADE and his personnel find themselves. This "juggling act" required that a more efficient management system must be found or developed in order to make management resources available to solve the inevitable critical problems that exist during the development of a training device but at the same time expend the exact the management effort necessary to routinely guide the normal development activities.

An acquisition management model called the Training Device Acquisition Management Model (TDAMM) has been developed. This generic model is specifically intended to be applied to any training device. The model, however, follows DoD guidance very closely. It is, therefore, applicable not only to the acquisition of training device of all of the military services, but to the acquisition process of any item being developed and acquired by any of the military services. The model is then modified to meet the unique characteristics of the particular device being developed to meet a requirement. At this time the status of each event of the model are manually reported. When the staff of PM TRADE gains experience with the manual TDAMM, the model has been designed with the characteristics that it can be easily automated. This is already in the advanced planning stage. The automated version of the TDAMM will, henceforth, be immediately responsive to training device managers telling them the status of a training device development. It bears repeating; the TDAMM can be applied to any training device of any service or any other item being developed.

TRAINING DEVICES AND THE ACQUISITION MANAGEMENT MODEL

It is the goal of DoD that all acquisitions of military materiel follow the Life Cycle Systems Management Model. The process for conceiving, developing, acquiring and fielding new items of materiel is formalized in the Life Cycle System Management Model (LCSMM). Management of the development of a single training device (or all training devices if each is considered independently of all other training devices) fits the LCSMM. This is surely true at least from a general point of view. Yes, there are differences such as holding In-Process Reviews rather than an ASARC and/or DSARC (Army Systems Acquisition Review Council and/or Defense Systems Acqui-sition Review Council respectively). Either the Validation Phase or the Full Scale Development Phase of training device development is normally severely curtailed. Also, the Production and Deployment Phase is often deleted due to the limited quantities of training devices needed. The Full-Scale Development Phase often fills the total requirement. These differences mitigate against the strict following of every event of the LCSMM and require the modification or tailoring of the model in order to meet the needs of the training device development managers. In this way the baseline of the Training Device Acquisition Management Model (TDAMM) was established, i.e., follow the Life Cycle System Management Model overlayed or modified with the unique requirements of the development requirements of training devices. This approach is a practical approach to any development and acquisition activity.

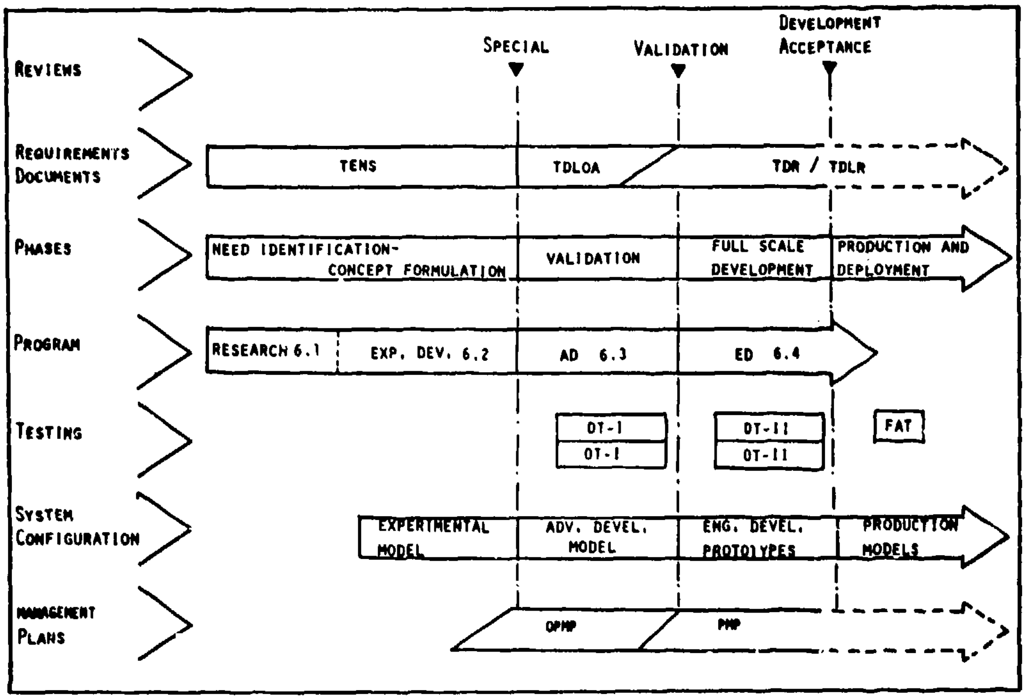

Figure 1 - TRAINING DEVICE ACQUISITION CYCLE

The relationships of the decision points, documentation, phases, testing, program funds, etc., are shown in the diagram below. This generalized representation of the acquisition process is the baseline for modeling the training device acquisition cycle to assure that the training device model and the more familiar DoD materiel acquisition model attain maximum compatibility with each other.

The significant differences between the LCSMM and TDAMM are summarized in the following chart.

LCSMM Activity	Relates To This	TDAMM Activity
ASARC-II/DSARC-II		VAL IPR
ASARC-III/DSARC-III		DEVA IPR
MENS		TENS
ROC		TDR

DESCRIPTION OF THE TDAMM

The Training Device Acquisition Management Model (TDAMM) has been designed to assist the Project Manager for Army Training Devices (PM TRADE) and his subordinate elements in the management of the training device development and procurement process; i.e., the materiel acquisition process. The TDAMM diagrams and the its accompanying explanations has the primary purpose of servicing as a "path with a series of sign-posts" in order to know what to do in traveling through the total Training Device Life Cycle.

The Training Device Acquisition Management Model, portrays all of the 202 events to be taken, or at least considered, to acquire a training device system from the time that a requirement is stated by the user through the items obsolescence, perhaps twenty years later. The four phases of acquisition of a training device, as for any other materiel acquired within the purview of the DoD Material Acquisition Model are:

1. Need Identification and Concept Formulation Phase.
2. Demonstration and Validation Phase (also known as Advanced Development (AD)).
3. Full-Scale Development Phase).
4. Production and Deployment Phase.

The first phase of TDAMM has the dual purpose of identifying training voids either presently existing or that will exist as new equipment is introduced into the Army inventory. Secondly, the purpose of this phase is to develop concepts of possible training devices that will meet the identified need.

During the conduct of training by the US Army Training and Doctrine Command (TRADOC) or the other Major Commands (MACOM) of the US Army, deficiencies in the training program will be found. During the development of major materiel items the Mission Element Need Statement (MENS) will first identify the probably need for training devices. Another way to find a need for a training device is during the development of training programs which are developed in order to teach operational and logistic support activities. Anyone may find such training voids that could be filled by a new or improved training device. When a training void is found, a Training Element Need Statement (TENS) (corresponding to the MENS), describes the need. The TENS is prepared by the Combat and Training Developer (normally the TRADOC proponent school) in coordination with the PM TRADE.

Based on the Training Element Need Statement (TENS) the Combat, Training, and the Materiel

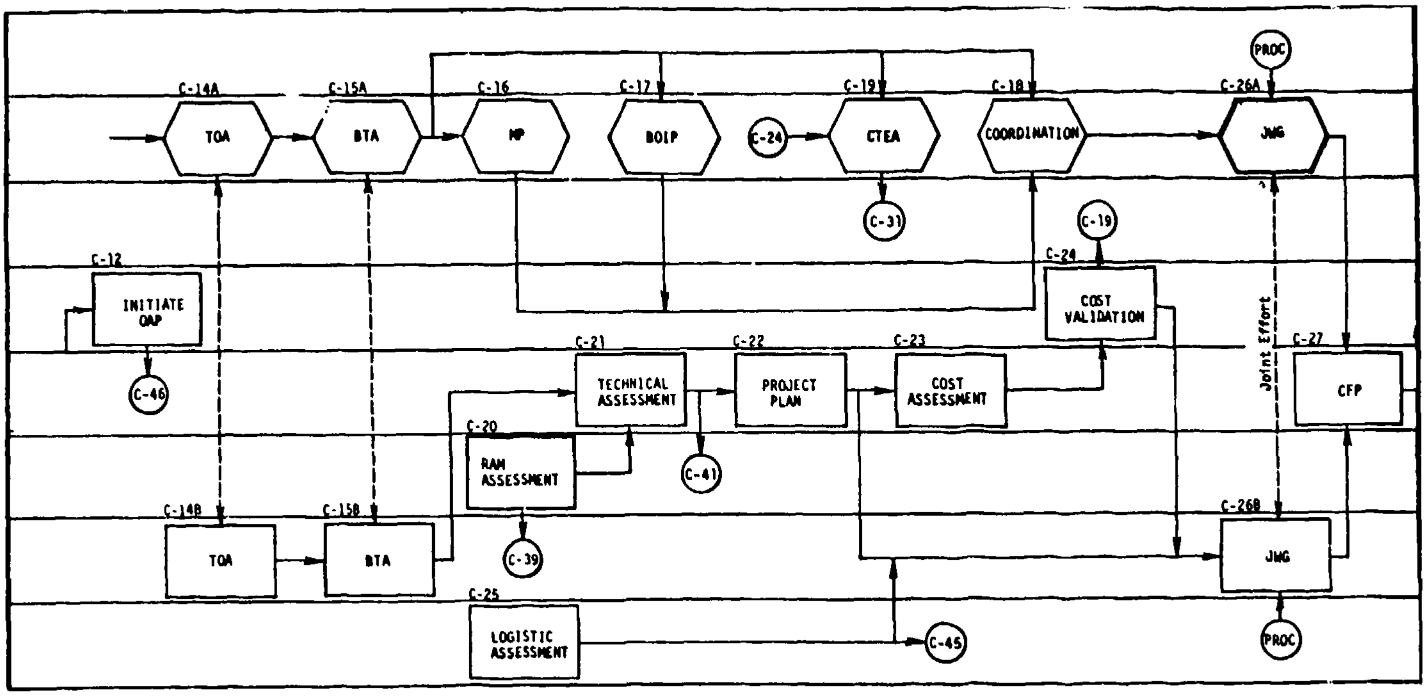

Figure 2 - CONCEPT PHASE (PARTIAL)

Developers prepare a Concept Formulation Package and an Outline Program Management Plan (PMP). The Materiel Developer develops technical and, in coordination with User, logistic concepts based on such things as engineering analyses, logistic support concepts, and the Reliability, Availability and Maintainability (RAM) goals. It is emphasized that the activities that are associated with concept formulation are repetitive, mutually supporting, fully interrelated between the Combat, Training and Materiel Developers and are continually being revised or updated. Moreover, throughout the CONCEPT PHASE, efforts are undertaken simultaneously on as many alternative concepts as practical so as to meet the potentially broader goals of the Training Element Need Statement.

The repetitive process of concept formulation demands the continued efforts to determine among other things:

a. A Trade-Off Determination (TOD).
b. A Trade-Off Analysis (TOA).
c. The Best Technical Approach (BTA).
d. Agreement on the system description.
e. Agreement on the Bands-of-Performance (BOP) of the characteristics of the system.
f. Preparation of a Cost and Training Effectiveness Analysis (CTEA).
g. The Basis of Issue Plan (BOIP).
h. A Qualitative and Quantitative Personnel Requirements Information (QQPRI) document.
i. A validated Baseline Cost Estimate (BCE).
j. A staffed Training Device Letter of Agreement (TDLOA) if the next phase is the VALIDATION PHASE or a Training Device Requirement/Training Device Letter Requirement (TDR/TDLR) if the next phase is the FSED PHASE.
k. A Concept Formulation Packate (CFP).
l. Program Management Plan.

In general terms, a concept of a training device is developed based on an identified need. The concept must be validated and undergo Advanced Development (AD) if there are sufficient unresolved technical risks before progressing to the undertaking of an Engineering Development (ED) effort. If the technical risks are not significant an ED effort can be almost directly undertaken with only a minimal VALIDATION PHASE in order to prepare the necessary documentation to support the FULL-SCALE DEVELOPMENT (FSD) PHASE.

The second, or DEMONSTRATION VALIDATION PHASE encompasses those activities necessary to demonstrate preliminary design and engineering, analyze trade-off proposals, resolve or minimize logistics problems already identified and validate that the technical concepts are achievable and that the training effectiveness is attainable.

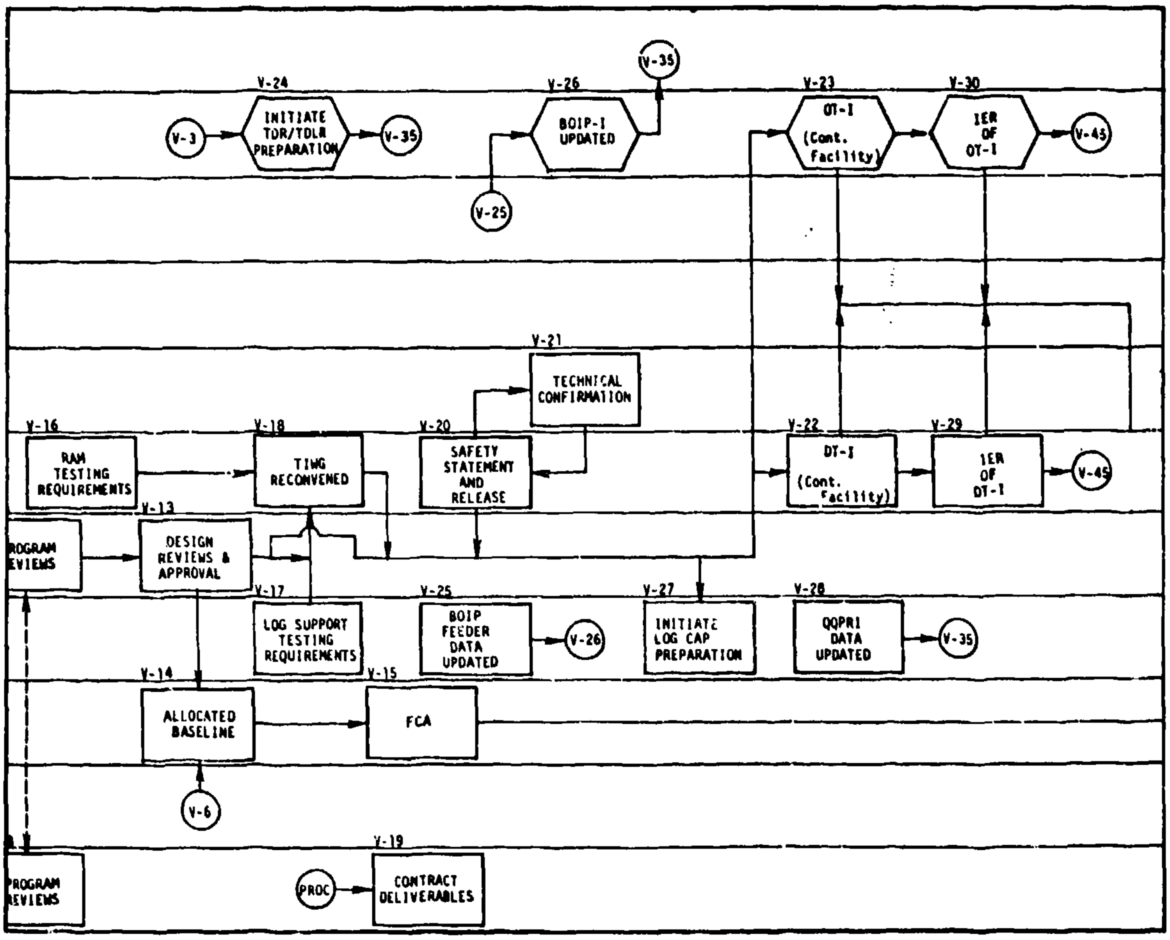

Figure 3 - DEMONSTRATION AND VALIDATION PHASE (PARTIAL)

This phase of the training device acquisition process is the phase wherein a Project Director (PD) becomes the principle manager. He uses a team of highly qualified personnel from the divisions of the PM TRADE and Navy Training Equipment Center to assist him in his management activities.

The repetitive process used during need identification and concept formulation is found in the VALIDATION PHASE. The several studies, analyses, and assessments made in this phase are repetitive, mutually supporting, fully inter-related and are continuously updated during this phase or are updated versions of like efforts from the previous phase. These repetitive and joint efforts may be illustrated by the updating of the Coordinated Test Program (CTP) for the Developmental and Operation Testing (DT-I/OT-I) series of tests and new or revised plans for later series of tests.

In general terms, the training device concepts of the CONCEPT PHASE are developed into breadboard models. They are then tested to demonstrate both the validity of the concepts and that they can be fully developed in order to economically fill the need. The design(s) selected by the Government will be further developed during the next phase of the training device acquisition cycle.

The complete VALIDATION PHASE is not found in many training device programs. At the present time the technology used to develop most training devices is in-hand and the technical risks, therefore, are minimal. The FULL-SCALE DEVELOPMENT (FSD) PHASE often follow the CONCEPT PHASE with a short VALIDATION PHASE.

During the ED Phase the training device system and all of the items necessary for its support are fully developed. The device is engineered, fabricated, tested, type classified as appropriate, and a decision is made as to the device's acceptability to enter the inventory.

The Engineering Development (ED) prototype is developed to where it can be tested and subsequently produced. The analysis of the test results will provide sufficient information to make a decision as to the usefulness of the training device by the US Army. The necessary supporting items are also developed. They are then tested to determine their acceptability to support the training device. At the same time, personnel and equipment requirements, publications, repair parts and modifications to doctrine and/or organizations are finalized so that an integrated training device system is ready to be deployed.

Certain training device programs may condense this phase if immediate acquisition is warranted; e.g., Military Adaptation of Commercial Items (MACI), non-developmental items or assemblages, etc. During the

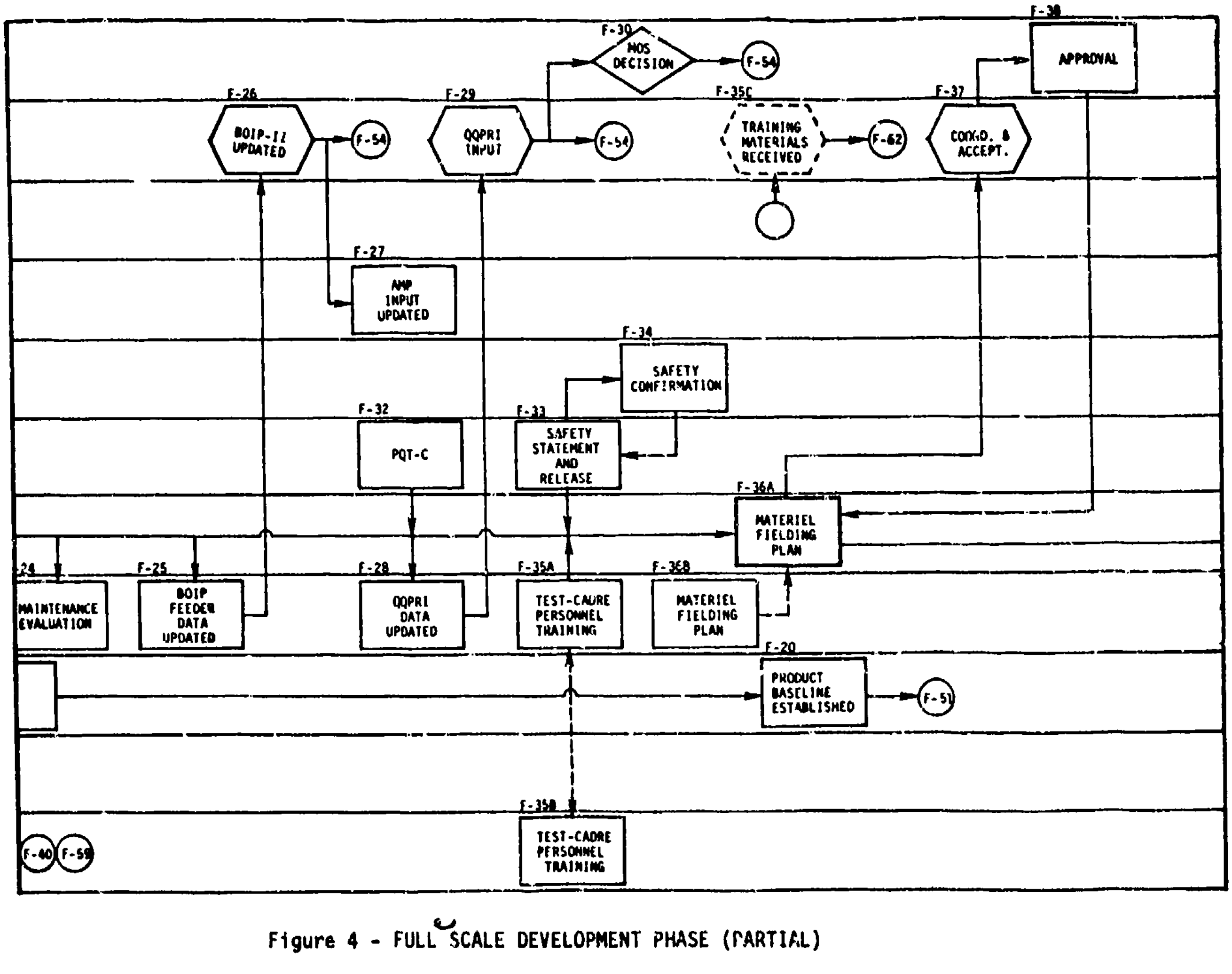

Figure 4 - FULL SCALE DEVELOPMENT PHASE (PARTIAL)

developmental and operational testing (DT-II/OT-II) conducted during this Phase, engineering development prototypes are used to arrive at a decision concerning the technological feasibility, training utility, cost, health hazards, human engineering, value engineering, producibility (if applicable), training effectiveness and supportability of the proposed training device. The Project Director is the primary manager with the assistance of a team of PM TRADE personnel.

The repetitive process found in the two previous phases of the Training Device Acquisition process is again present in this phase. The significant difference in this process as it is applied to the activities of the FSD PHASE are that conclusions, recommendations, procedures, plans, and assessments are completed and appropriately implemented particularly if there is no PRODUCTION PHASE to follow.

During the PRODUCTION AND DEPLOYMENT PHASE operational and support personnel are trained, training devices and their supporting equipment are procured and distributed in accordance with requirements, and logistic support is provided. Maintainance and cost data are collected, evaluated and used for systems management of the present training device and similar future devices.

The Engineering Development (ED) prototype is duplicated or manufactured and delivered to the Users. The DEVA IPR may have provided guidance to the PM TRADE and TRADOC that will be cause for updating some of the management documentation. If so, this is accomplished early in this phase. The plans and agreements e.g., the Materiel Fielding Plan, Integrated Logistic Support Plan, etc.) are coordinated, completed and implemented, as appropriate. The significant objectives of this Phase include the following:

a. Award a production contract.

b. Accept the Initial Production Facilities for the production of items to the prescribed form, fit, function and interchangeability standards that have been prescribed.

c. Receive the Long Lead Time Items that have been identified.

d. Review and update the logistic support and training documentation prepared or updated during the ED PHASE to insure compatibility with the configuration of the production items.

e. Audit the configuration of the initial production items and compare it to the production Technical Data Package.

f. Coordinate and finalize the Materiel Fielding Plan with each gaining Major Command before the Initial Operational Capability date.

g. Finalize and implement the Integrated Logistic Support Plan. The implementation of this plan is

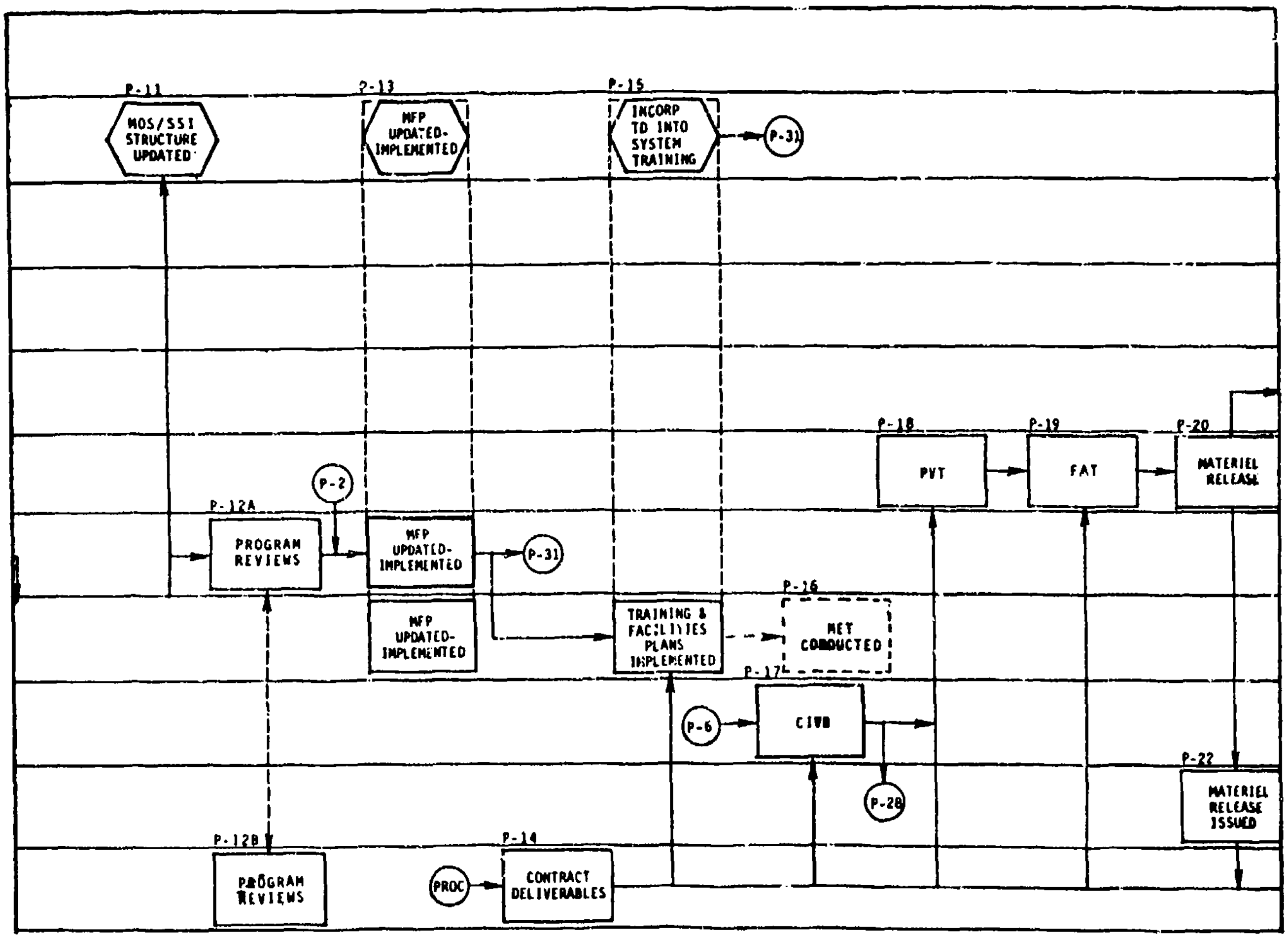

Figure 5 - PRODUCTION AND DEPLOYMENT PHASE (PARTIAL)

continuously monitored to assure the availability of trained personnel, supporting hardware, software, manuals, Test Measurement and Diagnostic Equipment, repair parts, etc.; to the gaining command before or with the training device being fielded.

h. Plan and conduct production testing and/or inspections.

i. Conduct New Equipment Training (NET).

The appearance of the TDAMM and some of its features are demonstrated in the above portions which have been extracted from the entire model. The numerical designations are to some extent arbitrary due to several events happening at one time. Each element is given the title of the event or effort being undertaken.

The alphanumeric code is a ready reference to the associated test which briefly describes what is to be accomplished within the context of this particular element, its inter-relationships with other elements and what organization is most responsible. The organizational elements are depicted on the model by the horizontal lines which are each given an PM TRADE organizational designation.

The Training Device Acquisition process has seldom found it economical to fully accomplish every task of all four phases nor to enter full-scale or limited production. It is of note, however, that many of the actions associated with the VALIDATION PHASE and the PRODUCTION PHASE are done to some degree in the FULL SCALE DEVELOPMENT PHASE in order to field low risk Engineering (ED) prototypes which represent the full quantity of training devices required. Some of these actions are:

a. The Technical Data Package may be reduced in the standards to which it must be prepared.

b. Test and cadre personnel are limited to a very limited number of schools and school operational and support personnel.

c. The Materiel Fielding Plan is completed and tailored to a single User.

d. The Engineering Development (ED) prototypes may be the sole quantity required.

e. The use of contractor support personnel with a "buy-out" of the necessary repair parts greatly reduces the provisioning effort and the burden on the logistic system to support very limited quantities of a training device.

f. The transition from the PM TRADE to a DARCOM Major Command is accomplished.

Each action shown in the TDAMM is examinated by the Project Director to decide which actions are to be done to a greater-or-lesser degree as dictated by the specific training device to be produced. Each action must, therefore, be considered and analyzed by the Project Director as to its applicability to the Training Device Acquisition process. The actions are selected to be included, deleted, expanded in scope or reduced in scope to form a tailored TDAMM just for the training device to be managed. The TDAMM is a disciplined guide to a Project Director to plan his project and then after tailoring it provides the means to track the status of his efforts.

From an overall generic viewpoint, the PRODUCTION AND DEPLOYMENT PHASE represents the progression of the acquisition process from the FULL-SCALE DEVELOPMENT PHASE to an Initial Operational Capability date.

APPLICATION OF TDAMM

The Training Device Application Management Model (TDAMM) is now available for use by the PM TRADE to anticipate training device developments to forecast, plan, test and execute a development of any training device or significant modification to a device. The model is also useful to any contractor developing a training device. It is applicable to all training device acquisition programs. Moreover, the model is applied to a system-unique as well as a non-system-unique device. It is an easily recognizable fact that not every training device requires all of the events depicted be performed. As the situation warrants, the acquisition requirement for a particular training device can be logically selected and a tailored version of the TDAMM prepared. As an example, the Conduct-of-Fire Trainers (COFT) for the present Main Battle Tank and the future MBT along with the Fighting Vehicle series were severly modified or tailored. The TDAMM was initially applied when the development program of the COFT devices had nearly completed one year of the three years Full-Scale Development effort. The development strategy was to use a "skunk works" method of development wherein two contractors were in competition to demonstrate their development of a COFT in a shoot-off. This strategy has lead to the avoidance of developing much of the documentation normully required at this stage of development; e.g., no Technical Data Package (TDP) was delivered. Under such circumstances, dependent activities (e.g.; the lack of a TDP delays the dependent Physical Configuration Audit) must be rescheduled within the phase or, as in the case of the COFT, delayed until the next phase. In the COFT development program, the model indicated the events that had been neglected or overlooked for one reason or another. Many have had to be done in order to be ready for the Development Acceptance In-Process Review (DEVA IPR).

The application of the TDAMM to the trainer device developments of PM TRADE illustrates its utility to guide management in its determination which actions are applicable leading to a system-unique tailoring of TDAMM. Caution, however, must always be taken to ensure that none of the 202 events is eliminated or reduced in scope so that there is an adverse effect upon the Government such that an unsatisfactory design results

Other developmental agencies within DoD and foreign countries have indicated interest in TDAMM to use in their developments. When the requirement for a training device is received a small project team is formed in order to, among other things, prepare a program plan. As part of this effort the TDAMM is reviewed and tailored to manage the developemnt of the project. The dates that the events are to be accomplished are established in order to track the project. The program plan and the tailored TDAMM are the baseline management tools turned over to the Project Director who, with a team of functional experts, will manage the program.

Each training device project is managed in a like manner. All of the training device develops are periodically reported to the PM TRADE in accordance with the individual program plans and the tailored TDAMM. In this way the PM TRADE is kept informed of the status of each program.

The TDAMM is a model to use in order to forecast, plan, test and execute the development of any device. When the model of each individual device is integrated into those of the other devices the total workload of PM TRADE is available. While this is tedious when done manually, the automated system will present to the PM TRADE his total workload and its status virtually instantly and continuously.

SUMMARY

The planning, management and execution of the 202 events necessary for a complete training device acquisition program are complex in their inter-relationships. In addition to the complexity of the acquisition process itself, is the added complexity of the organization and number of projects within the purview of the PM TRADE. The complete Training Device Acquisition Management Model, has been designed to logically inter-relate all of the events to be considered and undertaken by the PM TRADE as it develops and supports the Army's training devices. Based on the best available data of any specific training device program the TDAMM is entered and a project management plan can be prepared. The actual pacing factor for training device acquisition programs is the true progress of the evolving device, support, and associated technical data package rather than any administrative requirements. When it appears to be appropriate to the PM TRADE, phases may be eliminated, contracted, or re-sequenced to meet the requirements of a specific device. This tailoring-of-the-TDAMM capability recognizes the uniqueness of each training device development program while still considering all of the standard action that must be taken in any development.

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ABSTRACT

As computer based training devices proliferate, the need to maintain the software associated with the devices will cease to be an isolated need and will become a general requirement. Based on experience with tactical systems, it can be estimated that the maintenance of the software associated with a simulator over the life of the device will cost at least as much as the original acquisition cost of the software. In this paper the procedures and requirements for software maintenance are analyzed. The many associated trade-offs are examined. Based on the requirements of post deployment support the impact on the acquisition process is examined. Recommendations are made as to how the acquisition or development phase can best support post deployment support activities for software such that system utility can be maximized and life cycle costs minimized.

INTRODUCTION

In a recent IEEE tutorial on software cost estimation, Putnam shows software maintenance costs ranging from the same as initial acquisition costs to nearly three times the cost of original software development. (1) Jensen and Tonies report figures ranging from 50% to 80% of total software budgets being devoted to software maintenance. (2) Clearly, the Life Cycle Cost of a training device involving software will include significant expenditures on the support of the software after it has been deployed for operational use. Thus, proper planning for post deployment software support offers the training device purchaser at least as effective control over life cycle costs as does proper planning for the development of the software. Indeed, as the expected useful life time of a training device gets longer, more and more leverage will be available through control of post deployment costs. This paper attempts to describe the nature of post deployment software support activities, the nature of the resources necessary to accomplish the activities and to provide some indication of the planning considerations to be addressed during system acquisition.

SUPPORT ACTIVITIES

The need for post deployment changes to software come from such sources as:

- o Residual errors not previously discovered.
- o Inadequate design leading to dissatisfaction with performance.
- o Increased user sophistication leading to extension of performance requirements.
- o Modifications to the basic system leading to new training requirements.
- o Changes in tactical doctrine also leading to new training requirements.
- o Upgrading of trainer hardware leading to new interface requirements.

All of the above sources generate a continuing need to change or correct the software of a training device over its life time. The provision for accomplishment and management of these changes in a cost effective manner needs to be a high priority goal of those acquiring the training device.

The types of activity which characterize post deployment software support are illustrated in Figure 1. The two are not totally distinct and that which begins as one type of activity generally concludes as the other. The two types of activity referred to are immediate problem response and on going scheduled version production. Most training devices are of sufficient importance today, that significant error conditions, once discovered, cannot be tolerated while the lengthy process of formal version production is accomplished to correct the error. Instead, some form of immediate action is required to bring the device back to a state that is ready-for-training. Immediate action is characterized by focus on the single problem at hand and often takes the form of a "work around" that avoids the unwanted symptoms rather than curing the source problem. Such fixes are temporary in nature and are segregated from the formal change package that will eventually resolve the underlying problem.

One of the most important aspects of immediate action programming is simplicity. The programmer must find the simplest means possible to avert the unwanted performance. He must seek to minimize his impact on the system. If he does not, he will most likely introduce two or three new problems for each one he resolves. Some times he will find an obvious coding error and will totally clear up the problem with a simple correction. However, such errors will generally be found and eliminated early in the life of the system. Problems that are discovered post initial deployment are often caused by complex interactions of code that are only apparent now that the user has gained a level of sophistication in the use of the training device. For immediate action, it may be best to suppress an erroneous output rather than to make changes impacting multiple functional areas of the simulation. Very often the instructor can easily supply the missing information to the student allowing training to continue.

Meanwhile, thorough design analysis of the reported problem is conducted and a complete correction is developed, implemented and tested. Once that process is complete, the new version of the software, containing corrections to multiple problems and design enhancements as well, is released to the field. The process by which a problem report is processed to final solution requires formal control as described in the following section.

Processing of a Problem Report

A problem report is initiated when user of a training device sees some feature that does not appear correct to him. The report is forwarded through normal maintenance channels until it reaches the support facility

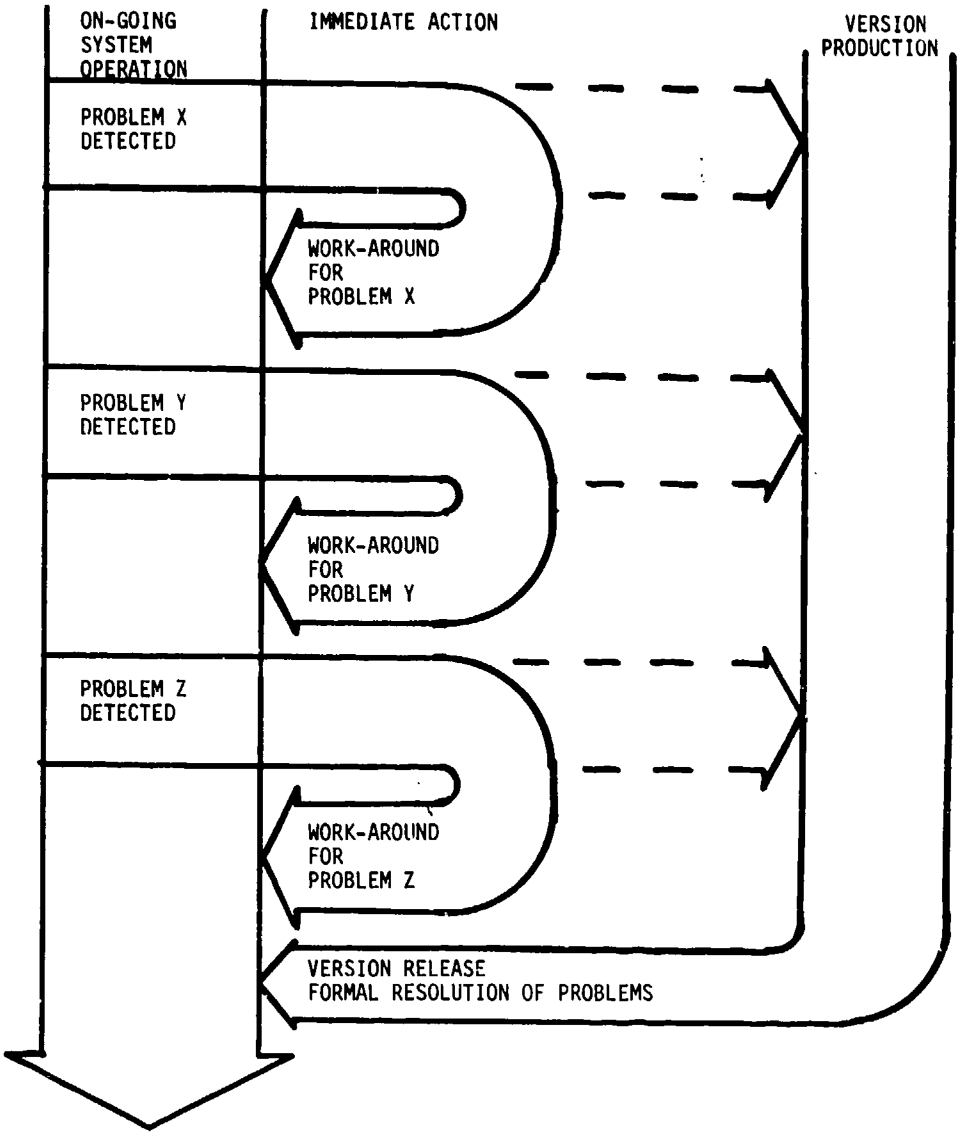

FIGURE 1 - POST DEPLOYMENT SOFTWARE SUPPORT ACTIVITIES

where an initial analysis is performed.

The initial analysis is technical in nature and seeks to answer the following questions:

1) Can the situation described in the problem report be duplicated? If not, the user reporting the problem is queried for more information until the problem can be repeated or is traced to improper operator action.

2) Is the system performing in accordance with specifications? If system performance does not match specified requirements, corrective action is explored.

3) If the system is performing according to specification, does the problem report indicate a situation that requires a design change? Very often an apparent problem, particularly in a simulation is, in fact, a trade-off that was made to gain some more important area of performance. For example, a simulation may have sacrificed full fidelity of some feature to maintain real-time operation. Such past decisions must be a matter of record to avoid unnecessary analysis each time that a new user detects the apparent discrepancy. On the other hand, continued reports of such a situation may be the basis for a re-evaluation of the design, indicating that the apparent training impact may have been more severe than originally anticipated.

The initial analysis, therefore, establishes if a problem really exists, and if it does, whether its resolution requires only corrective action or if it requires a design change.

Once the initial analysis has established the required resolution, the necessary corrective action or design change is scheduled for implementation in a forthcoming version. Based on the required effort, the urgency of the change and the available resources, one of the upcoming version releases will be selected for incorporation of the new code. If a minor correction of a few instructions is all that is needed, it will most likely be incorporated into the next release. However, each version has a "freeze date" beyond which, no further modifications can be incorporated. Actions that require significant design effort may be scheduled for further analysis before actually being scheduled for implementation. An important aspect of the analysis at this time is to establish "user" concurrence on the proposed design change. Only after the user has validated the new requirement can it be scheduled for incorporation in the system.

Prior to scheduling for implementation, any design change must be analysed to develop a proposed approach, a probable cost and an expected impact on system performance. This is, of course, standard ECP procedure. The process leading to formal scheduling for implementation is illustrated in Figure 2.

The "Version" Concept

Systems containing relatively little software require only informal means of control. The trend today, however, is toward large, complex software. Such systems require formalized baseline control and disciplined change procedures. Formal procedures become necessary whenever the software is too large or complex to be maintained by one or two people. Formal control is also needed when the software is one system of several being maintained by the same people at a central facility.

The primary means of obtaining formal control over software has been by means of Version Releases. Periodically, over the operational life of the system, new versions of the software are released for operational use. The frequency of version releases varies with the criticality of the system, the maturity of the software, and the dynamics of the system.

Critical systems, such as operational air defense systems may generate frequent version releases to insure continued peak performance of the system. As software matures, fewer and fewer latent errors are present, and version releases can be further apart without adversely impacting the system. Some systems will always be highly dynamic. Simulations of new aircraft, for example, will be in a constant state of change until the aircraft they represent mature and stabilize into a fixed version. For most systems, software version releases will be frequent during initial operations and will taper off to an as-needed basis as the system matures.

Just what is a version? Since it is released for operational use, it obviously must have undergone all the controls and checks and tests that any new item must undergo before it is released to the field for operational use. A software version must be thoroughly validated for correctness of design and implementation as well as for correctness of technical performance before it can be released. Further, all ncessary items needed to support the version must be validated and ready for simultaneous distribution to the field. This includes all user's manuals, performance aids, technical documentation, maintenance procedures and instructions and any necessary training materials. In situations where a significant design change is being implemented, training teams must be prepared to install the new version at each site and to train the operational crews on the use of the new system. As can be seen, support of systems at multiple sites poses a logistical problem for software as well as for hardware.

Version Production

Version production is the entire process of analysis, planning, design, implementation and test necessary to convert selected modification requirements into a software version ready for release to the using units. This process is illustrated in Figure 3. To accomplish version production, all selected changes must be carried through a design phase with appropriate reviews and coordination. The latter is particularly important in software maintenance efforts. The tendancy to view a particular change or enhancement as an isolated problem makes the possibility of inadvertant adverse effects on other areas of performance an ever present danger. A thorough, formal and disciplined process of review and coordination must be established and enforced throughout the version production process. If not, the version will never survive the prerelease testing to qualify it for operational use.

Design Teams

One technique for accomplishing such coordination and review is the establishment of design teams. Each change or design requirement is assigned to a lead analyst. Then a representative of each functional area is appointed to form a design team. Each member may well serve on several design teams, because their primary function is to review the work of the lead analyst to ensure that impact on their functional area of responsibility is correctly understood. The lead analyst is, of course, selected from the functional area most severely effected by the change. It is his responsibility to coordinate his design with all members of his team and to obtain formal concurrence from the team that this design is an acceptable implementation for all functional areas.

The design team also serves to coordinate the documentation and testing associated with the particular change package. Changes to user manuals, technical documentation, maintenance manuals, and training materials must all be prepared and coordinated. Tests must be prepared that will test out the change itself and also to validate that all other areas are not impaired.

Version Testing

Version testing mirrors normal software development testing, but with some significant differences. For modifications representing new design, a bottom up approach is generally followed. The modified modules are tested and debugged in isolation then integrated into the system and tested for correct operation at the system level. Smaller corrections may only require verification at the system level to show that they have, in fact, been correctly implemented. The most significant fact about version testing is that any one version changes only a very small percentage of the system software performance requirement. Thus, system level version testing does not require a new system test for each version, but rather a new version of the already validated system test. This approach to testing can allow significant savings in the testing effort required to validate a new version for release. A very desirable approach is to develop an automated system test that provides stimulating inputs and automatic analysis of results (See Figure 4). Such a test tool, once accepted by the user can greatly reduce the effort of version qualification. The automated test program can short circuit normal operator input and output since it is required to show only that unmodified software still performs correctly. Thus, by running prerecorded inputs through the system and automatically comparing the outputs with expected results, it validates the operation of the software not affected by the changes incorporated by the new version. (The system test itself,

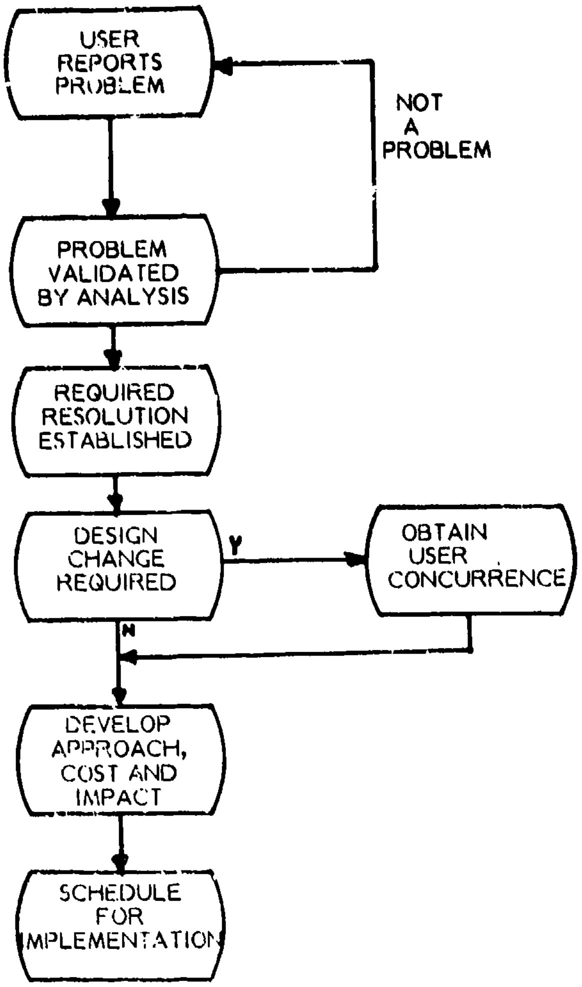

FIGURE 2 - PROBLEM REPORT PROCESSING

must be updated for each version, however, this is much more manageable than developing a new test each time.)

The test cycle for the version is as follows:

- Debugging at the module level
- Testing of new features for correct implementution at the system level
- Validation of unmodified software using the automated system test
- User (Operational) Testing of new features

An important consideration of the last step in the above sequence is how much user testing is required? Clearly, the user of the training device must be satisfied that it is performing correctly. However, it should not be necessary to revalidate by operational testing all performance parameters of the system at every version release. The ability to satisfy the user (he is, after all, the customer) that he needs only test the new features of the version will depend heavily on the degree to which the user can be convinced that the automated version test does successfully validate the unchanged software. This is further support for a well planned and well documented system test.

Formal, centralized control is a necessity in the test program. If central control is not maintained, testing can degenerate into an unending set of failures as test after test encounters unexpected side effects. This can only be avoided if proper resources are committed to the testing effort throughout version production. Testing is also very sensitive to "Version Freeze Date". If the input of change

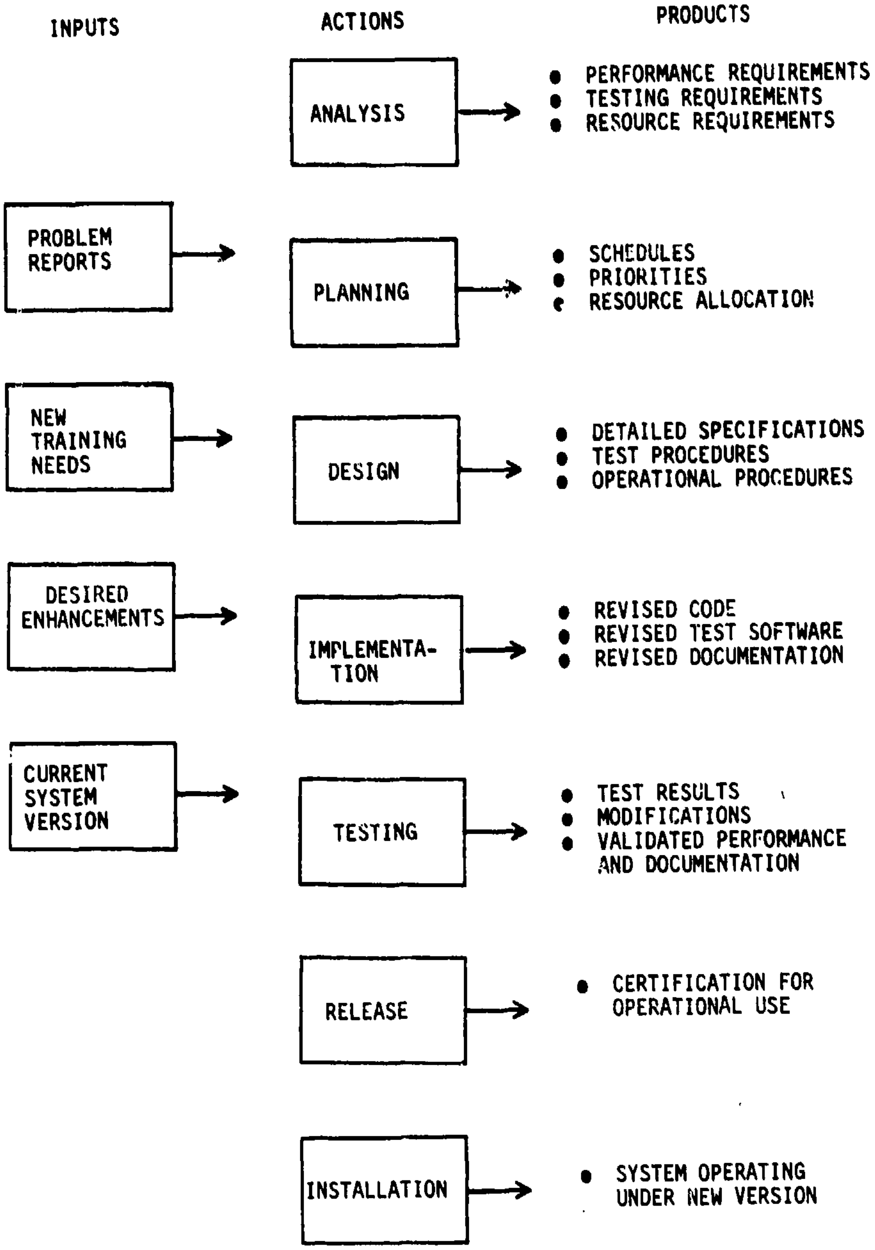

FIGURE 3 - THE VERSION PRODUCTION PROCESS

requirement for a particular version are not cutoff early enough, testing will suffer along with design. This can be offset by scheduling version release dates with sufficient frequency to reduce the pressure to keep adding "just one more change".

Scheduling of Version Releases

The time required to design, develop, implement, test and release a version will necessarily vary with its contents. If the version is primarily to correct coding errors then it will require a short period to prepare it for release. As new design effort is added to the version's contents, the required time length will go up. Thus, version release may take from 6 to 18 months. When significant hardware changes are also involved, the release time could easily approach the initial development schedule and run as much as 3 years.

For administrative reasons, it may prove desirable to schedule versions for release on a fixed timetable. In this case, version content can be adjusted to meet the schedule. In addition the start date for versions selected for significant change efforts can be set ahead of the normal version start time. The phased nature of version production lends itself to overlapped production of versions. That is, while one version is undergoing testing by the testers, a second one can be in the hands of the programmers, while system analysts have begun the design of a third version. In this manner three versions are in production at any one time. Version release occurs more frequently and the technical staff is allowed to specialize in the three specific areas of design,

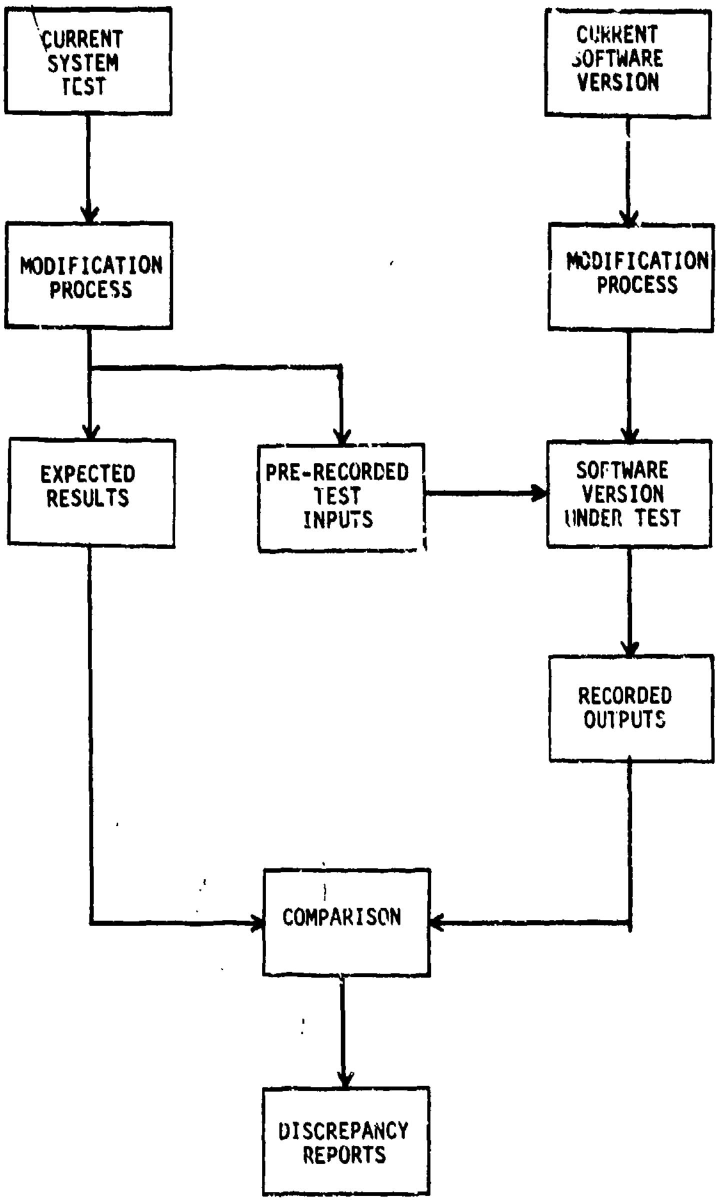

FIGURE 4 - AUTOMATED TESTING PROCESS

implementation and testing. Such specialization leads to increased efficiency since each area requires particular skills and not many individuals will be equally capable at all three areas.

PLANNING FOR POST DEPLOYMENT SOFTWARE SUPPORT

In establishing the Post Deployment Support Concept for a training device, questions such as where software support will be performed, who will accomplish the support, and what equipment will be required must be answered. The answers to such questions are not arbitrary, but are determined by several contributing factors.

Locating the Software Support Capability

Assuming that we are talking about a training device with a significant software support requirement, then the issue of where to perform the support task is largely a question of resources. Perhaps one of the primary considerations is the availability of equipment.

It does no good to locate the maintenance facility at the training site if the training device is so heavily committed to training use, that no time is available for software maintenance usage. The temptation to save money by planning to do all software maintenance on operational equipment must be balanced against the very real cost penalties of having programmers being paid to sit around waiting for computer time. The early planning for training devices generally includes an assessment of device utilization. Using this assessment plus an estimate of how much device time will be required for hardware maintenance, provides an indication of what time will be left over for software maintenance utilization. Analysis of the software maintenance task, based on the dynamics of the system that will lead to changes to the training device can provide an estimate of the size of the software workload and hence the required device access. If a conflict exists as to device availability, then the thought of using operational equipment should not be carried further since the initial estimates of software change activity usually tend to be low!

Once the decision is made to acquire a software support facility (i.e., computer equipment dedicated to software maintenance) the question of where to locate it still must be resolved. At this point the other essential resource must be considered--personnel. If a centralized support facility already supporting similar or related training devices exists, then it provides an attractive base for economically expanding to provide support for the new system. If a stand-alone maintenance facility is to be established, it will generally require more personnel than would be required as add-ons to an existing facility. An existing facility also provides a source of personnel experienced in the technical and managerial skills associated with software maintenance. (It should be recognized here and now that the developing contractor is not going to turn over his design and programming staff to maintain the delivered equipment. They will be off designing and programming new products.) A brand new software support facility will always undergo an expensive learning curve as the new personnel come up to speed with the system and with the maintenance process.

The equipment placed in the support facility need not necessarily be as elaborate as the full up training device. The majority of software development and testing can be accomplished without the full set of hardware required for the more elaborate training devices. While training time will not usually permit software maintenance to be fully supported on operational equipment, it usually can support some of the final system testing necessary for version release. Thus, a concept of shared facilities may prove a useful compromise with the majority of software maintenance being accomplished at a less elaborately equipped support facility and the formal system level version acceptance testing being accomplished at a designated operational "test" site.

When choosing the operational site or an offsite facility location, consideration should be given to the ease with which qualified personnel can be recruited andretained at the locations under consideration. Questions such as the availability of trained personnel, and the desirability of the geographical area will have long term significant economic impact on the operation of the facility.

The "WHO" of Software Support

Daley, speaking of commercial software, estimates that one full time programmer can maintain 10,000 lines of realtime software or 30,000 lines of support software. (3) This figure does not include configuration management, supervision, field support or other overhead. While his estimate is not necessarily directly applicable to training device software, it does serve to illustrate that the manpower requirements to maintain any significant software package are not small.

As Daley also points out, a programmer will be more effective in a maintenance roll if half of his time is devoted to maintenance and half to development of new software. (3) This effect derives partly from motivation and partly from proficiency maintenance gained by experience with new systems. This factor seems to argue against dedicated software support facilities. However, the experience of developing new software can be provided at a support facility if system enhancements are also assigned to the facility for development. Otherwise, it can be expected that a facility devoted solely to error correction and minor enhancements will suffer as good people move on to more interesting (and better paying) work and those that remain lose touch with the developmental side of software programming.

The question of contractor support versus Government in-house support of software is frequently raised. There is, however, no simple one time answer to the issue. The choice must be made and justified on a system by system basis.

The key issue, if Government in-house support is being considered very often comes down to whether or not the Government can make available the personnel resources needed to maintain the software. Right now the Government has limited capabilities in this area, however, as tactical computer systems proliferate, the software support capabilities within DoD will expand dramatically. Thus, it may be that in a few years, assignment of training device software to a Government software support facility will be routine.

The possibility of Government support of the software at some future date is another argument for the acquisition and maintenance of thorough and complete documentation of <u>all</u> software, even if it is to be initially supported by the developing contractor.

Post Deployment Software Support Equipment

When acquiring a training device, considerable thought should be given to the acquisition of software support equipment. As mentioned above, operational equipment is often not available for software support. This makes it necessary to have computer equipment dedicated to the support role. One means of accomplishing this is to assign prototype equipment to the support role upon completion of prototype testing. Another means is to buy excess computer power so that both operational and support functions can be accommodated in a timesharing mode. (This is only possible where the operational requirements can tolerate the limitations of time sharing operation.) In many cases it will be necessary to buy (or lease) a totally separate set of equipment for the support role.

Whichever method is selected, it is important that requirements for the support function are specified and designed in from the beginning. Attempts to go back and force such functions in later on always meet with limited success and are generally much more costly than when they are recognized and designed in from the beginning.

When the prototype of a training device is to end up as the software support facility, thought should be given to procuring excess computer power in the prototype configuration. Not only will this make the development of the operational software easier, it can also allow the support facility to support multiple programmers in a time-sharing mode. It will also make it possible to establish a test environment for the operational software by the addition of other software designed to provide on-line analysis of operational software performance.

SUMMARY

In conclusion, the planners of a training device development can, through proper provisions for post deployment software support, do as much or more to control the overall cost of the training device as can be accomplished by proper provision for the initial software development. Coversely, failure to consider support requirements for software can be just as disasterous as failure to consider hardware support requirements. Lack of adequate provision for software support can prevent effective use of the training device and can cause excessive growth of life cycle costs.

Software support, once the training device is deployed, will consist of software modifications to enhance device performance, to eliminate latent errors, or to reflect changes in the operational equipment.

These modifications must be managed to ensure that the operational validity of the training device is not lost. Thus, formal procedures must be established for the post deployment support operations.

Two primary activities characterize post deployment support operations; immediate action and version production. Immediate action is intended to provide quick fixes or work-arounds for problems detected during system operation. Version production is the formal process of analysis, planning, design, implementation, testing, release and installation that provides integrated and validated software enhancements and fault corrections that ensure effective and efficient use of system resources throughout its life cycle.

To make certain that the support facilities and resources required for post deployment software support are ready and in place when needed, planning must begin with the initial training device concept formulation. To accomplish the necessary planning, consideration must be given to where the software support activity will be accomplished; what personnel resources will be, a) required, and b) available to provide the support; What equipment is to be used for post deployment support and how it is to be obtained, and how the overall effort is to be managed.

It is strongly recommended that a Post Deployment Software Support Plan be developed early in the acquisition process and that it be maintained up-to-date throughout the device life cycle.

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MILITARY PERSONNEL SHORTAGES THROUGH THE YEAR 2000 - ENOUGH TALK! LET'S DO SOMETHING!!!

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ABSTRACT

The paper summarizes the implications of the shrinking U.S. person-power base in the 80's and 90's, including the competition for these resources by the government, military, and industry sectors. Probably the most practical solutions lie in designing as many O&M personnel out of the weapon systems as practical; and increasing the productivity of those remaining personnel via improved training-programs. Four key joint DoD and industry actions can facilitate these solutions: a) increase first term productivity; b) improve career selection; c) emphasize transfer of training studies; and d) reduce personnel requirements based on credible personnel subsystem life cycle cost modeling. The technology exists.

THE PROBLEM

Personnel shortages will exist. Figure 1 portrays the now-familiar demographic fact that the number of 18 to 24 year old males entering the workforce will decrease by a significant amount over the next 16 years. This represents a cross-section of personnel, from unskilled laborers through professionals.

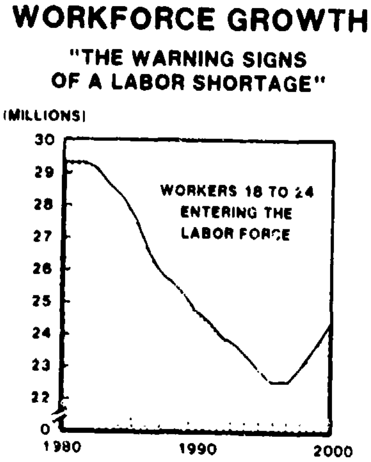

Figure 1: The Traditional Source of Manpower Base Will Not Keep Up with Demands

This shortage of available manpower is beginning to be felt right now. It is a problem that requires immediate solutions, because people are long lead time items: you can't grow an 18 - 24 year-old overnight.

The personnel shortage affects industry (and the generation of the GNP which pays for government), as well as government and the military. Industry demands are increasing, especially for the higher skill categories. For example, the electronics industry is growing at about 17% per year according to some recent statistics. The second major user of manpower, the government sector, has vowed that it is cutting back its requirements. However, increased industry requirements will probably counterbalance government cutbacks. The projected military manpower demands over the 1980 - 2000 time period are relatively constant at around 2 million personnel.

Since total manpower requirements of the three sectors will remain constant or increase, and the available workforce will shrink drastically, the military cannot realistically expect to satisfy its future manpower requirements by drawing from industry. The military will have to seek elsewhere to solve its personnel problems.

Various internal solutions have been proposed to solve the military manpower shortage problem; these include:

a) later retirement

b) more use of women

c) employing the "unemployable"

d) the draft

Upon examination, later retirement does not seem to provide a practical solution to the manpower requirements. As the military acquires increasing numbers of weapons systems, its greatest manpower requirements are for operators and maintenance personnel to man the fielded systems. Yet job advancement moves more-experienced personnel out of technical billets into supervisory and administrative positions. Attempts to fill many of the highly technical or lower skill-level military O&M billets with retirement-age personnel might create technical manning gaps, create severe morale problems, and be far too expensive in terms of pay and benefits.

Women are being employed in the military for both administrative and non-traditional technical roles. At one time this approach seemed to offer considerable promise. However, recent statistics published by the military indicate that this approach will not fill the gap.

The percentage increase of personnel in lower mental categories joining the military these days has been well-publicized in recent years. Placing increasing reliance upon such personnel to operate and maintain the increasingly-sophisticated weapon systems coming on-stream does not seem to provide a sound long-term solution to the manpower shortage.

Thus, it would appear that a more comprehensive solution to the increasing manpower-shortage is badly needed. The most-promising solution is to draw markedly increased productivity from the dwindling military-manpower resources available. Part of this increase can be achieved through improved motivation and commitment of the military workforce. Most of the productivity increase must be developed by: (a) reducing the numbers of people required to counter all anticipated military threats to the country; and (b) improving the training of those people.

Prerequisite to increasing the productivity of military manpower, we must define clearly every single job or billet in terms of its "productive" contribution to meeting the mission; and we must develop a valid means to evaluate how effectively the individuals occupying the billets meet those productivity goals. The measure of billet productivity may range from effectiveness in manning a system in combat, to maintaining the system to its availability and readiness specs, to restoring a high level of motivation and enthusiam through a well-planned and well-executed R and R program.

Increasing the productivity of military personnel will have a drastic beneficial effect upon the DoD budget. The cost of manpower (the personnel subsystem) is the most significant item in the budget, over 30% of the total budget, and over 50% of the O&M budget. These percentages do not even include the large annual retirement costs, housing construction, training, and other indirect personnel-related costs. When we devise ways to calculate such indirect costs accurately, and add them to the direct personnel costs, the budgetary importance of improving the productivity will be just as apparent as that of reducing the manpower shortage.

We're at the critical point. What can we do?

JOINT DoD AND INDUSTRY SOLUTION

There are four key actions that can be taken jointly by DoD and industry to solve the manpower shortage. These are:

a) Develop methods for increasing first term enlistment productivity.

b) Improve selection/motivation systems for potential career NCOs.

c) Fund more research into the cost effectiveness of improved training strategies and devices on transfer of training.

d) Develop simple, fast, credible personnel subsystem costing techniques keyed to weapon system design parameters, to substantiate designing people out of the system.

Each key action is designed to reduce the military's manpower requirements. The first three actions will enable fewer personnel to do more work by means of increased productivity. The fourth action will reduce manpower requirements by means of weapons system design tradeoffs.

First Term Productivity

Over 20 percent of the enlisted force consists of first year enlistees. The total percentage of "first term" enlisted and officer personnel is much greater. Therefore, it would seem that investment in technology to increase first term productivity would reap the highest near-term benefit. This might be envisaged as "return on investment" in terms of additional productive manhours per-dollar-invested in the personnel management and training system. Such investment in training not only reduces the drain on the scarce manpower pool (since more productive-manhours per person generally means less people required, even allowing for minimum manning requirements), but also reduces the attendant salary and support costs.

Figure 2 shows a typical first term personnel investment cost/productivity return cycle for an enlistee. The investment cost consists of recruiting, training, and support. The productivity return is the performance of mission-related job tasks.

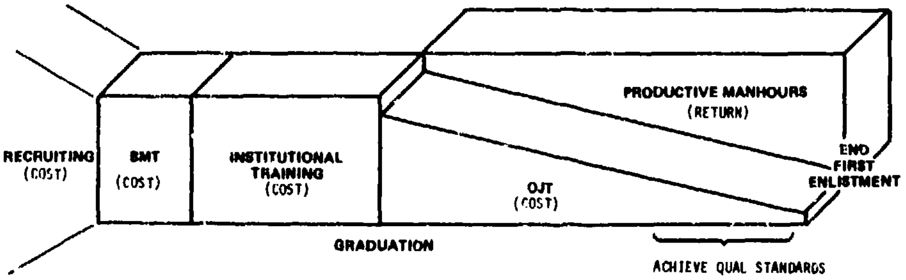

Figure 2: Low Productivity Results in Military Manpower Problems

The three most significant considerations controlling the productivity return are:

1) how soon after service entry the enlistee's formal or institutional training can be completed (graduation);
2) the enlistee's average level of productivity at graduation (e.g., number of productive manhours he can effectively provide per week);
3) how soon the personnel can become completely qualified in their assigned specialties (i.e., pass a realistic, criterion-referenced skill qualification test or SQT).

There has been considerable comment--via symposia, Senate Hearings, and speeches--to the effect that few first-termers qualify in their specialty during their first enlistment. This problem adds a further supervisory load to the already over loaded NCOs in the field. It also gives rise to the constant, though contradictory, complaint by NCOs in all services that the schools make work for them by not providing personnel who are qualified. (The contradiction is that these NCOs also harp on the theme that "experience is the best teacher.")

At issue is the need to establish a close-knit, honest, unselfish link between the school and the field by means of comprehensive "career" (first term) training programs for each specialty. The Army is making some headway in this, possibly as a result of the high (Four-Star) organizational level of the policy-making function for personnel, doctrine and training. The Navy Air community is also attempting to achieve this with their newer (F/A-18) Fleet Introduction Team/FRAMP program; coupled with Personnel Qualification Standards and Fleet Evaluation Teams.

The key to success of this program is a systems approach to developing each individual specialty training program covering every step from enlistment to achieving "qual" standards. School training must be task-oriented, and carefully designed for transition to field training. The latter phrase implies that the training material is designed by teams of experienced trainers and field experts who can identify those tasks best-trained in school and those tasks best-trained in the field. In response to the traditional objection to shifting tasks to the field, General Hilsman, Director of DCA, made two significant observations in his speech presented to the NSIA-sponsored tri-service conference on Personnel and Training Factors last May:

1) we must train professional leaders on how to train people in the field (ensuring that the training material is well designed for use in the field); and
2) we must teach these professional leaders time management so that they can train people in the field.

The design and development of each comprehensive first-term training program should be based on such factors as task criticality, hazard, time-to-learn, use of fielded capital assets, wartime versus peacetime scenarios, etc.

One very significant contribution to task and skill-oriented training programs can be made by identifying design and development parameters for families of low-cost part-task and part-mission trainers for both school and field application. Making more use of cost-effective Computer Based Training System (CBTS) technology would enable both school and field personnel to individualize the training. Thus the instructors could concentrate their skills on helping individual learners solve individual problems, rather than resorting to time-consuming traditional stand-up lectures. These factors should enable the enlistee to graduate earlier from the schoolhouse, at a higher level of productivity, with confidence of achieving full qualification early in the enlistment--as depicted in Figure 3.

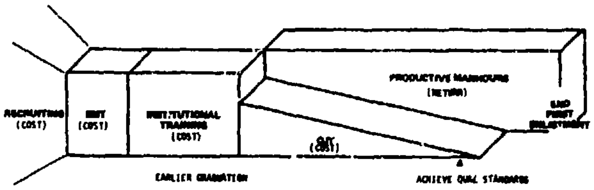

Figure 3: Career Training Approach Means More Productive Manhours

Significant *technical* training system design improvements can be made in the schools and in the field with existing technology. Having the technical knowledge baseline, or access to it, and the required skills will not solve the productivity problem if the trainers, operators and maintainers do not have the "attitudinal" skills to make the system work. When the standard set of proceduralized cures documented in the TM do not solve an equipment problem, what creative value-judgement-based steps can (and *will*) the person take to solve the problem? What attitudinal training techniques can be used to convince him that all problems are solvable and that the equipment is designed to work? This has been subject to considerable academic research. The technology exists to support practical, experimental research which is end-result-oriented such that it can be immediately implemented in service school and field training programs.

Potential Career NCO Selection and Motivation Systems

The increased productivity described earlier can only be achieved if the comprehensive first term "career" training programs are implemented by experienced, competent, motivated career NCOs. The problem is how can prospective career NCOs be detected, selected, and motivated during their first-term enlistments, and convinced to stay in the service? The selection system must be criterion-referenced to identify as potential NCOs those personnel with the best career potential. The selection system must be designed to resist challenge by other personnel.

The services might consider borrowing from industry some of the techniques used to spot and develop project leaders and more junior supervisory personnel, particularly in the more technical fields. This involves tracking and evaluating promising personnel early in their careers in such areas as technical ability, desire to lead or manage, and willingness to learn supervisory and managerial techniques. This should be accomplished by experienced NCOs and officers, using semi-standardized (but not proceduralized) matrices of leadership characteristics for guidance. Assignment of progressively more responsible tasks on the job, including temporary lead functions, permits observation of individuals' performance.

This is the critical factor. Because of short enlistment times and perhaps several assignments (recruit, depots, schools, etc.) early in the first enlistment, it is otherwise nearly impossible to adequately observe a first-term enlistee's performance, and evaluate his potential.

If the grooming and motivation is not started early in the first term enlistment--if it is left until the pre-discharge career counseling sessions--then promises of bonuses, schools, challenging assignments, etc., will likely fall on deaf ears, for the short timer will have already made his decision to leave the service.

Also, from an economics viewpoint, the services must be selective in identifying and wooing their future NCOs. For example, the FY81 retired pay for the U.S. Army alone was over 10% of the total Army budget.

Increased Government Sponsored Transfer of Training Studies

Although much research has been done into media selection models and transfer of training effectiveness, particularly in an academic light, conditions are now ripe for some concentrated practical research and experimentation on a broader, DoD-sponsored scale. Instructional system design and training methodologies have been advanced considerably in recent years. Some of the larger aerospace companies, involved in major weapon systems design and production, have refined the techniques for isolated training tasks, especially performance-oriented tasks. However, at present, there is a gap containing one of the most potentially important training activities.

Past and on-going research has been devoted to the evaluation of the transfer of training in the lower fidelity portions of the trainer fidelity spectrum or continuum (e.g., pencil and paper, sound slide, etc.) and in the higher physical fidelity portions (e.g., whole-mission or whole-task trainers such as flight simulators or system specific maintenance simulators). For example, it is reported that the 747 simulator has been refined to such a state that pilots can be FAA-certified in it. As shown in Figure 4, however, a gap in research exists in the area of low physical-, but high psychological-fidelity, highly interactive part-task and part-mission trainers.

The costs for designing, developing and producing small part-task and part-mission trainers have come down considerably, particularly in the area of computer-based trainers using off-the-shelf computers and delivery device hardware components with higher order computer languages. The problem is that the cost-effectiveness of various training techniques and training equipment design on transfer of training has not been rigorously validated and documented well enough to justify their funding in new systems procurements. Nobody has yet developed models for comparisons of cost effectiveness between a large-scale simulator and a family of small part-task or part-mission trainers, or for comparisons between an AET and a family of small trainers.

A tri-service coordination of research and experimentation in this area could assure that it is conducted according to a master plan (and a firm time table); could minimize duplication of effort and funds; and would ensure enthusiastic participation by each of the three services in later follow-on applications.

The master plan should include sub-plans to investigage the comparative effectiveness of training transfer from various computer-based part-task trainers for each of the basic training requirement categories (e.g., recognizing patterns, making decisions, gross motor skills,

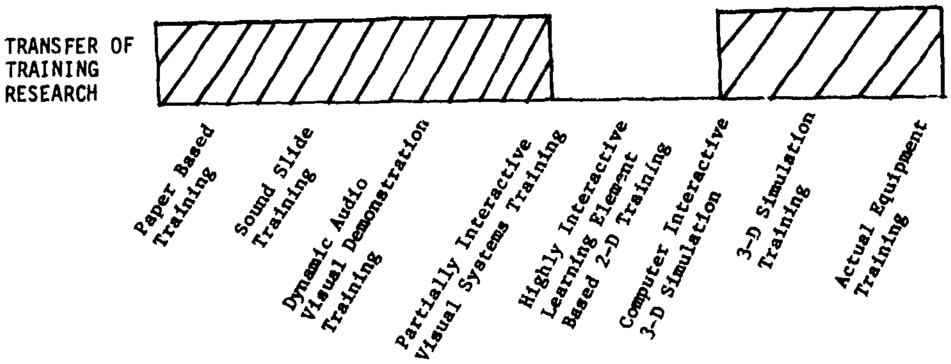

Figure 4: Extent of Research into Simulation-Based Training for Continuum of Low to High Physical Fidelity

etc.) as depicted in Table 1.

TABLE 1

ISD TRAINING REQUIREMENTS CATEGORIES

MENTAL SKILLS	1. RULE LEARNING & USING
	2. CLASSIFYING-RECOGNIZING PATTERNS
	3. IDENTIFYING SYMBOLS
	4. DETECTING
	5. MAKING DECICIONS
INFORMATION SKILL	6. RECALLING BODIES OF INFORMATION
PHYSICAL SKILLS	7. PERFORM GROSS MOTOR SKILLS
	8. STEERING/CONTINUOUS MOVEMENTS
	9. CHAINED POSITIONING MOVEMENTS
	10. VOICE COMMUNICATION
ATTITUDE SKILL	11. ATTITUDE

The training system requirements are derived through detailed evaluation of each of the subtasks. See Figure 5. Each training "system" to be evaluated includes the mini-curriculum, the devices, the courseware, the software, etc. designed to effect transfer of training for a particular part-task or sub-task.

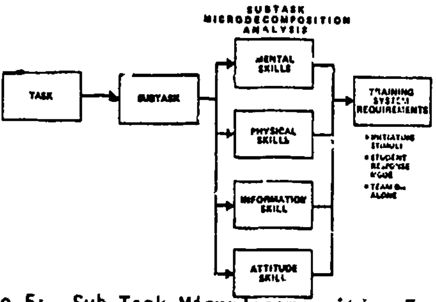

Figure 5: Sub-Task Microdecomposition Forms The Basis for Cost-Effective Part-Task Trainers

The goal of this research into cost effectiveness of part-task trainers as compared with full system simulators or AETs would be to prove concepts - not to sell hardware or software. Hardware computational and delivery devices and software "power" are changing at too rapid a pace to be "spec'ed" as limiting design concepts. Only through rigorous definition of the concept to be evaluated, its relationship to the master plan hierarchy of learning strategies, and rigorous cost accounting will funding authorities for future trainers feel confident in "buying off" on innovative, cost-effective approaches to meeting the complex training challenges of new weapon systems.

Personnel Subsystem Costing Techniques Keyed to Design Parameters

Until now we have discussed techniques for stretching the available manpower by increasing the productivity of military personnel. The other half of the battle lies in eliminating the requirements for many military personnel at the weapon system concept definition stage by use of refined life cycle cost (LCC) models.

Many LCC models now exist. Some of these consider people in broad terms such as numbers, salary levels, and skill levels. However, none are designed to provide sensitivity to people-dependent weapon system design parameters. In a broad sense, they can reveal gross savings by deleting billets from a proposed TO and E. However, for a new weapon system, they have not been proven valid or reliable enough to be exercised rapidly to affect design decisions at the concept definition stage.

In some cases, meticulous cost trades have been developed by hand to justify manpower savings through innovative configurations, but they have been rejected as outlandish. For example, waterproof carpeting versus tile on a recent destroyer design was shown to significantly reduce facility maintenance costs (manpower). The design proposal was rejected during concept definition (but retrofitted ten years later at significant cost). Contrarily, if the concept-definition planners make arbitrary, unvalidated manpower reductions to satisfy RFP requirements, such actions reduce the credibility of the personnel and training community.

Thus, LCC models must be designed to support the weapon system creator or "synthesizer", to perform trade-offs among the hardware, software and personnel subsystems. Furthermore, the models must aid the personnel subsystem designer to influence the hardware and software design by showing the complexity and cost impacts of various proposed configurations on manning levels and training costs. The models must be designed to be exercised rapidly to immediately reflect personnel impacts of design decisions, and permit redesign prior to prototype production.

Participation in the design process, supported by accurate personnel subsystem LCC data, permits the PSS designer to propose design alternatives to minimize manpower in several ways. These range from merely redefining tasks and jobs, through minor configuration changes, to total deletion of tasks by completely automating certain functions. Conversely, when a task analysis shows that the operational or maintenance staff is undertasked during routine operations, the complexity of hardware or software design might be reduced, with more functions transferred to the personnel subsystem. In each case, weapon system effectiveness must be verified as being within acceptable limits.

As was pointed out in the personnel and training R and D factors conference last May, most of the basic hardware LCC models now exist. The problem was stated as lack of valid data and lack of skill in managing or using the models. In development and use of the personnel subsystem cost model, the data problem will be compounded-as anyone who has tried to find out true DoD people costs well knows. However, in this case the results will more than justify the research.

A very significant subset of the cost model concerns the trade-offs within the personnel subsystem development or training program itself. For example, the perennial controversy of the "real" thing (Actual Equipment Trainers) versus simulation-based whole or part task/mission trainer could be translated into objective parameters for evaluation in the model. This would eliminate the problems caused when new system program managers are hamstrung by the "color of money". It's easier to buy extra units of operational equipment (that don't meet the true training need) than trainers. It's easier to provide (high cost) spares and support from the supply system (at "training priority" levels). However, the results of the transfer of training research discussed earlier, translated into parameters suitable for trading off of cost and effectiveness, would greatly enhance the credibility of the personnel subsystem life cycle cost model.

Those who control the purse strings for weapon system procurement and fielding (O&M) are basically businessmen. Consequently, if a valid, reliable and sensitive cost model can show them that significant personnel subsystem cost savings over the life cycle of the system can be achieved by additional initial investments in the hardware or software subsystem of new or modified weapon systems, it would seem that changing the "color" of the money (O&M to R&D or Procurement) would not be a problem. We in the Personnel and Training community have been talking qualitatively about such savings for too long. We must now talk quantitatively in this inflating environment, or we'll never beat either the numbers (manpower scarcity) problem or the cost problem.

Enough talk! We in the Personnel and Training community must find an advocate - a czar - in a DoD policy making position to integrate the R and D efforts of the "four" services to produce and validate such a model as soon as possible. It must be designed to interface with existing LCC models to ensure that such high cost drivers as spare parts are considered in the hardware/software/personnel subsystem cost trades. It must address - and trade-off - both operational/crew personnel and logistic support personnel requirements.

The people support costs are possibly the biggest single contributor to the cost per head of the on-line crewman or maintainer. Although some figures have been released recently on this cost per head of the individuals assigned to specific systems operations and maintenance, the data is highly suspect considering the total budget dollars unaccounted for. Suffice it to say that each person eliminated from the system by careful design can result in very significant cost savings over the life cycle of the total system. For example, a factor often ignored by both industry and government in discussing the "high cost" of training for new weapon systems is the fact that the student salaries, burdened with the costly load of hidden support costs, coupled with their non-productivity during training far exceeds the cost of developing and conducting the training. In fact, additional training development costs including those for developing computer or simulation based training, which shorten training time, can often be more than offset by the student costs saved. These are the points that we can establish clearly through the use of an adequate cost model.

Conservatism

Five years ago, the personnel and training community would have found it virtually impossible to obtain widespread military and industry approval of the solutions to the manpower shortage problem recommended herein. The stumbling block would have been the conservatism that has existed in both the military and industry sectors. The services cannot afford to buy what they don't need. Industry cannot afford to be innovative in advancing the state-of-the-art in a competitive market place without incentives.

Now, however, implementation of this plan would be extremely difficult, but possible. At this point, the military is beginning to experience the effects of the growing manpower shortage. Many high-level policymakers in both DoD and industry understand clearly that the problem will soon grow far worse. Thus, the plan could be implemented if it should attract the full support of a key policymaker, who had the required power over the necessary resources.

In such case, the specific problems resulting from conservatism that would have to be overcome are:

1) School/user interface
    - schools are unwilling to shift some school training tasks to the field ("field people don't know how to train");
    - field units are unwilling to accept field training packages prepared by either the schools or contractors ("they don't know my particular job");
    - distrust of self-paced training (you need the "soldier role model");
2) DoD/contractor interface
    - the contractor is always trying to sell a "bill of goods" (everything must be staffed and managed/monitored "to death"); or
    - the customer is always trying to "get something for nothing" ("give him exactly what he asks for whether it makes sense or not");
3) Simulator/trainer procurement
    - spread the responsibility by ensuring that everyone with a possible interest is part of the proposal evaluation process;
    - the only good simulator or trainer is one which is "spec'd" to death (regardless of whether it meets a training need, e.g., a $30M trainer based on a $10K "ISD");

- big trainers mean big budgets; a group of small part-task or part-mission trainers projects are too difficult to handle;

4) Joint service R and D projects

- "wasn't invented here and won't work in my service" preventing effective cross-utilization or joint sponsorship of innovative Personnel and Training R and D;

- only "well-published" people are qualified to do R and D.

CONCLUSION

In the paper, two major thrusts are recommended to ease the effects of the looming manpower shortage upon the military in the 80's and 90's:

1) redesign the training and selection/retention system to improve productivity; and

2) develop valid personnel subsystem costing models to support the design of weapon systems with less people.

Increased productivity per individual, coupled with reduced weapon system manning requirements (skills and numbers), should go far in helping the military to meet its manpower demands through the year 2000 in spite of the projected reduction in manpower base and increased per capita manpower costs. Although it is recognized that activities are underway in many different sectors which would contribute to the success of these efforts, the need remains to attract a strong advocate with a high enough authority level to establish policy to implement an integrated manpower-conservation program.

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DSMC PROGRAM MANAGEMENT EDUCATION

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ABSTRACT

The Defense Systems Management College (DSMC) was chartered in 1971 by then Deputy Secretary of Defense David Packard to be "the academy of management for the Department and for all four services." DSMC has become a high priority school for a high priority mission: defense systems acquisition management. It is the only institution that provides DOD military and civilians and defense industry students with a concentrated 20-week Program Management Course (PMC). A key feature of the PMC is that students learn not only the fundamentals of the functional disciplines—business management, technical management, organizational management, and acquisition policy—but they also participate actively in the integration of these disciplines through management case-study simulations. This paper will describe the key features of the Program Management Course and some of the initiatives DSMC is undertaking to insure its program meets the need for trained acquisition managers throughout the 1980s.

DSMC TODAY: EMPHASIS ON INTEGRATION

The Defense Systems Management College was chartered in 1971 by then Deputy Secretary of Defense David Packard to be "the academy of management for the Department and all four services." DSMC has become a high priority school for a high priority mission: defense systems acquisition management. The curriculum that has evolved over the years has been built on the theme that learning the various functional disciplines in acquisition is important, but even more critical is learning how to *integrate* these disciplines. It is absolutely essential that program managers (PMs) be *master integrators*! With the complexities of technology—and the organizations involved in managing defense systems acquisition—program managers are faced with the task of organizing and managing projects that must interface with numerous other projects and organizations. In order to achieve balances between cost, schedule, and technical performance of these programs, they must be able to get their whole system to "play together at the same time." It is not enough for a PM to be a good engineer or a good manager of people or even just a good businessman. To succeed in the world of program management, a PM must be knowledgeable (to the degree necessary—very difficult to define) in many functional areas and be exceedingly well-skilled in the art of integrating these functions. The DSMC has built its program around the idea that acquisition managers need experience in how these functional areas interface with one another in the complex arena of systems acquisition.

The Defense Systems Management College's program includes the 20-week Program Management Course, numerous short courses in specific functional areas, and several executive-level courses.

The core of the DSMC program is the PMC. It is attended by military and civilian students from all services, as well as representatives from defense industry. The PMC is offered to about 180 students twice each year and includes courses in the functional areas of program management: business management, technical management, organizational management, and DOD acquisition policy. Students learn the fundamentals of these disciplines in the functional courses listed in Figure 1. Each of the functional disciplines is complex in its own right, and studying all of them at once compounds the complexity. What becomes apparent in teaching program management also becomes apparent to any PM: it is not enough to know about each of the functional disciplines; one must know how they interrelate. To achieve this, the College puts a great deal of emphasis on integration in the PMC.

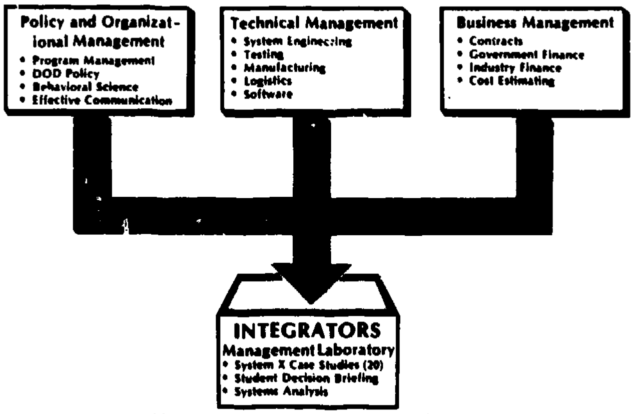

Figure 1. Program Management Courses

Department	Functional Course	Content Emphasis
Organizational Management and Policy	Program Management	Data Management...Importance to the Program Office...The "Data Call"
Business Management	Contracts	Data Management...Requirements and Description...Data Rights
	Cost Estimating	Cost Performance Reports...C/SCSC...Budget Data
Technical Management	System Engineering	Engineering Data...SOW...Engineering Drawings.. Specifications..Configuration Management... Software Data
	Logistics	Logistic Plan...Operator Manuals and Handbooks... Parts Manuals...Training
	Testing	Test and Evaluation Master Plan...Test Data and Reports

Figure 2. Functional Interrelationships: Data Management

Functional Course Interrelationships

The first step in teaching integration in the PMC is identification of the interrelationships between the functional courses. Many areas in the business, technical, and organizational management courses relate to the content in other courses. For example, concepts and principles of data management are covered in the broad sense in the Fundamentals of Program Management course (Figure 2). The Business Management Department discusses the contractual aspects of data, as well as the data requirements in the world of financial management. In several Technical Management courses, the faculty discusses the definition, purpose, common practices, etc., of technical data—drawings, manuals, handbooks, plans, and reports. The student first learns these as separate functions, but then must integrate them to learn, for example, how to specify data requirements for a total program.

Functional Course Caselettes

Another way in which students are aided in understanding these "real-world" interrelationships in functional courses is through the use of short cases or "caselettes." Normally not exceeding one or two pages in length, the caselette becomes a means of establishing a common point of departure to demonstrate techniques or concepts related to the material being discussed. With relative ease an instructor can move from discussion with the class to a desired teaching point, using the caselette as the vehicle. This student-faculty interaction permits learning to take place anywhere along the knowledge-comprehension-application learning spectrum (Figure 3).[1]

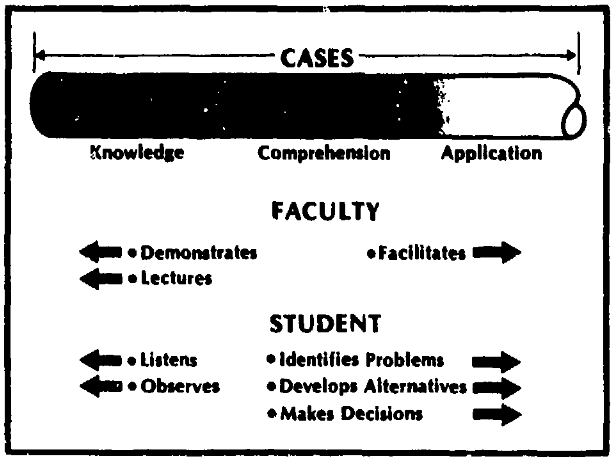

Figure 3. Learning-Behavior Spectrum

System X

The third method used in the PMC to achieve integration is a series of management simulation cases known as "System X." System X ("SX," as it is called by students and faculty) consists of 20 case studies with a common story line that takes the student from the beginning to the end of a weapon system acquisition life cycle (Figure 4).

System X attempts to simulate the real-world environment of acquisition management. Students work in heterogeneous five-person groups designed with student interaction in mind. Students are free to present their views about situations created in the case-study scenarios and get involved with solving acquisition problems with their classmates. Faculty facilitators use various methods to have the students actually live the situation in question. Having students assume the roles of the characters presented in the case or having them participate in simple guided discussions are the best ways of getting them to understand the issues through such methods. The students are placed in the position of having to actively solve the problems they have discovered. This ability to think in new circumstances is what the PMC is all about. The College believes this is what differentiates the highly successful program manager from less satisfactory ones.

Program Management Decision Briefing

A fourth way in which a student can fully experience the integration of several disciplines is the requirement to make a program management decision briefing. This requirement forces the student to select an issue from an SX case and prepare a 15-minute decision briefing (as opposed to a status or information briefing). The student must define the problem, present alternative solutions with an analysis of these alternatives, present his conclusions, and recommend a course of action. Through this experience, the student learns not only how to construct a logical, well-organized briefing, but also learns how to deliver it credibly. At the conclusion of the decision briefing, a faculty evaluator gives the student feedback on the strengths and weaknesses of his presentation and its effectiveness. This ability to scope an issue into a manageable 15-minute briefing for a decision adds yet another dimension to the repertoire of skills required of today's program manager.

Summary: Where We've Been

DSMC's program was designed to (1) provide students with an understanding of the management fundamentals in the functional areas, (2) teach them how those functions interrelate, and (3) give them practice in integrating the functions.

Phase	**Mission Area Analysis (Ongoing)**	**Development**			**Production**	**Deployment**
		Concept Exploration	**Demonstration**	**Engineering**		
	User analyzes his mission—determines if deficiencies exist.	**Search for alternative solutions.**	**Verify the feasibility of the solution—possibly by building a partial or complete prototype.**	**Develop the design and engineering package—build a model.**	**Produce the system.**	**Distribute the weapon system to the user.**
Milestone		**0**	**I**	**II**	**III**	
SX Cases		**1 2 3 4 5**	**6 7 8 9 10 11 12**	**13 14 15 16**	**17 18 19 20**	

Concept Exploration Phase		**Demonstration and Validation**		**Full-Scale Development**		**Production/Deployment Phase**	
SX-1	**Program Initiation Phase**	**SX-7**	**Systems Engineering**	**SX-14**	**Cost and Technical Performance Monitoring**	**SX-17**	**Subcontractor Management**
SX-2	**Sensitivity Analysis**	**SX-8**	**Design-to-Cost**	**SX-15**	**Change Management**	**SX-18**	**Second Source/Breakout Decision**
SX-3	**Contingency Analysis**	**SX-9**	**System Support Concept**	**SX-16**	**Preparation for Production**	**SX-19**	**Foreign Military Sales**
SX-4	**Acquisition Strategy**	**SX-10**	**RFP Preparation**			**SX-20**	**Support Equipment and Operational Availability**
SX-5	**System Specification**	**SX-11**	**Prototype Evaluation**				
SX-6	**Demonstration Validation Decision**	**SX-12**	**Preparation for Source Selection**				
		SX-13	**Contract Negotiations**				

Figure 4. Defense Systems Acquisition Life Cycle

This initial design was accomplished in the early '70s by experts in functional areas of systems acquisition and program management. It has been continually updated and changed as DOD policy and management emphases shifted. Over the years, new course directors with functional expertise have kept the content up-to-date by introducing new lecture material, student assignments, and readings. The College has also kept in close touch with the systems acquisition community through its extensive research and consulting program. Program managers and key DOD people have been frequent guest lecturers at the College and bring current issues and lessons learned to the campus. Thus, the course content has been "quality controlled" extremely well for the past 10 years.

DSMC TOMORROW: EMPHASIS ON RELEVANCE

As acquisition managers reach into the 1980s, however, defense systems are getting more complex and the layers in the bureaucracy continue to be burdensome. The number of activities program managers must integrate continues to increase. As we look to the immediate horizon, PMs are faced with complexities in multinational programs, decreasing productivity, the high cost of energy, long lead times of critical materials, and implementation of the Carlucci Actions, just to name a few. As the PM's job becomes more complex, the College is initiating several efforts to insure that its program continues to prepare managers to meet the challenges of the '80s (Figure 5).

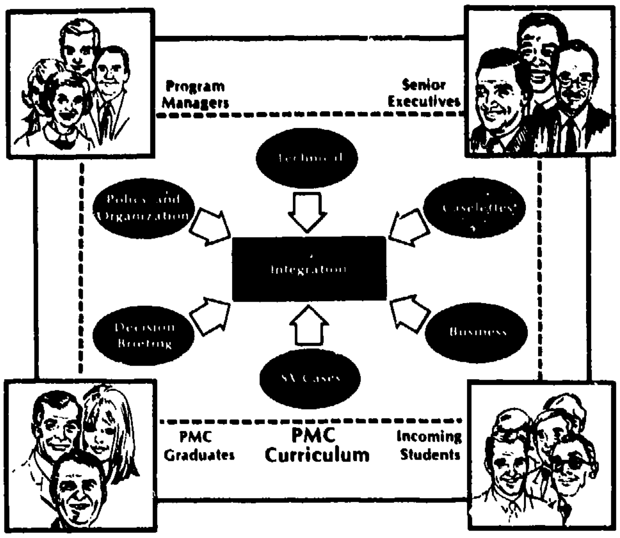

Figure 5. Acquisition Curriculum Integration Review

Program Management Job Model

To identify the baseline of what the program manager's job tasks (as described by current PMs) are, the DSMC is developing a program management job model. The effort involves obtaining a consensus from a sample of current, exemplary program managers on what they actually do in managing their programs. Six major-system PMs (two from each service) worked together for a week and developed a systems-engineered model of their job functions. The model was validated by several more PMs from the Army, Navy, and Air Force, as well as several senior system commanders. The College sought to have working PMs describe what they do to see how it compares with what the College currently prepares program managers to do. Although the model is not in final format at the time of this writing, its length alone—40 feet—is testimony to the complexity of the PM's job. It is no surprise that the function of integration was emphasized by the program managers as being critical to the success of their programs!

Senior Executives Evaluation

The College is also gathering information from other sources to help fine-tune the curriculum for the 1980s. Senior management executives from the services and industry are evaluating the relevance of course objectives and content. They will be evaluating the configuration of the courses and will suggest ways to organize the content to improve the effectiveness and the integration of the courses.

PMC Graduates

Graduates of the Program Management Course will also be ranking the relevance of the various PMC courses to their job and will be commenting on areas they feel need more or less emphasis in the PMC. This will help give a perspective of how effective the PMC is in preparing students for job assignments in acquisition management.

Incoming Students

A fourth source of data will come from students entering the PMC. They come with varying levels of experience relative to acquisition management. To identify more precisely the profile of student knowledge, a pretest inventory of acquisition management knowledge will be given to incoming PMC students. This will help identify how much the typical student already knows, not only about the various functional areas, but also how those areas are integrated. Thus, the course content can be better tailored to the real education needs of the incoming students.

Latest Management Concepts

Another important source of data in determining curriculum content is the latest, most up-to-date management techniques and concepts. Information about successful program managers is only part of the answer to making a curriculum job-relevant. The College must continue to keep pace with the latest management concepts and the application of new technology to the management of resources and programs.

Demographic

While the College works to assess the type of education program needed for the acquisition management arena, it will also be working to identify the potential student population. Data will be obtained from all the services on the number of people working in acquisition management, including their functional area, location, and grade/rank. Turnover and promotion rates will be identified as well as trends in skill mixes and motivators. In order to prescribe an educational program which will really meet the services' needs, the College is working to identify what the acquisition manpower resource will look like in the coming years.

Moving into the Future

When the College has reassessed the need for acquisition management education and identified the type of people who need it, the College will be in a position to analyze ways in which its program might be improved. DSMC is committed to maintaining an education program which prepares acquisition managers for the very complex job of integrating and managing programs.

SUMMARY

The world of program management in defense systems acquisition is complex. The College's educational program was designed to prepare acquisition managers for this complex job by first providing them with a foundation in the functional disciplines, then giving them the opportunity to apply the knowledge and concepts in real-world scenarios. DSMC's objective is to make its program even more of a lived experienced by simulating actual problems of program management.

It is likely that the College will need to increase its reliance on simulation in order to achieve this objective. It is difficult to lecture to students in the conventional classroom sense with the expectation that it will equip them with the type of managerial competencies required in the program management environment of the '80s. Students must have the opportunity to apply new knowledge and practice new skills at the College if the learning is to transfer effectively back to the job. Simulating real-world problems that students can practice, and then receive feedback on their performance, will continue to be a key element in DSMC's approach to the future.

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[1] Benjamin S. Bloom, ed., *Taxonomy of Educational Objectives, Handbook I: Cognitive Domain*, (New York: David McKay Company, Inc., 1956), p. 18.

TRAINING ASPECTS OF FIELDING A MAJOR WEAPON SYSTEM - THE UH-60A BLACK HAWK

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ABSTRACT

The Sikorsky UH-60A Black Hawk is the United States Army's newest Utility Helicopter. The Black Hawk was designed and developed to replace the UH-1H Iroquois for assault, air cavalry, and aeromedical evacuation missions (See Figure 1). The UH-60A carries the Infantry squad of 11 men and their equipment as a basic load. Particular emphasis during development was devoted to reducing vulnerability, improving crashworthiness and maintainability. An essential aspect to fielding of any weapon system is insuring that all aspects of training on the new system have been considered. The Black Hawk was issued to operational units in May 1979 and achieved Initial Operational Capability on 4 November of that year. At that time, all the resident schools were open and functioning and most parts of the "training package" had been completed. Training is, of course, a never ending process and so there is still much to be done with the UH-60A, especially in the areas of flight simulation, continuation training, providing training materials for units in the field and updating the various training devices and literature presently in use.

INTRODUCTION

In 1977, the Training and Doctrine Command (TRADOC) created a series of offices entitled, "TRADOC System Managers (TSM)." The philosophy behind the TSM was to provide the link between the Army's developer, the Development and Readiness Command (DARCOM), and the user representative, TRADOC. There were just too many areas receiving insufficient attention. The materiel developers were essentially doing an excellent job within the scope of their responsibilities. However, with increasing frequency, materiel was being delivered to units in the field who were unprepared to accept the new equipment. The situation was even more alarming because of the large number of new systems that were to be fielded in the late 1970's and early 1980's. The TRADOC System Manager is basically charged with the responsibility to see that TRADOC's missions of training, personnel, logistics, doctrine and operational testing have been properly accomplished prior to fielding the system. Proper doctrine and adequate testing are essential elements of the process that must be carefully thought out very early and executed vigorously to provide information for favorable production decisions. The areas of training, personnel and logistics are interactive and essential to the success of a new system once it is fielded. Of the three elements, training is the key. If the training program is inadequate to support the system, the overall program will certainly fail. If training is conducted early and correctly, then the field can accept sophisticated and highly technical systems with little disruption to normal operations. The TSM for the Black Hawk was appointed in April 1977 in recognition of the scheduled fielding of the system. There was much to do especially in the field of training.

THE TRAINING PACKAGE

This is an often used phrase that bears little identity to its true meaning. What comprises the package? I am sure in defining this I will offend some, if not all, by leaving out an ingredient or two, but nonetheless, here is a sample of the major elements of training to support new systems in the field.

-- Training Strategy

-- Instructor and Key Personnel Training

-- Resident Training Plans

-- Training Software

-- Training Hardware and Devices

-- Flight Simulators

-- Plans for Follow-on Training

-- New Equipment Training Teams

Let's take a look at each of these items and hopefully see how they all fit together to form the training package.

Training Strategy

How the training for a major system is to be accomplished is embodied within the Individual and Collective Training Plan (ICTP). This plan is developed by the Director of Training Developments assigned to the TRADOC mission proponent of the weapon system. In the case of the Black Hawk, this was the Infantry School. The ICTP of the Black Hawk was probably the first such plan produced to support a major weapon system. The plan is a roadmap. As such, it contains all the details; training concepts, tasks and objective schedules, logistical support of training, new equipment training, resident courses of instruction, unit training, instructor requirements, training equipment support, training literature, training devices, facility requirements, and probably most important, the requirement for resources and funding. The ICTP encompasses the training plans for all those locations where training takes place. For the Black Hawk, it covers the comprehensive plans of Fort Eustis, VA, for maintenance, Fort Rucker, AL, for pilot training, Fort Gordon, GA, for avionics training and the Armor and Infantry Schools and the Academy of Health Sciences for their particular interest in the doctrinal use of the Black Hawk. The ICTP was approved for TRADOC by the TSM and forwarded to the Department of the Army. It is probably the first document that DA receives that identifies what must take place in order to accommodate a new system. The ICTP is without a doubt the most important single document involved in the establishment of the training process for a new system. Admittedly, it rapidly becomes dated as production schedules, funding, and other priorities change, but as mentioned, it is a superb reference document for what must be done.

Instructor and Key Personnel Training (IKPT)

This training is set up and funded by the DARCOM Project Manager. The training involves exactly what its name implies and is normally conducted by the contractor. Ideally, you would want the contractor to give instruction to potential instructors in the same manner that you would expect students in the future to receive it. To do this, the Project Manager funded an extensive effort with the contractor to develop the program of instruction for the IKPT to represent what should be taught in the Army's resident schools. Some $800,000 was allocated for this effort. In essence, the contractor performed the front end analysis and the definition of task objectives so vital to creating a program of instruction. Again, this was new territory. At that time, the Army initiated Integrated Technical Documentation and Training (ITDT) now known as Skill Performance Aids (SPAs). However, the Black Hawk was developed prior to initiation of this innovative process of training and could only catch a portion of it. The key point here is that there must be a concerted cooperative effort between the Project Manager, contractors and the TRADOC schools in establishing this entire process; if done in isolation by any major command, the training set-up will fail.

Resident Training Plans

The three schools that train skills in the maintenance and operation of the Black Hawk are: the Aviation School at Fort Rucker, the Transportation School at Fort Eustis, and the Signal School at Fort Gordon. Many other installations teach subjects involving the Black Hawk, but more in the operational use as opposed to training particular skills. In support of the Government Competitive Test, the Army had to train individuals in the operation and maintenance of the aircraft. How much training and what to train was a constant subject of debate when the Army decided to provide the pilots with nine hours of actual operation of the aircraft and a ground school of some 50 hours in length. Enlisted mechanics were provided contractor courses of varying lengths depending upon their particular Military Occupational Specialty (MOS). Since then the courses have evolved as shown:

COURSE/MOS	DURATION
Aviators and Instructor Pilots	4 weeks
Tactical Transport Helicopter Repairer -- *67T10/20	8 wks/1 day
Senior Tactical Transport Helicopter Repairer -- *67T30	9 wks/3 days
Aircraft Power Plant -- 68B	3 wks/3 days
Aircraft Power Train Repairer -- 68D	3 wks/2 days
Aircraft Electrician -- 68F	6 wks/1 day
Aircraft Structural Repairer -- 68G	1 wk/3 days
Aircraft Pneudraulics Repairer -- 68H	3 wks/1 day
Maintenance Test Pilot Course	3 wks/4 days

*New Military Occupational Specialty

(See Figures 2 and 3)

This brief discussion of resident training plans would not be complete without mentioning development of training requirements. Training requirements are developed by Department of the Army and passed to TRADOC for preparation and resourcing the Courses of Instruction. The process by which this is done is incredibly complex and out of synchronization with the materiel development process. For example, the process starts with the development of a TOE at the proponent school which is forwarded through TRADOC to DA for approval and eventually distributed to the field. The field then modifies this document and the result is then fed to a group of computer models among which are VTAADS, TAADS, SACS, and PERSAC. From this, the Military Personnel Center (MILPERCEN) can conduct a Personnel Inventory Analysis which examines such things as how many UH-1 mechanics should we train in the Black Hawk or what should we do with the displaced skills of the CH-54 trained mechanics since the aircraft has been assigned to the National Guard or yet what information should be given to the Recruiting Command concerning new accessions. The result is the determination of training requirements for which TRADOC develops courses of instruction which in turn are announced by the Department of the Army. This process in the most optimistic terms takes 35 to 40 months. The situation becomes even more tenuous (as it did in the case of the Black Hawk) if you accelerate the development cycle. The Black Hawk Project Manager appeared before the Defense Systems Acquisition Review Council (DSARC) in November 1976 seeking a Low Rate Initial Production (LRIP) decision and was told to enter full production immediately. That single decision removed 18 months from the development cycle, making it very difficult for the training community to keep pace. In spite of this, UH-60A met all training commitments but only by expediting and in some cases circumventing established procedures.

Training Software

One of the training factors receiving too little emphasis was training software. While software because of its very connotation may not seem important, much of the UH-60A training software was key to the success of the program. At the heart of this subject are the publications to support the system. It not only allows the instructors in the schools to conduct their classes, but it allows the most important element, the trainer in the field, to conduct individual and unit training. Software, in addition to the manuals on the aircraft, included training plans for resident instruction and new equipment training extension courses. The preparation for this type of training in turn develops a demand for course outlines, lesson plans, student information sheets, handouts, audio visual aids, practical exercises, student worksheets, examinations and evaluation forms.

A certain amount of doctrinal literature was also required. This was used more to educate leaders and operators in the capabilities in employment of the Black Hawk. These manuals cover performance data, load planning data for both troops and equipment, safety information, and the details of the tactical employment of air mobile and parachute forces. The air crew training manuals, probably more than anything else, typifies the software necessary to support a weapon system. This particular manual specifies in some detail the tasks an aviator must accomplish to achieve the required level of training to complete his combat mission. After performing to the requirements of the air crew training manuals, skill qualification tests, periodic unit checkrides, and visits by the Director of Evaluation and Standardization at Fort Rucker are used to evaluate the training level of pilots and mechanics. The Army Training Evaluation Program is used to evaluate the status of unit training readiness. However, the core to this process remains training software.

Training Hardware and Devices

Closely tied to the development of the Black Hawk was the development of the associated training devices which in some cases are almost as complex as the aircraft. Taking the lead in this area is the DARCOM Project Manager. The Project Manager requested that the prime contractors for the aircraft and the engine provide reports recommending specific training devices that could be made available. Then each school responsible for Black Hawk training within TRADOC was tasked to identify their particular training device requirements to support courses of instruction. The requirement for training devices was then staffed through Headquarters TRADOC, included in the ICTP and the device development program was then funded and managed by the DARCOM Project Manager.

The devices fall into three categories: (1) part task trainers, (2) composite trainers, and (3) the aircraft and its components (see Figures 4, 5 and 6). This effort represented one of the Army's first attempts to support a major weapon system with a complete package of training devices at the training location prior to arrival of students. Listed here are those devices required by the resident schools.

Transportation School

- Composite Trainer
- Power Plant/Drive Trainer
- Hydraulic System Trainer
- Powertrain System Trainer
- Electrical System Panel Trainer
- Electrical System Programmable Trainer
- Caution/Advisory Panel Trainer

Signal School

- Stability Augmentation System Trainer
- Command Instrument System Trainer

Aviation School

- Prototype Aircraft
- T-700 Engine Simulator
- Fuel System Panel Trainer
- Hydraulic Panel Trainer
- Electrical System Panel Trainer
- Fire Detection System Trainer
- Caution/Advisory Panel Trainer
- Command Instrument System Trainer
- Horizontal Situation Indicator Trainer
- Doppler Navigation System Trainer
- UH-60A Flight Simulator

Essential to the success of the training device program was the involvement of TRADOC schools and their instructors during the various progress reviews. To insure user satisfaction, the user did and always should participate in the critical design reviews and the decisions leading to the acceptance of the training devices. After all, they have to live with them and use them on a daily basis.

The training devices were completed and delivered close to schedule. The major problem with the training device is like the major system itself. At some point, the design must be frozen. If this is not done, the contractor continually changes and updates rather than producing. If the training device is sufficient to train the operation of the system, then it should be fielded and an update accomplished later.

Flight Simulator

A UH-60 flight simulator is under development to compliment aviator training. Use of the flight simulator is planned for initial aircraft qualification training as well as continuation training. The prototype Black Hawk simulators are presently undergoing an operational test at Fort Rucker and scheduled for completion in 1982.

The relatively high cost of the aircraft, fuel, maintenance and facilities dictate that lower cost training methods be used where possible. Flight simulators have been widely accepted as cost effective alternatives or complements to actual flight time in aircraft. While cost savings with the UH-60 flight simulator are only forecasts at this time, actual savings will be determined when the results of the operational test have been properly analyzed. Cost savings are dependent on the amount of simulator time that can be substituted for actual aircraft training time, referred to as the transfer ratio.

While transfer ratios for qualification and continuation training will quantify cost savings, there are other important benefits that are very difficult to quantify. Examples of these more abstract benefits include the following: up to 200 emergency procedures can be practiced in the Black Hawk simulator, many of which cannot be done in the aircraft. Training can be conducted any time and is not dependent on light and weather. In fact, light and weather can be simulated as required for training, and maximum safety is provided for the aviators. A mission or maneuver can be recorded, frozen, restarted, played back in real or slow time, and retrieved for debriefing. Since maneuvers can be simply repeated, the need to go around, land and perform other fuel consuming actions is eliminated. The result is more efficient use of training time and a better trained aviator.

An important operational lesson was learned in developing the UH-60 Flight Simulator. While it is highly desirable to conduct parallel development and fielding of an aircraft and its companion flight simulator, it is virtually impossible to final stage a simulator while the basic aircraft is in a competitive prototype stage. Far too many design changes occur between a prototype aircraft and the production model, and the last thing the aircraft manufacturer designs is the cockpit. Conversely, the cockpit is the first thing the simulator manufacturer designs. As a consequence, simulator manufacturers must wait until the aircraft design freezes before completing the simulator design. The end result is that simulator availability falls well behind fielding of the aircraft.

With the Black Hawk, simulator procurement has been further complicated by the fact that we are competitively evaluating two very different visual display systems. One system is a relatively conventional camera model system which uses an elaborate terrain board. The camera model system produces a very high resolution visual display. The other system uses digital image generation and is totally computer controlled. While the computer generated imagery has less resolution and terrain detail than the camera model system, it requires much less space and power (See Figure 7).

As mentioned previously, the Black Hawk simulator operational test is now being conducted. The test started in April of this year and is now scheduled for completion by mid-year 1982. The operational test will be the basis for selection of either the camera model system or the digital image generation system. It will also provide data to develop the appropriate training transfer ratios.

The operational test is being conducted in two stages. The first stage is the institutional portion and uses actual student pilots who are being qualified in the Black Hawk at the Aviation School. The second stage will use pilots already qualified in the Black Hawk to determine the transfer ratios for continuation training.

Plans for Follow-On Training

One form of follow-on training previously mentioned was continuation training. The continuation training in units with Black Hawks takes several forms, but they are all designed to result in a unit trained to be mission ready. The pilots continue to train using the Aircrew Training Manuals (ATM). The enlisted mechanics, supervisors and component repairmen continue their in-unit training under the Skill Qualification Test (SQT) program. Units will also be evaluated under the Army Training Evaluation Program (ARTEP).

Resident training at the various schools will continue to train pilots, mechanics and component repairmen. The resident courses will be periodically reviewed for content and effectiveness and be updated as required. Some updating will be required due to the different type students anticipated in the future. Most of the Black Hawk crew chiefs and mechanics were previously trained as UH-1 mechanics. Their Black Hawk training was in the form of a transition to a different aircraft. In the future, there will be a shift to initial training on the Black Hawk direct from basic training. This program has already started and will increase as more aircraft are fielded.

The component repairmen have similarly received their Black Hawk training on a separate qualification basis. In the future, all component repairmen will receive Black Hawk training.

Since the UH-60A replaces the UH-1 and literally all Army helicopter pilots are rated in the UH-1, the UH-60A qualification program included only pilots already rated in utility aircraft. In the future, we may see a separate UH-60A track in Initial Entry Rotary Wing Aviator training. When this occurs, a more extensive Black Hawk training program will be required to replace the utility training formerly taught in the UH-1.

Exportable training packages are another form of follow-on training. An example is door gunner training. This is conducted in the unit with the aid of an exportable training package. A Black Hawk pilot exportable training package is being developed for possible field qualification of pilots in the future. While this package is not yet certified to qualify an aviator in the unit, it is presently used for refresher training. Already developed and in the units are six TEC lessons, 21 ETV tapes and a series of lesson plans and slides.

New Equipment Training Teams

In addition to the resident training courses, New Equipment Training Teams (NETT) have been used to provide training in the units receiving Black Hawks. The NETT normally accompanies the initial fielding and provides training for the enlisted supervisors at the installation. Composition of the teams have varied from a low of three instructors to the projected 15 instructors to be used in the Europe fielding effort.

New Equipment Training is designed to be given one time at each installation receiving Black Hawks. When the NETT effort is complete, a training package is left with the unit. This package includes lesson plans and appropriate audio visual aids to support the conduct of follow-on courses as required.

SUMMARY

What has been the result of all this? It may be too early to tell, but at least on the surface, it appears that the job of training operators and maintainers for the Black Hawk is well in hand. It was not easy and not without many simple mistakes committed along this critical path. The aircraft has been in the field for almost 30 months, and there have been very few incidents and none directly attributable to lack of or insufficient training. I guess this is proof enough.

ABOUT THE AUTHOR

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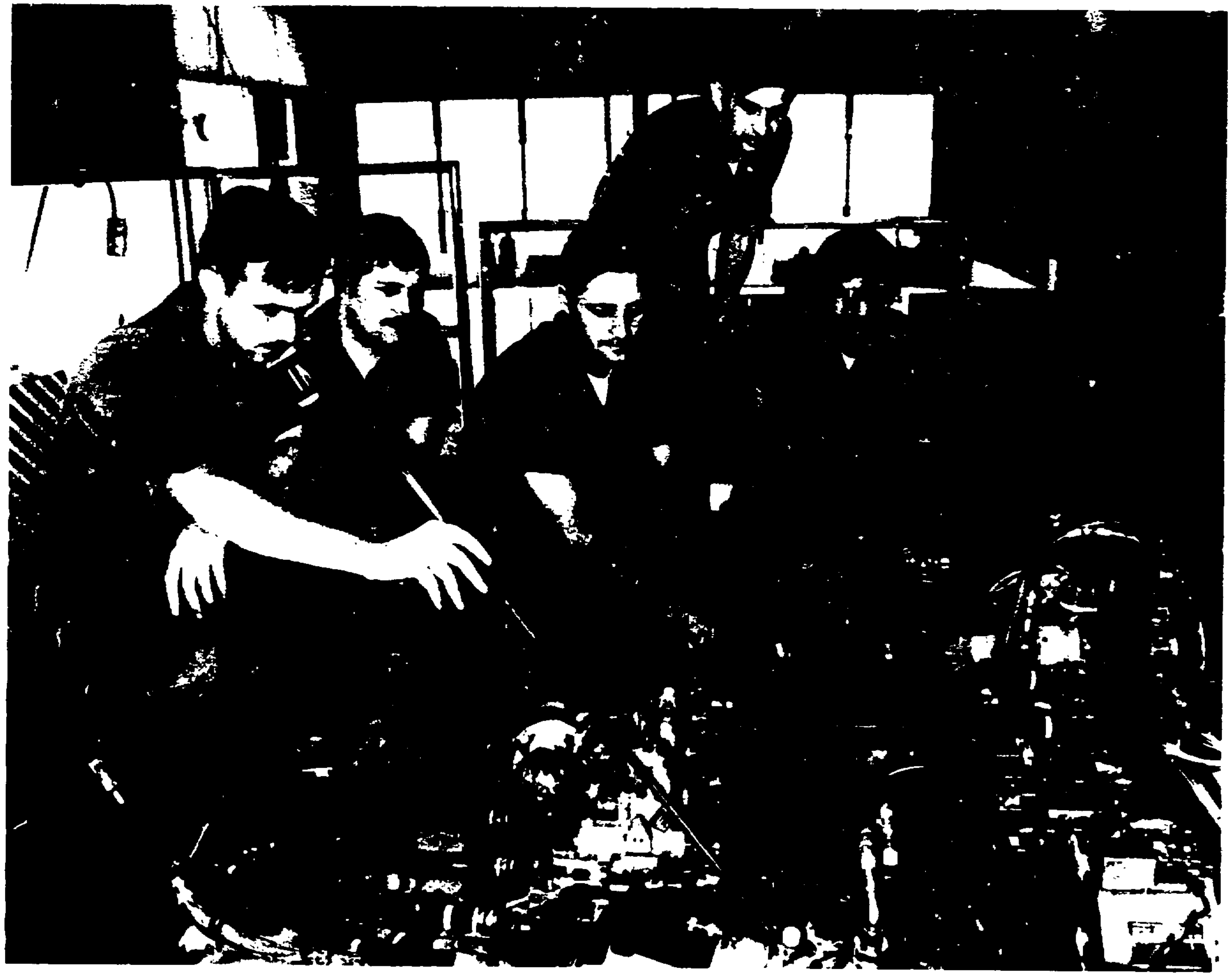
--Entered Federal Service on 25 February 1952
--Served as Commander of an Assault Helicopter Company and Combat Aviation Battalion in Combat in the Republic of Viet Nam
--Attended Naval War College in 1970-1971

THE UH-60A, BLACK HAWK

FIGURE 1

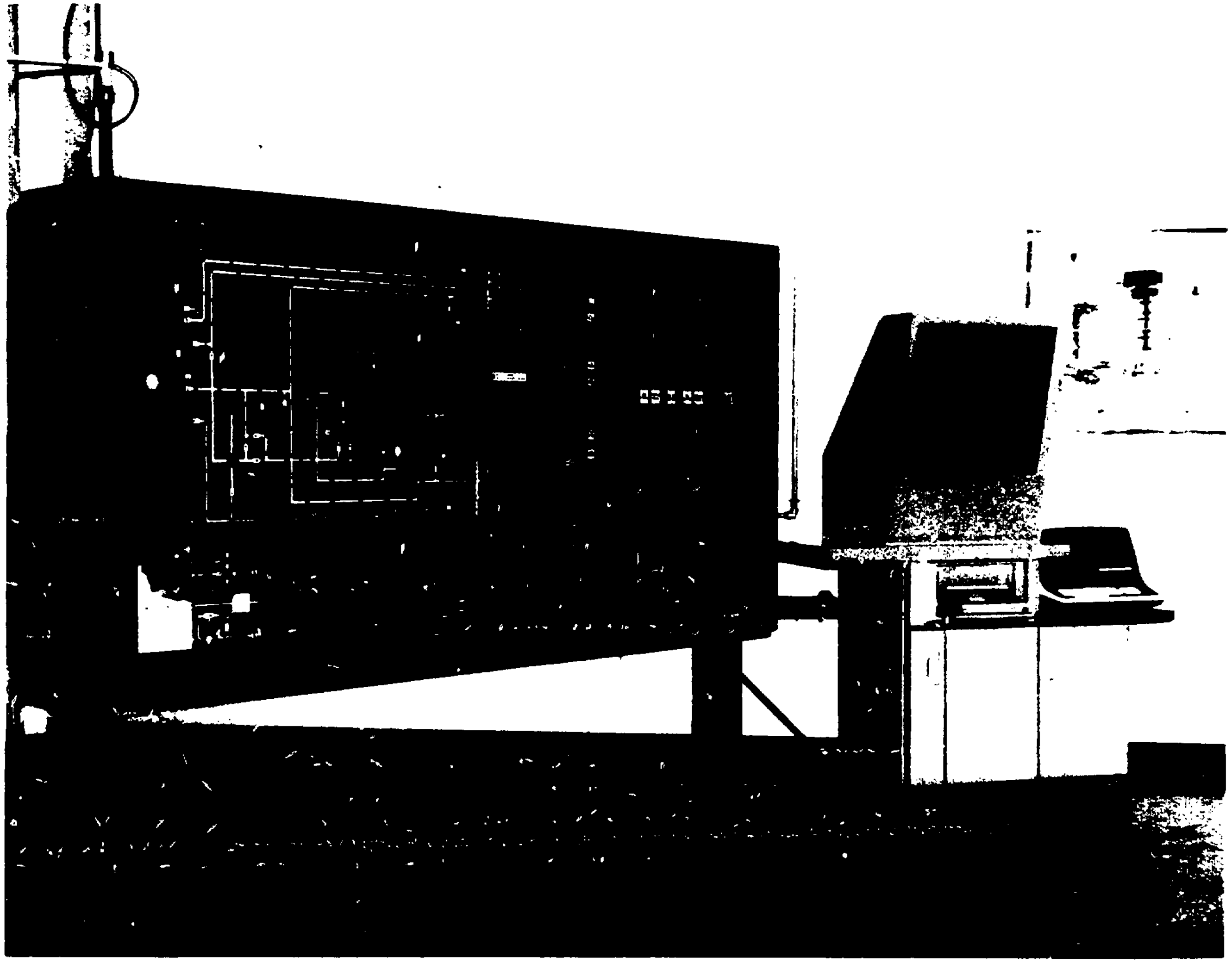
HANDS-ON TRAINING WITH ACTUAL
AIRCRAFT COMPONENTS

FIGURE 2



COMPOSITE TRAINER

FIGURE 3

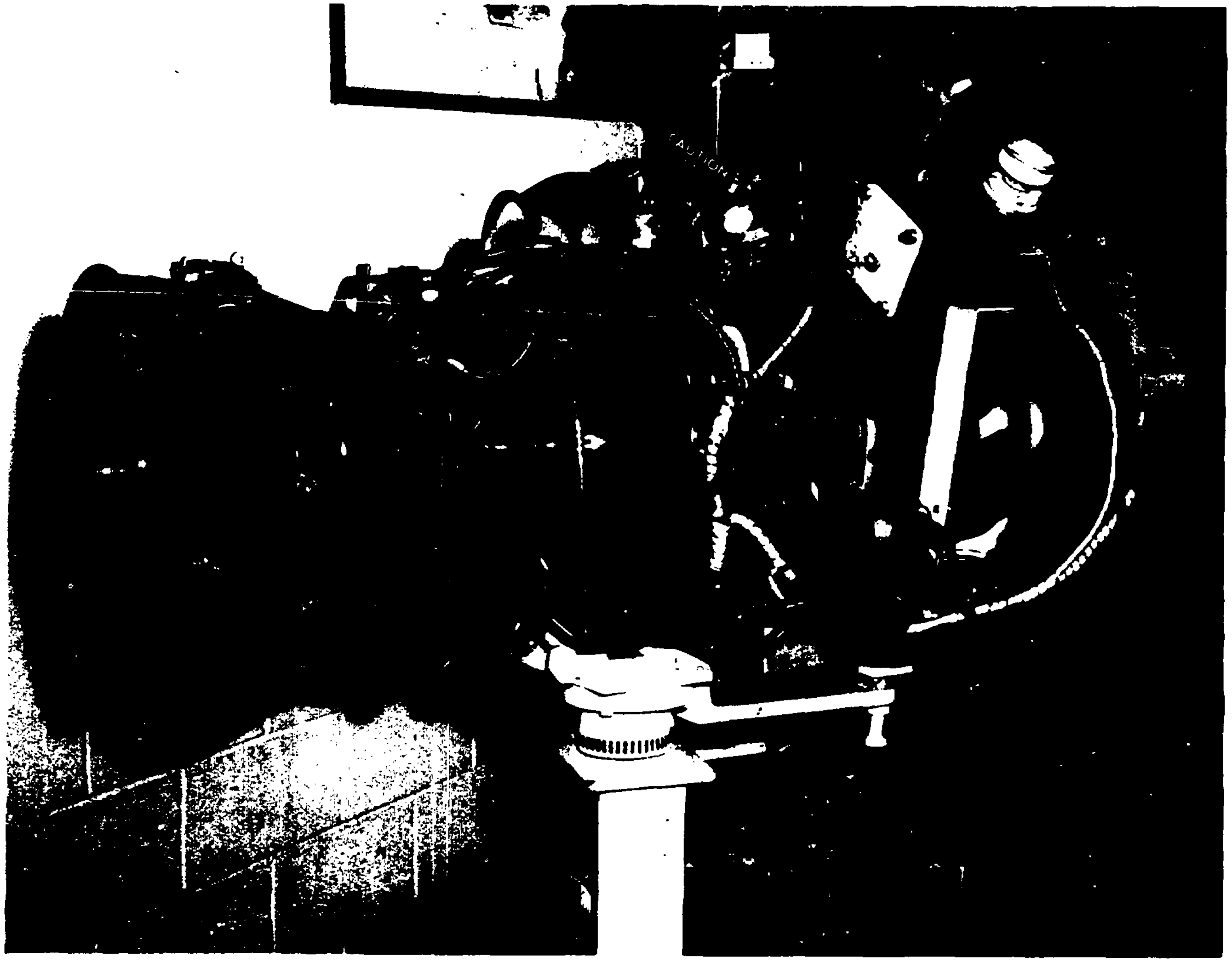


HYDRAULIC SYSTEM PANEL TRAINER

FIGURE 4

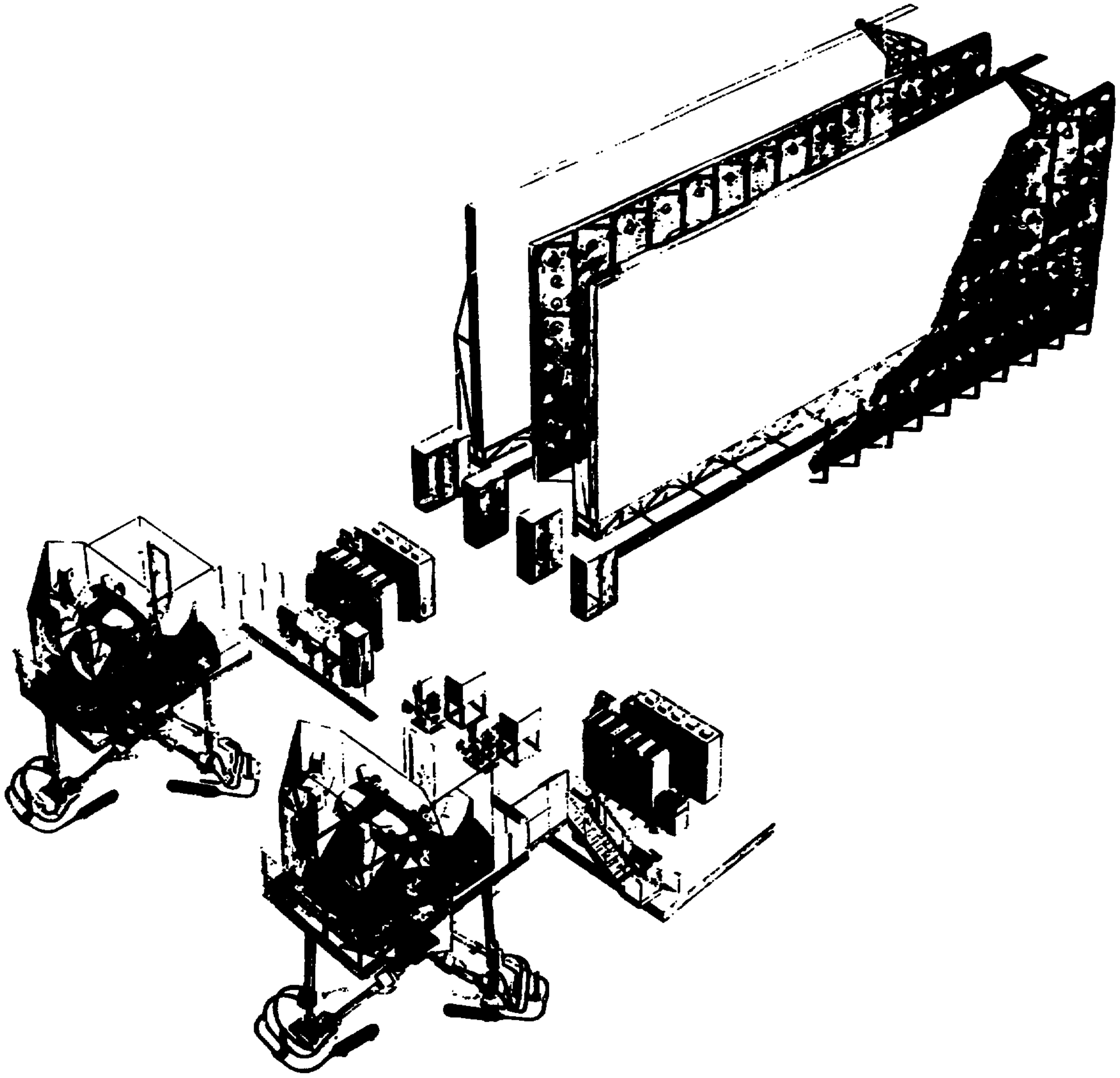
T-700 ENGINE SIMULATOR WITH COCKPIT

FIGURE 5



T-700 ENGINE CUTAWAY

FIGURE 6



UH-60 FLIGHT SIMULATOR

FIGURE 7

TITLE OF PAPER: Targets for the Eighties

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ABSTRACT

The proof of combat readiness has been, and remains, the demonstrated ability of a tactical unit to move, shoot and communicate. Modern technology is providing the Army with weapon systems that have stabilized firing platforms (so as to shoot on the move) and the capability to engage targets day or night in all weather conditions. Crews of these modern weapon systems should train on ranges that challenge them to identify and decisively engage the dominant threat vehicle from a multiple array. Proof of crew proficiency is a hit on the crucial target by the correct threat defeating munition. Training, however, will not be enhanced until the U.S. Army replaces current nondescript two dimensional plywood targets, immobile U.S. tank hulks and anti-aircraft targets that are incapable of providing realism and threat vehicle identification with targets that provide realistic size, shape and thermal characteristics.

The phrase "The Army must train as it will fight" is as valid today as it was for the Roman Legions centuries ago. To the Legions training was a "bloodless war" and war but "bloody training."

Realistic training today, however, is neither as simple nor as cheap as it was for the Romans. Close order hand to hand combat with swords and spears has given way to ever increasing dispersion and engagements that begin beyond the horizon with weaponry whose munitions are as destructive as they are swift.

It is common knowledge that modern weapon systems possess multiple munition selections, stabilized weapon platforms and all weather night and day engagement potential. What isn't as well known is the adverse impact these advances in technology have had on existing equipment and facilities.

Today a gunner must not only demonstrate his ability to hit a target, he must also confirm his capability to select the proper threat defeating munition for the target engaged. Additionally if we are to train as we will fight, our weapon crews must also be able to identify and decisively engage the dominant threat target from a multiple array of targets.

It is essential, therefore, that current and future gunner and crew training be conducted on ranges that possess targets that provide realistic size, shape and thermal/radar reflective characteristics. These requirements sound the death knoll for single, non-descript, two-dimensional plywood targets and immobile old tank hulks!

In an effort to define and articulate Army target requirements, TRADOC hosted a "Targets for the Eighties" Workshop during January 1981. The results of that meeting are provided below. Hopefully, by having identified what is needed "down range," the mechanisms to lift and move the various targets can be fully developed and standardized.

As proponent for Training Circular 25-2, Training Ranges, the Deputy Chief of Staff for Training (DCST), TRADOC, is keenly aware of current U.S. Army range equipment limitations. He also realizes that many commands desire to procure commercial range equipment in an effort to enhance gunnery training and fully appreciates the reasons for this. However, the continued uncontrolled procurement of commercial systems, will not only become a costly maintenance liability to the U.S. Army, but it will adversely affect the standardization of targets, ranges and training.

Light Targets

- Definition. Light targets represent individual soldiers and multiple silhouettes (e.g., command group, machinegun/ATGM crew). These targets will be used in basic rifle marksmanship, crew-served weapons training, and on unit collective training ranges.

- Characteristics.

a. Provide a three dimensional bas-relief view in order to provide realism, target identification, and engagement priority training. (RATIONALE: A three dimensional targets aids in target identification and allows interlocking fields of fire (mutually supporting fire).

b. Must be identifiable at a minimum distance of 500 meters.
(RATIONALE: By presenting the same visibility as a man in the open to a distance of 500 meters, soldiers can acquire/sharpen detection skills).

c. Size and color must as a minimum represent Warsaw Pact individuals and crews.

d. Must be capable of withstanding multiple hits from non-fragmenting munitions (up to 25-mm).

e. Must be capable of sensing hits and kills from MILES and .22 caliber thru 25-mm munitions (may be an add-on device). *

f. Must be durable and capable of withstanding climatic and weather variances world-wide.

g. Must be identifiable beyond 500 meters by soldiers/crews using visual aids and/or gun sights.

h. Provide realistic thermal/infrared signature for identification during periods of reduced visibility (may be an add-on device). *

i. Must be easily repaired at field site and maintenance requirements must be simple.

j. Must be capable of being mounted and operating on stationary and moving target elevating mechanisms.

k. Must at a minimum represent: Individual soldier (standing and prone); command group; machinegun crew; ATGM crew; antitank gun crew.

l. Must be rigid enough to be moved on a target moving device at variable speeds of 0-8 mph.

Heavy Targets

- Definition. Heavy targets represent threat ground vehicles or hovering aircraft. These targets will be used in basic gunnery and unit collective training.

- Characteristics.

a. Provide a three dimensional bas-relief view in order to provide realism, target identification, and engagement priority training.

b. Must be identifiable within 2-km of observation point.

c. Size, color and markings must, as a minimum duplicate Warsaw Pact vehicles. The capability to replicate North Korean or other nations vehicles is desirable.

d. Must be capable of withstanding multiple hits (all targets).

e. Aircraft targets must be rigid enough to explode the STINGER/REDEYE warhead.

f. Must be capable of sensing hits and kills from MILES and all munitions .22 caliber and above (may be an add-on device). *
(RATIONALE: Miles and .22 caliber to .50 caliber are used on scaled targets. Miles and .50 caliber and above are used for "full-up" training).

g. Must be durable and capable of withstanding climatic and weather variances world-wide.

h. Must be easily repaired at field site and maintenance requirements must be simple.

i. Must be capable of being mounted and operated on stationary and moving target elevating mechanisms.

j. Must provide realistic simulation of gun/missile firing (may be an add-on device). *

k. Must provide realistic simulation (smoke, flash, flame, etc.) when hit (may be an add-on device). *

l. Must provide LASER reflectivity (may be an add-on device). *

m. Must provide thermal, infrared and millimeter wave detection signature (may be add-on devices). *

n. Aircraft targets must have capability of providing an infrared/radar reflection (may be add-on devices). *

o. Aircraft targets must be in attack profile.

p. Must be rigid enough to be moved on a target moving device at variable speeds of 0-25 mph.

q. Vehicle targets must be available in full size and 1:60; 1:30; 1:10; 1:5 scales for various gunnery applications.

r. Must at a minimum, represent the following Warsaw Pact equipment:

ZSU 23-4 anti-aircraft gun (front and flank)
T-62 tank (front and flank)
T-72 tank (front and flank)
PT-76 amphibious tank (front and flank)
BRDM scout car (front and flank)
BMP armored personnel carrier (front and flank)
GAZ-66 track (flank)
Mi-24 (HIND-Du helicopter) (front)
M-55 (122-mm gun) (flank)

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* Requires effective interface with target elevating mechanism and other range control equipment.

TARGET CHARACTERISTIC REQUIREMENTS MATRIX

LIGHT TARGETS	AIR DEFENSE	ARMOR	ARTY	AVN	ENGR	INF
3D	X	X	X	X	X	X
Visual Identification	X	X	X	X	X	X
Hit Sensing - Munitions	X	X	X	X	X	X
Capability - Laser Beam	X	X	X	X	X	X
Fixed Route	X	X	X	X	X	X
Variable Route						
Thermal Imagery		X		X	X	X
Size (NATO Standard)	X	X	X	X	X	X
HEAVY TARGETS						
3D for Targets within 2 KM	X	X	X	X	X	X
Visual Identification	X	X	X	X	X	X
Hit Sensing Capability	X	X	X	X	X	X
- Munitions	X	X	X	X	X	X
- Laser Beam	X	X	X	X	X	X
Size	SCALED	NATO	FULL	FULL	FULL	FULL
Fixed Route (Ground Targets)	X	X	X	X	X	X
Variable Route (Ground/Air)	X		X	X		
Infrared Signature (IR)	X					
Radar Reflective (RF)	X					
Thermal Signature		X	X	X		X
IR Counter Measure (IRCM)	X					

("X" INDICATES AN IDENTIFIED REQUIREMENT)

SUMMARY

The recently published FM 71-999A (DRAFT), Infantry and Cavalry Fighting Vehicle Gunnery, states: "To capitalize on the benefits derived from firing your weapon first, the whole Fighting Vehicle crew must be highly competent in: detecting the targets; locating targets; identifying targets as friendly or enemy; and classifying targets as most dangerous, dangerous, or least dangerous."

The U.S. Army has equipment second to none. Shouldn't it also have training second to none? It will not until plywood and junk is replaced by targets that are realistic.

BIOGRAPHY

Lieutenant Colonel Martin C. Fisher is with the Coordinating Office for Ranges, Ammunition and Targets, Unit Training Developments Directorate, Office of the Deputy Chief of Staff for Training, US Army Training and Doctrine Command, Fort Monroe, Virginia. He graduated from Virginia Military Institute and has a Masters Degree in Civil Engineering from Arizona State University.

CONTRACTOR DEVELOPED TRAINING PACKAGES

ARE THEY ADEQUATE?

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ABSTRACT

Currently, the Department of Defense is procuring the most sophisticated weapons systems in the history of this country. Unfortunately, this is resulting in a rather serious problem in that current technological developments are vastly outpacing educational systems approaches. Studies reveal that a wide gap is becoming evident between the skills possessed by the high school graduates and their ability to deal with complex weapons systems. From this, it can be deduced that increased emphasis must be placed upon the design and development of educational and training methodologies for these systems. Innovative and motivating training data, which includes everything from simple handbooks to complicated scenarios, must be provided by the contractors concurrently with the piece of equipment. In addition, this data must meet the needs of the target audience in the military today.

Ideally, these materials are to be designed in compliance with the Instructional Systems Development (ISD) model and must meet specifications required by Data Item Descriptions (DIDs) which vary from contract to contract. In addition, whenever possible these materials should be performance-based and criterion referenced.

Unfortunately, past experience has shown that many initial deliverable items which are being produced under contract to the government are less than adequate training tools and do not meet the basic requirements of the DIDs or the ISD model. There exists many possible reasons for this inadequacy ranging from poorly written specifications, and thus different interpretations, to a lack of expertise in educational foundations and technical writing. From a review of various training packages delivered by several contractors, one can conclude that although contractor personnel who develop training material possess a great deal of technical expertise and subject matter knowledge, many do not apply the fundamental skills of education theory and technical writing. This results in poorly written training deliverables and ineffective communication concerning educational requirements.

This paper will highlight and investigate the problems that the authors have experienced in the area of evaluation and acceptance of technical weapons systems training material. It will also offer suggestions as to what government contractors, as well as the government, may do in order to produce and deliver a better quality product in a much more cost-effective and expeditious manner.

INTRODUCTION

As we sit down to write this article, we have just returned from what many may consider a typical government/contractor progress review. Perusing our notes, it becomes apparent that a multitude of breakdowns in communication occurred between the government and the contractor as well as internally within both the government and the contractor's plant. These breakdowns, unfortunately, resulted in numerous arguments, increased interpersonal friction, and the creation of ever present government change orders causing an escalation in the price of the contract.

A cursory examination of a successful contractor's resources reveals that the foundations required for effective curricula development are generally present. Therefore, the question must be asked: Are these training foundations properly utilized in order to meet the high demands of the Department of Defense? This paper will examine this issue, offer insights into current vendor produced training materials and provide suggestions for improvements.

In evaluating the adequacy or inadequacy of contractor-produced training materials, it is necessary to briefly examine the procurement process and highlight the potential anomalies which exist. The cycle commences with the solicitations. Simply stated, it is here that the government, via an Invitation for Bid (IFB), Request for Proposals (RFP), Request for Quotations (RFQ), etc., describes the service and/or product it wishes to acquire. Herein lies the first problem. Surely you have experienced the difficulty and frustration of not being able to explain exactly what it is that you want. This level of difficulty can vary from relatively simple instructions such as "turn on the light in the living room" to much more complex communications as "describe the operation of your 318 V8 turbocharger." Imagine the numerous communication hurdles which must be overcome by government personnel in describing a training program for a device or system which has yet to be conceived. How can training element managers provide explicit details for training programs related to a novel system when the capabilities of that system cannot be sufficiently identified or described by representatives of the user in the field? This is one basic problem faced by training element managers on a daily basis.

Take a step back and look at the existing state-of-the-art in current weapons systems development. Compare today's defense systems with those of a few years ago. It becomes readily apparent that technology has advanced at an escalating rate. On the other hand, pick up a daily newspaper and read one of the articles concerning the inability of many of today's high school graduates to read and comprehend. The combination of more complex and sophisticated technology with an apparent decreased reading grade level has created a great amount of concern among personnel in the operating forces. It is apparent that no matter how "wonderful" and sophisticated a system is, it is of absolutely no value unless it is properly operated and maintained. There then exists a dichotomy which generates a "hypothetical gap between technological development of hardware procured by DOD and the educational accomplishments of the target population assigned to operate and maintain this equipment." (2) Training personnel within the government have recognized this, and in the mid 70's began to institute a number of rather dramatic changes to both in-house and contractor-developed training programs. Now all programs must be developed in accordance with Instructional Systems Development (ISD) procedures. ISD is basically a total systems approach to training. That is, training as a whole is analyzed and initial determinations are made as to what constitutes a task. These tasks are then further analyzed, and the ones selected for training are associated with an objective as well as an evaluation criterion for that objective. When this has been determined, the training design and media selection are undertaken.

The ISD model is basically a very sound model which utilizes many of the highly theoretical education concepts presented to us in college education courses. These theories were highly idealogical and very rarely worked as they were supposed to in the public schools. Nonetheless, initial military training material developed under ISD is now being fielded throughout the military spectrum and the results are surprisingly pleasant. Studies indicate that a greater amount of learning transfer is taking place via ISD-produced material than by older, more traditional methods of instruction. (1) This initial evidence has caused many high officials in the Department of Defense to take a second and third look at ISD. As a result, it may be safe to predict that ISD-developed materials will be getting greater attention and will continue to be required for training material development. Therefore, it would be of great benefit to both government and contractors to have a deeper understanding of the current state of affairs concerning ISD.

Unfortunately, in the view of the authors, industry has not yet achieved a working understanding of the basic theory and operation of the ISD model. This has caused deliverables to be in non-conformance with ISD principles, and therefore, unacceptable to government reviewers. Private contractors seemingly still recruit personnel familiar with the technical aspects concerning operation and maintenance of hardware but neglect to hire ISD specialists. Without innovative training technology, the result is very often an inferior or unacceptable product. Let us examine the effect that this lack of ISD understanding has on training system design.

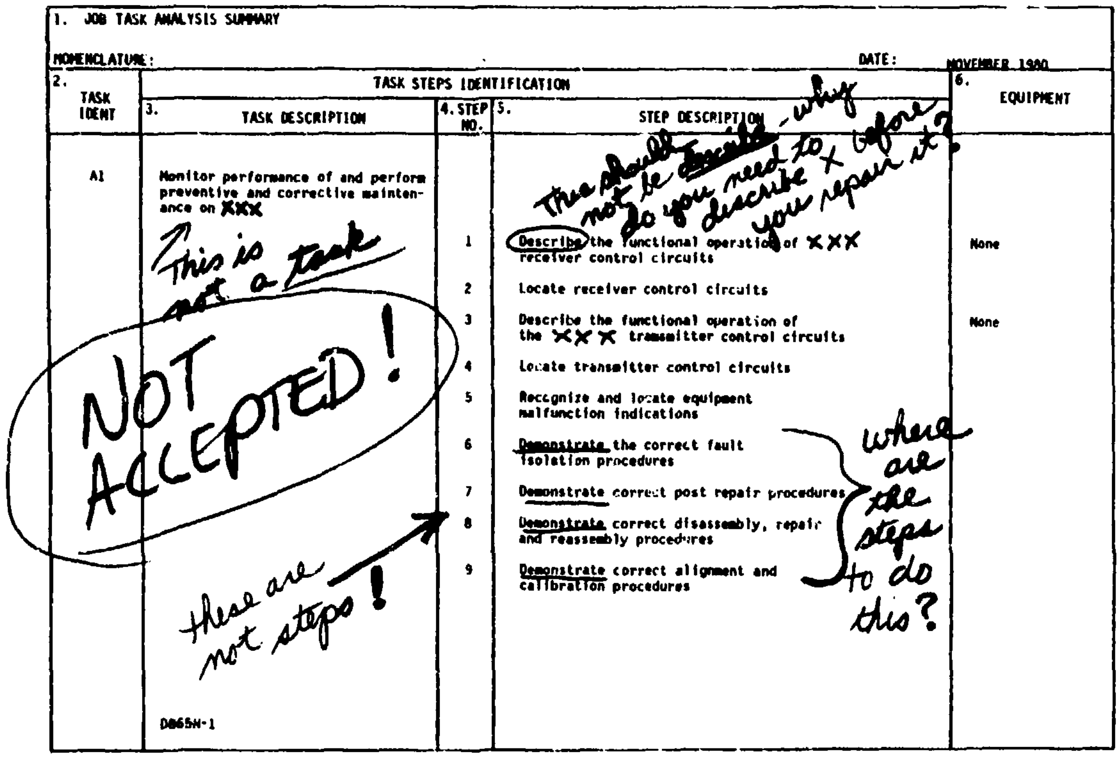
TASK ANALYSIS

The first step in the ISD process is to establish what constitutes or will constitute adequate on-the-job performance. This is referred to as a Task Analysis. The Task Analysis should serve to generate the criteria and data that provide a basis for initial foundations as well as assist in the selection of alternative concepts and designs without constraining creativity. More specifically, Task Analysis answers the question of what tasks, performed in what manner, under what conditions, in response to what questions, and to what standards of performance make up the job. Regardless of how well the next steps are carried out, if the job analysis data is not valid and reliable, the resulting instructional program will fail to produce personnel competent to perform their duties at a basic level.

Currently, the government is receiving far from adequate task analyses. It seems that all too often contractor training personnel do not understand what is required in order to construct a solid task analysis or simply do not have access to the necessary information needed for decision making. One available resource which contractor training personnel may use to support this phase of development is the Logistic Support Analysis Report (LSAR). (5)

The LSAR, which is supplied by contractor project engineers and logistic managers, provides a breakdown of operation and maintenance support activities currently being experienced or expected to be experienced by fielded systems. It is the job of contractor training personnel to analyze this data and make recommendations as to task determination and the requirements for training. Some tasks are seldom required on the job and only minimum job degradation would result if the task were not performed. On the other hand, some tasks are highly critical to successful job performance, or the complex nature of the task makes training essential. Economic and time considerations require the trainer to make decisions as to which tasks will be selected for training and the extent of training which will be provided. Many contractors either fail to realize or neglect to consider the importance of this task selection process. The result of this inattention to proper task selection destroys the foundation of the training design and results in the production of an unacceptable training curriculum. Figure 1 provides an example of what an unacceptable submission of a task and skill analysis would be. It is apparent from this example that the curriculum developers either: a), did not have a working knowledge of education concepts or the ISD model; or b), were not provided with sufficient information via preliminary research, i.e., LSAR; or c), did not take an adequate amount of time to prepare the document, or d), simply had a very poor writing ability.

As was mentioned earlier, the task and skills analysis is the base of the development effort. It is the foundation upon which the curriculum will be built. If this section lacks continuity or is vague, as shown in Figure 1, the whole program suffers. Many developers fail to realize or understand this, as evidenced by actions such as delivering an instructor's manual or a student's guide, months before the task and skill analyses. When asked about it, they reply, "It's not complete as yet, but will be completed soon." It equates to a student writing a required outline after the completion of a term paper. Contractors do not understand that an outline, Task and Skill Analysis, is a tool which helps turn out a professional product. Figure 2 is representative of an acceptable analysis which supports this initial development effort. It is apparent that the developer of the document demonstrated in Figure 2 manifests the considerations of the ISD model in this phase of the curriculum development process.



1. JOB TASK ANALYSIS SUMMARY

NOMENCLATURE:

DATE: NOVEMBER 1980

2. TASK IDENT	TASK STEPS IDENTIFICATION			6. EQUIPMENT
	3. TASK DESCRIPTION	4. STEP NO.	5. STEP DESCRIPTION	
A1	Monitor performance of and perform preventive and corrective maintenance on XXX			
		1	Describe the functional operation of XXX receiver control circuits	None
		2	Locate receiver control circuits	
		3	Describe the functional operation of the XXX transmitter control circuits	None
		4	Locate transmitter control circuits	
		5	Recognize and locate equipment malfunction indications	
		6	Demonstrate the correct fault isolation procedures	
		7	Demonstrate correct post repair procedures	
		8	Demonstrate correct disassembly, repair and reassembly procedures	
		9	Demonstrate correct alignment and calibration procedures	
	D065N-1			

This should not be describe - why do you need to describe + before you repair it?

This is not a task

NOT ACCEPTED!

these are not steps!

where are the steps to do this?

FIGURE 1

This is an example of an unacceptable task and skill analysis which does not demonstrate the requirements of the ISD model.

JOB TASK ANALYSIS SUMMARY

1\. Nomenclature FIRE FIGHTING/DAMAGE CONTROL Date 29 November 1979

2. Task Ident.	TASK STEPS IDENTIFICATION AND ANALYSIS			
	3. Task Description	4. Step Number	5. Step Description	6. Equipment
L1.1	Operate fire fighting equipment.	L1.1.1	Operate the P-250 pump.	
		L1.1.1.1	Prepare the P-250 pump.	
		L1.1.1.1.1	Assemble all necessary equipment in the operating area.	Foot valve and strainer
		L1.1.1.1.2	Connect the foot valve and strainer to the suction hose.	Suction hose Exhaust hose
	accepted!	L1.1.1.1.2.1	Place the female threads of the foot valve and strainer against the male threads of the suction hose.	Spanner wrench Tri-gate
		L1.1.1.1.2.2	Give the foot valve and strainer a quarter turn counterclockwise to align the threads.	2-1/2 inch fire hose
		L1.1.1.1.2.3	Turn the foot valve and strainer clockwise until it is tight.	Two 1-1/2 inch hoses
		L1.1.1.1.3	Connect the suction hose to the P-250 pump.	Two all purpose nozzles Fuel tank Screwdriver

FIGURE 2

This is an example of an acceptable portion of a task and skill analysis. Note that the enabling objectives are modified by specific job performance measures. The numbering system identifies a topical outline format.

As government representatives tasked with the responsibility of accepting and/or rejecting the deliverables provided by private contractors, curriculum reviewers devote a great deal of time to the evaluation of the task and skills analysis. Specifically, they examine the logical progression of the tasks selected to determine whether the tasks are actually tasks and if so: a) do they satisfy a need for training; b) can training be provided in a practical and cost-effective manner; c) do the tasks complement each other for use on the job; and d) how will performance measures be constructed?

The area of performance measures provides an interesting observation. A surprising number of contractor training personnel seem to be encountering difficulties in the construction of job performance measures. Review meetings between government and contractor personnel repeatedly revealed this fact. Questions pertaining to what should be measured, i.e., product, process or both, via what method, and with what consequences of failure often were the cause of many vague responses. Inquiries about predictive validity or fidelity seldom were answered in concrete terms. Since these topics were questioned early in the design process, it often led to strains between contractor and government personnel. This, unfortunately, caused tension to develop and decreased the level of interpersonal communication which is greatly needed throughout the design-development of the curriculum.

DESIGN

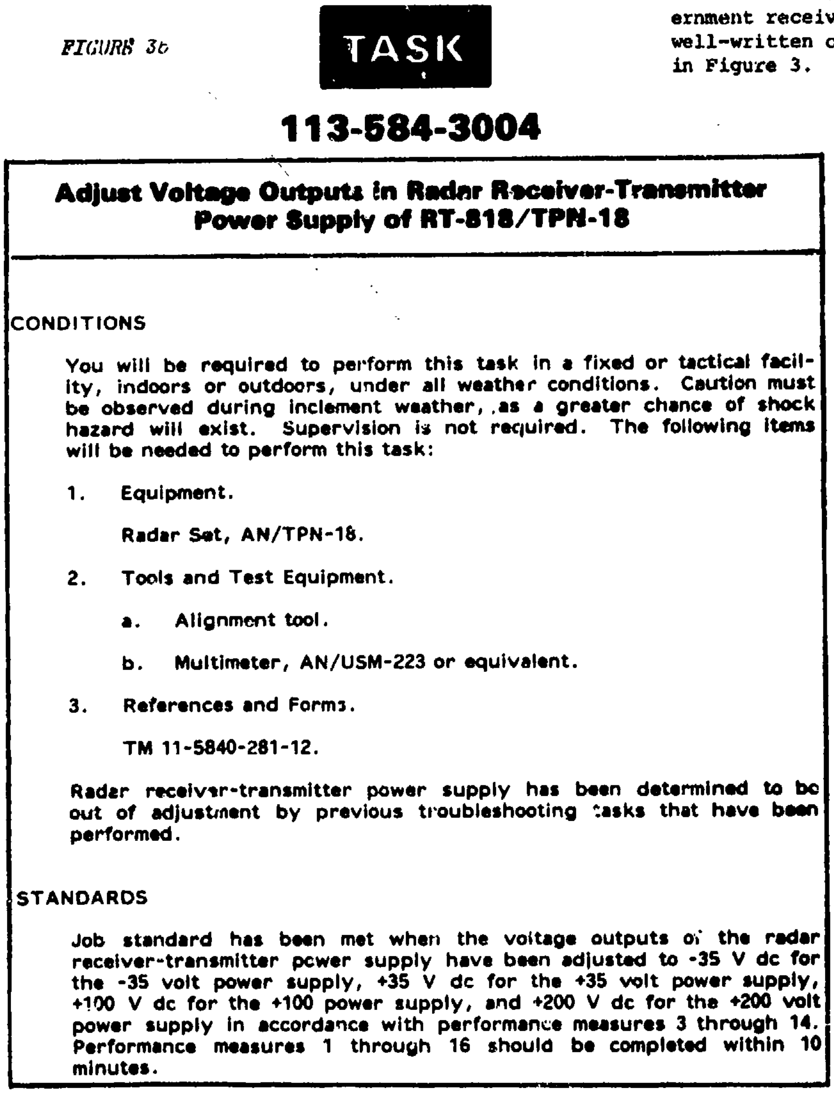
The second phase of the ISD model is that of design. Unfortunately, the reaction by many government Training Element Managers, as to whether or not the curriculum is favorably received, is usually based solely upon how well the materials are initially presented. It can be compared to the new home buyer who bases his opinion of a house solely on curb appeal - new paint, nice lawn, etc. Ideally, government reviewers must go beyond that and examine the foundation as well; thus, a "pretty" instructor guide with little substantiation for its contents will not necessarily meet the rigorous government acceptance standards.

Learning objectives, which are the "heart" of the design phase, are reviewed closely. Adequate job performance measures which are developed in the task analysis provide the basis for developing these learning objectives. Terminal learning objectives are actually direct translations of job performance measures (JPMs) into learning objectives for the training world. Therefore, if the designer takes time to prepare a well constructed task analysis which contains rather detailed JPMs, the design of the associated materials should be relatively simple.

Objectives contain specific descriptions of an action the learner is to exhibit after training, the conditions under which the action will take place, and the standards or criteria which must be reached for satisfactory performance. These objectives are generally behavioral in nature and are concerned with various types of learning or performance. The philosophy under which they and all other curriculum efforts operate are based upon numerous education theories which become very abstract in nature. It is necessary to hire personnel familiar with education concepts and who can appreciate the importance and usefulness of the prerequisite research and development work that must be accomplished prior to the "painting" of the final product; that is, task analysis.

Unfortunately, it is rare that the government receives deliverables which contain well-written objectives. This is illustrated in Figure 3. The reasons for this vary with

FIGURE 3b



TASK

113-584-3004

Adjust Voltage Outputs in Radar Receiver-Transmitter Power Supply of RT-818/TPN-18

CONDITIONS

You will be required to perform this task in a fixed or tactical facility, indoors or outdoors, under all weather conditions. Caution must be observed during inclement weather, as a greater chance of shock hazard will exist. Supervision is not required. The following items will be needed to perform this task:

1. Equipment.

   Radar Set, AN/TPN-18.

2. Tools and Test Equipment.

   a. Alignment tool.

   b. Multimeter, AN/USM-223 or equivalent.

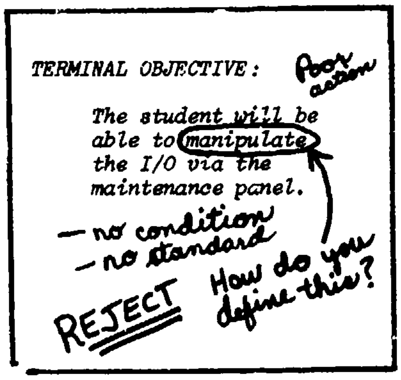
3. References and Forms.

   TM 11-5840-281-12.

Radar receiver-transmitter power supply has been determined to be out of adjustment by previous troubleshooting tasks that have been performed.

STANDARDS

Job standard has been met when the voltage outputs of the radar receiver-transmitter power supply have been adjusted to -35 V dc for the -35 volt power supply, +35 V dc for the +35 volt power supply, +100 V dc for the +100 power supply, and +200 V dc for the +200 volt power supply in accordance with performance measures 3 through 14. Performance measures 1 through 16 should be completed within 10 minutes.



TERMINAL OBJECTIVE: Poor action

The student will be able to manipulate the I/O via the maintenance panel.

— no condition
— no standard

REJECT

How do you define this?

FIGURE 3a

Figure 3a is an example of an unacceptable objective actually submitted for review. Figure 3b is an example of a correctly written objective. Note that here all three elements, action, condition and standard are included in this example as required by the ISD model.

such things as contract requirements, the philosophies of the contractors as well as the government Training Element Managers, overly specific or extremely vague data item descriptions (DIDs) and writer inability or misunderstanding. Let us examine this a bit further.

One of the major dilemmas which has a direct effect upon the design of instructional materials is legal requirements of contractor scheduling. The contracting officer places a great deal of emphasis upon delivery dates as is necessary to meet the terms of a contract. This is often dictated by such things as operational equipment delivery, ready for training dates, etc., which are established by higher headquarters, thus placing any decision out of the realm of working level personnel. Unfortunately, this causes the contractor to be forced into an obsession to comply - delivery on time becomes the striving goal. As a result, the quality of the program is often overshadowed by the delivery date, and the government receives numerous blank pages titled and noted "to be developed" because of insufficient data. This is extremely frustrating, as well as very costly.

Perhaps, there should be a re-examination as to the legitimacy of scheduling requirements and the applicability of data item descriptions or other specific working standards before any development of curricula is undertaken. It is apparent that something needs to be done in order to focus the attention toward quality research and design rather than compliance with delivery dates just to satisfy legal requirements in the contracts.

Corporate philosophies also affect the training product. Technology growth in the last ten years has been astonishing. Attitudes toward training design have also changed dramatically. Although the basic foundations of education are still the same, the training methodology has taken on new dimensions. Innovative government education and training specialists have realized this and are experimenting with novel approaches to training for their programs. Such vehicles as videotape and videodisc, computer assisted instruction as well as visual and physical simulation, are being solicited in new weapons systems procurement. The reasons for this can be capsulized into the fact that training via these avenues is more efficient, interesting, cost-effective and practical.

This is not to say that the traditional written material is to become obsolete. There will always be a requirement for written documentation and instruction. Fortunately, as many innovative contractors are beginning to realize, these simple written materials must be augmented by innovative training devices. The Department of Defense's training requirements have become so technical, complex and expensive that now the most efficient method of training is often via non-traditional methods similar to those mentioned earlier. It is the opinion of these authors that the time has now arrived that if a contractor does not soon make a decision to hire competent personnel who are well versed in the non-traditional avenues of training; i.e., simulation, video/computer interface, etc., he will fall by the wayside in his quest to obtain defense systems contracts.

In essence, then, there must be certain changes made in the training acquisition process. Initially, the government must provide more specific direction to the contractor regarding the product which is to be developed. In addition, it is imperative that the contractor be given the freedom to determine, a) what is needed for training, b) the most effective methods to provide that training, and c) adequate time for the preparation of the instructional material.

In summary, this paper has provided a cursory examination of the current process of training system acquisition. There exist many problems, ranging from minute to monumental, caused by both the government and contractors. It would take a dissertation to expound upon all of the anomalies which are present. Obviously, this is beyond the scope of this paper. Figure 4 is a capsuled attempt to highlight areas where deficiencies are perceived to exist. It is structured so as to remain objective in nature, yet be highly critical of both parties in DOD training acquisitions. The ISD model serves as its base, since it is the vehicle by which we, as government Training Element Managers, review contractor produced deliverables.

On the other hand, a private contractor whose business is training development must be aware of the current state-of-the-art in education. He must realize that trends in technology are vastly outpacing those in education and that attempts must be made to bridge this hypothetical gap. This can be done by recruiting personnel who are knowledgeable about current trends and are willing to step out and take the necessary initiative to introduce the innovative training methodology dictated by current technological advances. (1)

We do not purport that an individual well versed in ISD is the panacea for inadequate training program development. Obviously, there is no one perfect method which will ensure effective training. But, as Montemerlo and Harris suggest, the development of effective training packages requires among other things an interdisciplinary team of subject matter experts and skilled instructional technologists. (4) The recommendations alluded to in this paper are just as susceptible to inept application as are current methods. The authors suggest that if training development is given additional attention, and conscientious consideration, there will be a significant impact upon future training developments.

		SUGGESTED GOVERNMENT ACTION	SUGGESTED CONTRACTOR ACTION	CURRENT PRODUCT	SUGGESTIONS
ANALYSIS	Task Selection/Determination	Provide adequate job description/constraints.	Analyze LSARs, etc. and make determinations for ISD incorporation.	Tasks not definitive.	Contractor insure proper interface and understanding between LSA and ISD personnel.
	Select Tasks for Training	Insure contractor understands/develops logical rationale for selection.	Examine complete picture as to need, practicality and cost.	Entire instructional system not considered	Contractor should take further steps to analyze target population and training environment. Government should provide more definitive guidance as to the product they desire; examples should be provided. Government should also provide adequate preparation time for foundations of training. Quality suffers if this phase is eliminated and COTR should budget accordingly.
	Write Job Performance Measures		Provide rationale which may determine evaluation of tasks.	Not being done prior to design of material as evidenced by lack of evaluation criteria.	Contractor should make all efforts to recruit personnel familiar with training evaluation and task selection techniques.
DESIGN	Objectives	Provide regulatory instruction (DIDs) which demonstrate concrete guidelines and do not stifle contractor creativity.	Construct objectives which contain all elements (Action, Condition, Standard) and are criterion referenced as well as performance based whenever possible.	Objectives generally not acceptable due to lack of one or more elements. Often numerous behaviors are contained in one objective and performance measures are vague.	Contractor's viewpoint needs alteration. Behavioral objective approach is often viewed as a necessary evil and not understood. Consequently, end product generally unsatisfactory.
	Tests	Must insure that salient points of objectives are tested. Insure written and performance evaluations have predictive validity.	Insure all facets of objective are adequately measured.	Tests are constructed after instruction is written; result is a simple reiteration of classroom presentation.	Contractor should employ specialists in the area of test construction. Curriculum should not just provide instruction necessary to "pass the test."
	Media Selection/Format	State of the art in training must be considered and leeway for contractor creativity allowed. COTRs cannot be reluctant to introduce innovative design.	Examine target population as well as subject matter and make determination as to most efficient media for information presentation.	Little, if any, target population analysis done. Training material currently consists primarily of traditional written manuals which impact upon learning transfer due to student's comprehension of material.	Contractor's should strive to introduce more innovative and creative training methodologies. Visual literacy of target population must be examined and modern techniques employed.
	Validation	Should inform contractor of desired outcome of product; i.e., what they expect the product to accomplish.	Design evaluation procedure before material is fielded; i.e., inform the government as to the methodology which will be employed in determining if a product is reliable and valid.	No real guidelines or procedures which may determine if a product (curriculum) accomplishes its objectives.	Experimental test design procedure for validation be constructed and delivered to government prior to delivery of material to the field.

FIGURE 4

Summary of deliverables relative to the ISD model.

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TRAINING THE FIELD ARTILLERY CANNON SYSTEM

Abstract

Field Artillery units are preparing for combat in a training environment that is often characterized as hostile. One of the factors contributing to this difficult training environment is the availability of training resources needed to achieve and maintain a high state of combat readiness. These resources include personnel, budget, time, fuel, repair parts and a suitable location to conduct realistic training.

The field artillery is not without training devices and simulators at present; however, in the past the philosophy has been that the best way to train field artillerymen is with live ammunition. While a strong case can be made to support that philosophy, and while adequate resources in the past have permitted that philosophy to reign, the recent dramatic cost increases for these resources are driving the Army to do things differently. These changes have been recognized and are being dealt with by the Field Artillery School.

The Army and the Field Artillery are heavily committed to the use of training devices as a method of simulating force-on-force combat. As technology advances and the understanding of the factors required for effective training increases, devices continue to be one of the best solutions for economically and realistically conducting combat training.

WHY WE NEED TRAINING DEVICES AND SIMULATIONS

Field Artillery units are preparing for combat in a training environment which is characterized as hostile and ever-shrinking. One of the several factors contributing to this difficult environment is the availability of training resources needed to achieve and maintain a high state of combat readiness. Spiraling costs for ammunition, fuel, and repair parts, combined with limited training areas and available training time are resources which are becoming scarce. This trend will continue over the coming years.

During the period 1977 to 1980, the cost of 105mm and 155mm ammunition increased 91%, while the cost of an 8-inch full-service round has increased by 234% during the same period. As a result, ammunition allocations for training of active as well as reserve component field artillery units have been cut significantly, and future reductions in training ammunition allocations should be expected.

The "energy crunch" and the associated high fuel costs have had an adverse impact on availability of fuel to support training. The cost for mogas and diesel has increased by over 200% since 1977. Using an annual, average expenditure of 40,000 gallons of diesel and 15,000 gallons for mogas for training, a 155mm FA battalion annually must pay $37,000 more for diesel and $13,000 more for mogas today than it did in 1977.

Repair parts have also increased in cost dramatically over the past 4 years. In 1977 average annual repair parts costs for a CONUS FA battalion were $388,000. Today the cost is approximately $600,000.

The adequacy and availability of training areas are other factors that contribute to the hostility of the training environment. Frequently, those training areas that are adequate are heavily committed and, in many cases safety considerations for many special munitions mean their use in training is restricted to a very few firing ranges. Additionally, environmental considerations, particularly noise pollution, are becoming increasingly important. Civilian communities in the vicinity of artillery impact areas are more concerned about the noise of impacting artillery than they were ten years ago, and this has caused increasing pressures to restrict the availability of training areas.

TRAINING THE CANNON SYSTEM

There are several ways to look at field artillery cannon unit training when designing a family of training devices and simulations to complement live fire training. Traditional approaches involve consideration of the elements of a firing battery, i.e., the fire direction center, the forward observer, and the howitzers themselves as a way of analyzing or expressing the need for training devices and simulation. It is also possible to look at training device and simulation needs in terms of individual training and collective training requirements. These perspectives have several fundamental flaws, however, which may have contributed to the current state of affairs. There is a more fundamental perspective that appears to yield better insights into how field artillery units can take advantage of training devices and simulation. This perspective involves consideration of where field artillery units train, what type of training is conducted there, what training devices or simulations are currently available to support this training, and what training devices and simulations should be developed to improve the training conducted there at less cost with no loss in effectiveness.

Training is normally conducted by FA units in three training areas: garrison areas, local or closein training areas, and major training areas (MTA).

1. Garrison. Field Artillery related garrison training is characterized as focusing on development of individual skills and section level proficiency. Normally the training is done in a classroom, or the motor pool, and seldom do the sections integrate their training efforts. This mode of training usually follows ARTEP type training where the commander identifies his training weaknesses, diagnoses the cause of each weakness, and prescribes training at individual or section level to improve proficiency prior to

the next evaluation. Garrison type training because of these characteristics is by its nature less expensive than training in the other areas. Therefore, training devices and simulations here should make a contribution toward improving effectiveness of training.

At present, there are several training devices and simulations in the inventory which can be used to train in garrison:

105 Ammo Handler's round
Time Training Fuze
Artillery Direct Fire Trainer
Nuclear Training Rounds M455 155mm,
  M423 8-in
Training Set, Fire Observation
Puff Board
A variety of Battle Simulations (war games)

As can be seen, this is not an impressive array of training devices and simulations considering the current state of the art, and the list highlights the earlier statement that field artillery device and simulation development has been done on a piecemeal basis.

In the light of the type training conducted in garrison and the training devices and simulations available to support that training, several gaps can be identified which provide the basis for training devices or simulations currently under development or for establishment of a training device requirements document.

Training devices and simulations currently under development to support garrison training are:

a. Copperhead Training Round: This device will provide cannoneers with realistic crew drill on a dummy, full-caliber 155mm cannon-launched guided projectile. The round does not leave the tube and must be extracted through the breech. Crew drill will include inspection, arming and loading.

b. Battery Computer System (BCS) Trainer: This trainer is being designed as a means of conducting operator training on the BCS while simulating the interface with systems having an input to BCS (TACFIRE, Digital Message Device.

c. Training Set, Fire Observation (TSFO): This training device is designed to provide realistic classroom training in adjust fire procedures, both for institutional and unit use. It utilizes image projectors and a minicomputer to display target and burst symbols on a slide-projected terrain scene. It will be fielded two per division artillery plus selected TRADOC schools and reserve component locations.

d. Ground Laser Locator Designator Evaluator (GLLD-E): This device is designed to allow FIST personnel to practice GLLD tracking without the safety hazards of the actual GLLD. It incorporates a Maverick TV camera and provides feedback to the operator via a scoring device. In addition to these devices currently under development, there is a need for additional devices to fill other existing gaps in training the cannon system in the garrison environment: for example, devices which will enable the total field artillery system to train as a team without the expenditure of service ammunition. This means of training the total system is seen as a way of closing the loop between the observer and firing battery in dry fire training and may be viewed as a long term replacement to the M31 trainer. It would also enable units to train with minimum expenditures of fuel because they would not be forced to travel to maneuver and impact areas. An overview of how this integration of devices might take place is outlined below:

a. The Fire Support Team (FIST) trains with the Training Set, Fire Observation in garrison. A direct communication link is established with the TACFIRE or Battery Computer System element of the battalion and battery Fire Direction Center in the motor pool.

b. The Fire Direction Center (battery or battalion) computes firing data and sends it to the guns, collocated with the FDC in the motor pool or local training area.

c. The gun sections load a type of dummy projectile while error measuring equipment on the howitzers feeds data to a central computer which determines "did hit" coordinates.

d. A burst/flash symbol is displayed on the TSFO screen at the "did hit" coordinates. (Note: The central computer could be the TSFO computer, BCS, TACFIRE, or a separate "training-only" computer.)

e. A data link from the central computer to target acquisition systems provides "did hit" coordinates, trajectory information, and burst symbols on data display units.

2. Local Training Area (LTA). Training in the LTA primarily concentrates on development of collective level ARTEP tasks at the battery and battalion level. For many CONUS units, the LTA and MTA may be one and the same training area. For units stationed overseas, there is a marked difference between these two areas. The LTA is generally characterized as limited in space but large enough to allow units to conduct some training in reconnaissance, selection, and occupation of position. Any live firing for artillery units, if permitted, is restricted to subcaliber devices. Training in this area builds upon the individual and section level proficiency obtained during the garrison training, and allows the command, control, and coordination function to be exercised at the battery and battalion level. Some training devices and simulations can also be used in the LTA as units train to a high level of proficiency prior to conducting live fire training at the MTA.

Two field artillery devices currently used in this environment include the M31, 14.5mm subcaliber trainer and the miniature moving target (a Soviet model tank used in conjunction with M31 ranges). At present, there are no devices under development specifically designed to enhance training in the local training area. Some other devices mentioned previously for use in garrison areas can also be used in the LTA (105mm ammo handler's round, artillery direct fire trainer, and nuclear training rounds).

The integration of devices to enable the total field artillery system to train as a team without the expenditure of service ammunition (discussed under "garrison" training) would also be an excellent means of training the battery/ battalion collective tasks in the local training area (LTA). It would allow the units to integrate the firing, maneuver, and RSOP tasks without expending service ammunition. In the LTA, one additional device is needed:

A low cost, full caliber training projectile which can be rammed/loaded into 105mm, 155mm, and 8-inch howitzers, provide bang and recoil, and either consumes itself or literally plops out of the end of the tube so that dry fire training for howitzer crews can be more realistically done while not creating safety constraints which would require impact areas. This round would also be used during engagement simulation exercises. A round which can be rammed but must then be extracted through the breech does not provide for positive training responses.

3. Major Training Area (MTA). Training in the MTA is characterized by live firing with service ammunition within the framework of battery and battalion level ARTEP tasks. In some MTA locations, field artillery units are able to participate in live fire combined arms exercises. This however, is the exception rather than the rule, due to the many safety restrictions in force at the various training areas.

The primary emphasis in the MTA is use of actual combat equipment and munitions in simulated combat scenarios. Few training devices are used during this "verification of combat readiness" training. One exception in the future, however, will be the use of full caliber, training-unique ammunition. The field artillery is currently developing a low-cost indirect fire training round (LITR) to be used in lieu of high explosive service ammunition in training at the MTA's. These non-exploding indirect fire training rounds will significantly reduce the cost of live fire training for 155mm and 8-inch battalions and institutional training. The rounds are ballistically matched to their parent HE round; the FDC uses the same firing tables as with the HE round; and a smoke/ flash signature is provided so the observer can see and adjust them.

There is another major type of training to be conducted in the near future at the MTA's and that is engagement simulation exercises using the Multiple Integrated Laser Engagement System (MILES). This type of training will allow free-play, force-on-force scenarios to be conducted with a degree of battlefield realism never before obtainable. The use and effects of live ammunition are effectively simulated with the MILES laser transmitters and detectors. The current state of development of MILES equipment is primarily limited to direct fire weapons systems. A large training gap exists which indicates a need for devices and methods to realistically play indirect fire systems in MILES exercises, both at the National Training Center and other installations having MILES equipment.

Five distinct elements of the indirect fire problem have been identified below and prioritized according to their importance in development:

a. An audio/visual cue to be activated at the simulated grid of impact. This cue (smoke, bang, flash) does not need to simulate every round fired, but a representative number is required to give the Artillery Observer and other players an appreciation of the suppression/ killing power of their supporting artillery/ mortars and to insure that the attacked unit is clearly aware of why it suffered the casualties/ damages it did and what preventive measures could or should have been taken.

b. An automatic casualty assessment system which is not dependent upon the subjective decisions of a fire marker controller on the battlefield with a controller's laser gun. This system must automatically assess casualties and damage according to the distance from the impact grid of the simulated rounds, the type of munitions employed, and the protection available to the players at the moment of impact.

c. A means of getting the firing battery and FDC realistically involved in the exercise. The overview of an integration of devices designed to train the total FA system, described earlier, may also be applicable here. The "did hit" coordinates determined by the central computer, based upon the FDC's computations and subsequent data applied to the howitzers, could be used as the basis for the casualties assessed on the battlefield. In this manner, the firing battery and FDC personnel have direct input to the success/ failure of the field artillery in engagement simulation exercises. In conjunction with the error measuring equipment on the howitzers, the dummy projectile, described earlier, could be used to increase the realism of engagement simulation by the crews.

d. A GLLD simulator which will allow Copperhead and Hellfire to be played in MILES exercises. A trainer which looks like a GLLD or an adaption to the actual GLLD itself must be developed which will interface with existing Miles equipment so that FIST personnel can realistically simulate the coordination and laser designating skills involved in the employment of laser-guided munitions.

e. A means of realistically involving the various target acquisition elements into the exercise. Again, the earlier discussion on the overview of an integration of devices designed to train the total FA system may have application in solving this need.

CONCLUSIONS

The following points should be highlighted concerning the development of devices and simulations to train the field artillery in the 1980's:

1. This paper addresses training device needs which have been identified and should not be confused with requirements. Every need must undergo a thorough front end analysis (to include task analysis, media selection analysis, and cost and training effectiveness analysis) before a legitimate requirement can be substantiated and requirements documents written.

2. This plan is not to be considered an all inclusive listing of training devices/simulations. As front end analyses for new combat systems are completed, additional device requiremants will be identified. In addition, TRADOC's Comprehensive Plan for Training Device Developments is a listing of every device currently in the inventory, under development, and proposed for future development. It is updated on an annual basis.

3. Combat systems which have computers as part of their equipment are prime candidates for the development of software embedded training. This kind of training reduces the requirement for separate, costly training devices/simulators and also permits soldiers to train and be tested on their own combat equipment.

4. A prime consideration in the development of training devices is not to train personnel at the institution with devices that will not be available at their unit. However, this should not become a stumbling block to the development of cost efficient training at the institution. There are times when it is cheaper or more effective to develop an institutional-only trainer due to space constraints in the actual combat equipment, large numbers of students to be trained in short periods of time, or insufficient quantities of combat equipment available to the institution.

5. The development of devices to integrate the training of the total cannon system and target acquisition systems without the expenditure of service ammunition is of prime importance, both for unit collective training programs and for combined arms training exercises using engagement simulations.

BIOGRAPHICAL SKETCH

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IMPACT OF INFLATION

AMMUNITION	1977	1980	% INC
105 MM	$ 33	$ 63	91%
155 MM	$ 70	$ 134	91%
8 INCH	$ 90	$ 301	234%

FIGURE 1

IMPACT OF INFLATION

FUEL	JULY 1978	MAY 1980	% INCREASE
MOGAS ($/GAL)	$ 0.45	$ 1.29	187%
DIESEL ($/GAL)	0.36	1.29	258%
REPAIR PARTS	430.00	603.00	40%

(M109 HOWITZER TRACK PADS)

FIGURE 2

UNIT TRAINING

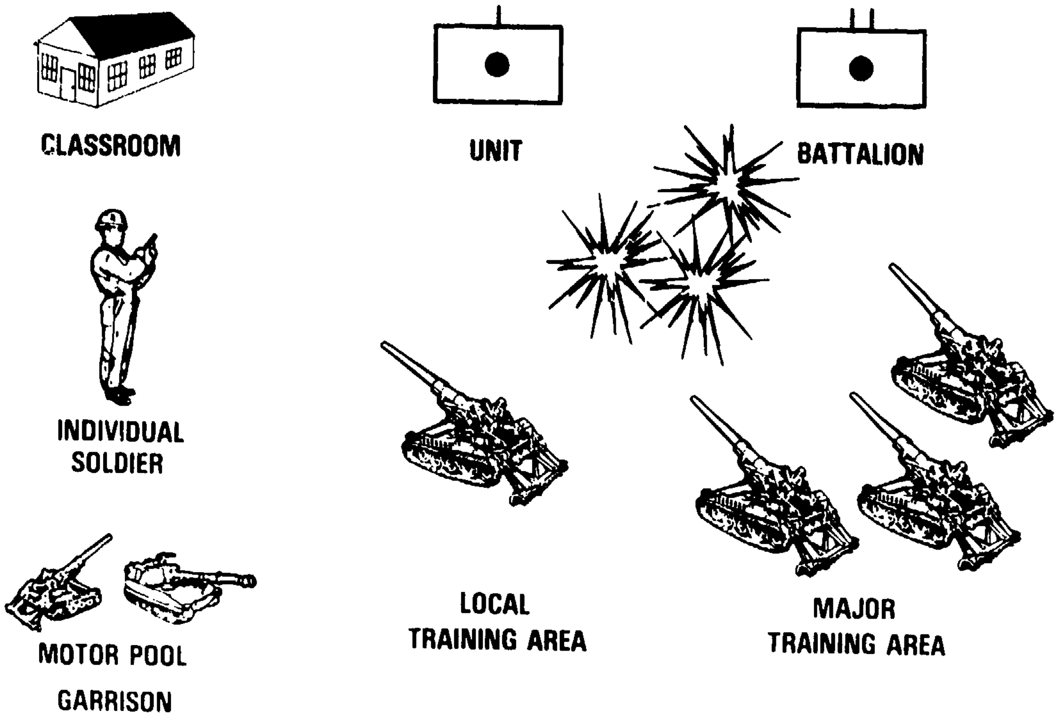
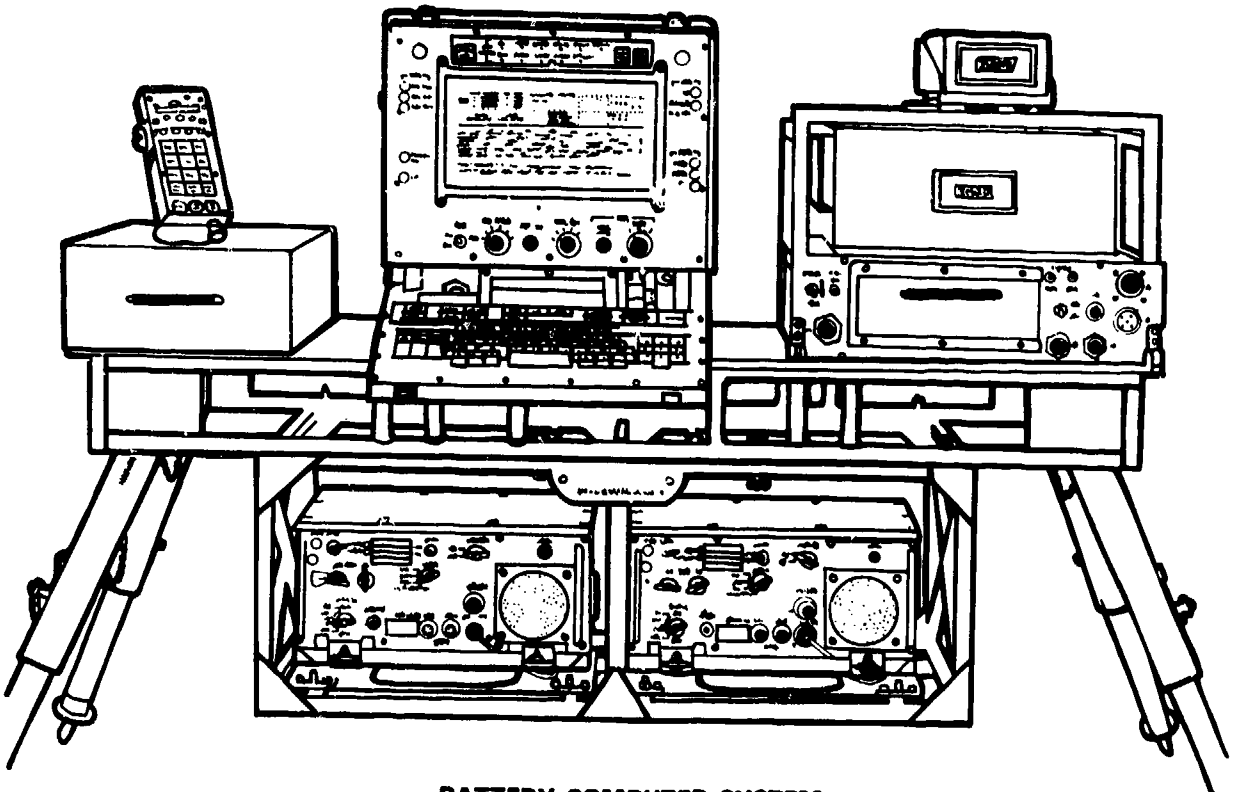


FIGURE 3



BATTERY COMPUTER SYSTEM

FIGURE 4

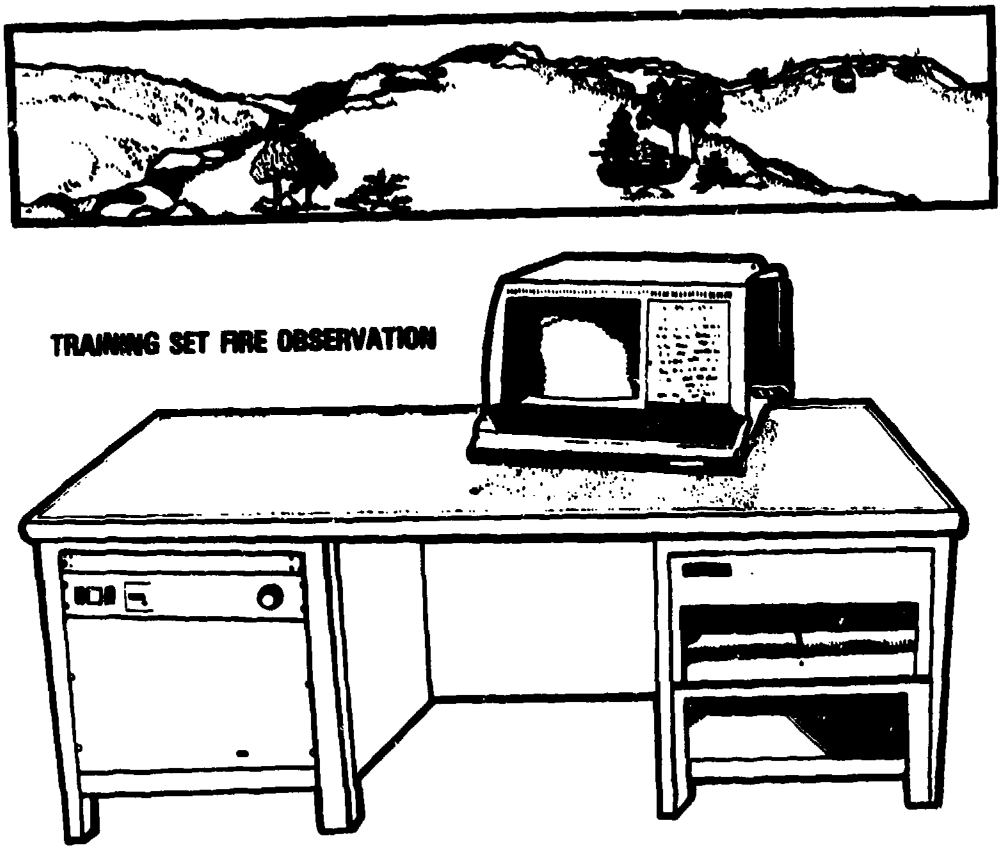


FIGURE 5

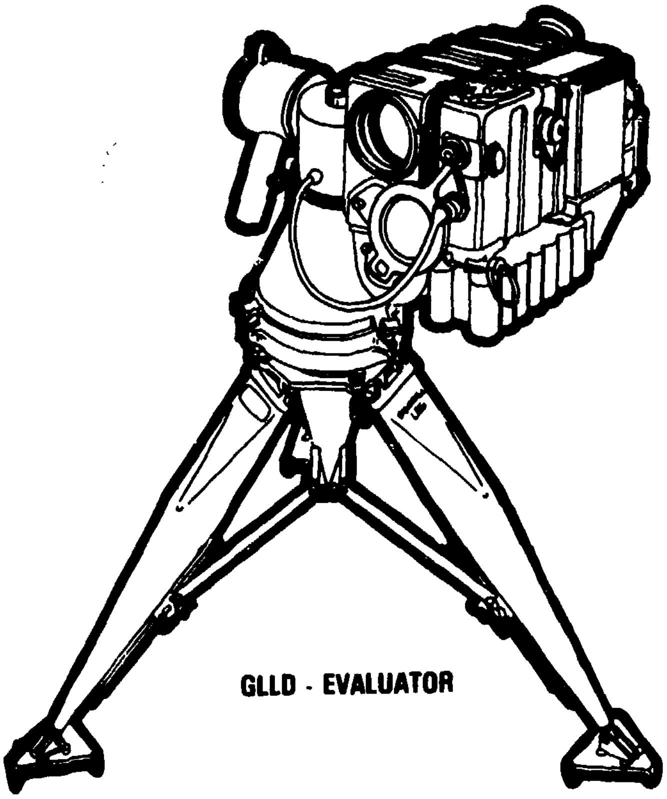


FIGURE 6

INDIRECT FIRE ENGAGEMENT SIMULATION

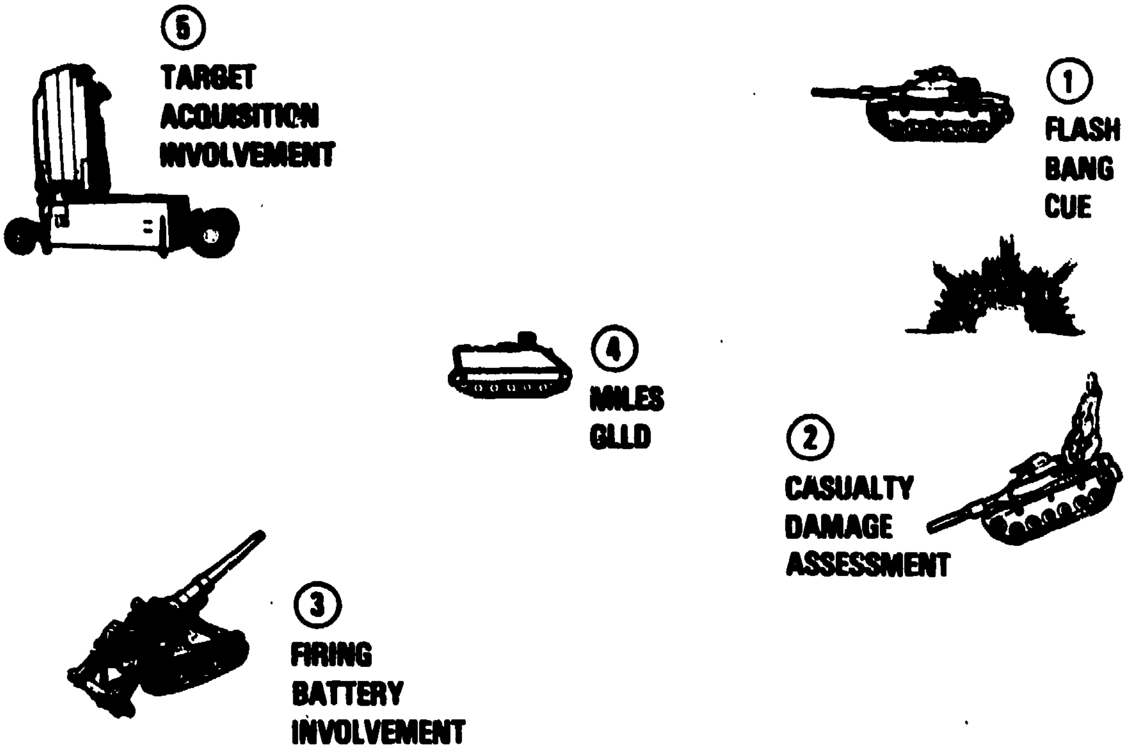


FIGURE 7

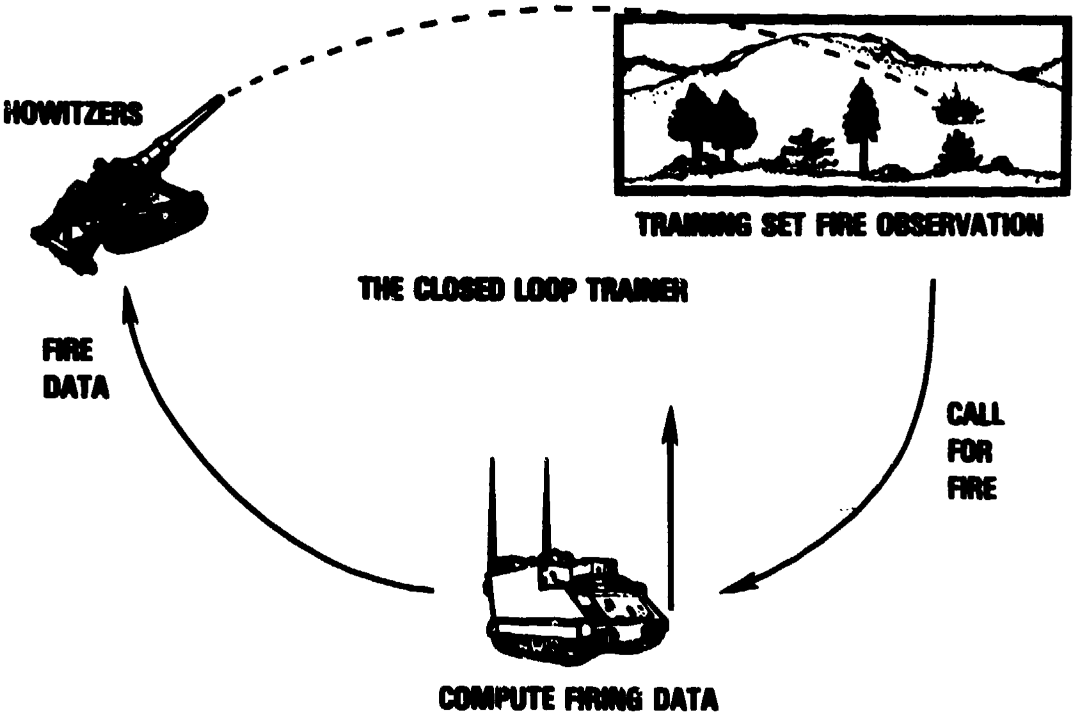


FIGURE 8

SIMULATION IN THE CANADIAN FORCES

By

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ABSTRACT

The Canadian Armed Forces stress the use of simulation to both increase effectiveness and realism, and reduce costs associated with military training. An integrated approach to the use of simulation across all three Services ensures that the maximum benefit is derived from new technology.

INTRODUCTION

One year ago, General Ramsey Withers, Chief of the Defence Staff directed that simulation be accorded a much higher priority in the training of the Canadian Armed Forces. A Simulation Permanent Working Group was formed to serve as a focal point for simulation throughout the Canadian Forces.

The present policy in effect across all three Services directs that simulation be incorporated into the training system whenever savings in resources or energy accrue while improving or maintaining operational proficiency. It further directs that in all new projects, simulation opportunities be addressed. New projects will also address the energy factor and stress conservation in all non-renewable resources.

Since the Second World War the Canadian Navy has, by and large, sailed in ships designed and built in Canada and the majority of Canada's military research and development has been directed towards the maritime requirement. Notwithstanding, the Navy training philosophy has followed that of the Royal Navy and many training devices have been purchased from United Kingdom sources. The new patrol frigate program has given new impetus to the development of naval simulators that will replace our outdated trainers and match the needs of the updated DDH 280, and the new patrol frigates.

Due to the close association among North American aviation industries and joint North American Air Defence agreements our Air Force has adopted similar aircraft and consequently has similar requirements for simulators and training devices as the USAF. The recent additions to the CP 140 Long Range Patrol Aircraft and the decision to purchase the F18 with their new technologies have generated the need to push the state-of-the-art to develop associated modern training equipments and methods.

In the Army most equipment is purchased outside of Canada, generally in the US, while training and organizations have tended to follow the British Army. While individual training standards have been maintained, attitudes towards the use of sophisticated simulation have been rather conservative until fairly recently, when, with the acquisition of the Leopard Tank, trainers became more aware of the potential offered by simulation. This, plus the high ammunition costs along with large personnel turnovers have given those responsible for training the desire to seek out new and innovative approaches for maintaining the high standard for which the Canadian soldier is renowned.

While we have a small Armed Forces, our current inventory of simulators is worth about $200 million and if tentative plans are approved the value of that inventory will exceed one billion dollars by the end of this decade. To give you an idea of what we have and our plans for the near future let me run through some examples.

COMPUTER ASSISTED LEARNING (CAL)

In co-operation with the National Research Council of Canada the Canadian Forces is engaged in a five-year R&D project to experiment with Computer Assisted Learning with a view to large-scale implementation in our training system. NRC has, in conjunction with this, developed a high level, second generation courseware Authoring Language known as NATAL, National Author Language. This common instructional language is easily adaptable, transportable, flexible, bilingual and is machine independent. Most important it is easy to use and trials have confirmed that instructors without previous ADP experience can program courseware within two weeks. The CAL project will investigate a number of potential uses, for example; substantial savings may be expected in the number of operational equipments required for training purposes.

NAVY

Navy Bridge Trainer

Installed at Esquimalt (near Victoria, B.C.) in 1980, this British designed (SOLARTRON) simulator effectively teaches junior officers in ship handling techniques, use of radar, voice procedure and bridgemanship leading to watch keeping certification. It has a digital coastline radar simulation and most significantly teaches the handling of ships in close company and collision avoidance under various weather and sea states as well as navigation under zero visibility conditions. Needless to say we dare not afford to let junior officers thrash around congested and hazardous waters trying their hand at ramming, colliding and running aground, normally the prerogative of senior officers. A positive benefit of this trainer is the greatly reduced time it takes to reach watch keeping certificate standards. In addition, we believe that it will prove to be effective in improving confidence and morale of junior Naval officers.

The Action Speed Tactical Trainer

Just installed this summer at our Maritime Warfare School in Halifax, this trainer, designed and manufactured by Ferranti Digital Systems UK, employs state-of-the-art simulation and displays to provide tactical scenarios for exercising surface, sub-surface and aircraft under various Naval combat conditions. Its purpose is to practise maritime officers in tactical decision-making. Capabilities include the full complement of modern sensors and weapons systems with the capability to accommodate future developments. This trainer permits the training of officers to cope with the multi-threat environment as well as the development and evaluation of new tactics. It also provides a depth of experience that could not be achieved in other than a synthetic environment. In addition to these recent acquisitions we have in service on both coasts a wide range of sonar, EW, radar, blind pilotage and operations trainers, most of which are out of date.

We are about to start a complete modernization program of all Navy combat procedures training facilities. Already identified are an advanced Command Team Trainer, a basic Command Team Refresher Trainer, two Tactical Data System Trainers, two Sonar Trainers, and an EW Trainer. Yet to be defined are a series of trainers in support of the new Canadian patrol frigate. In addition, there is a program to refurbish the entire spectrum of training aids and devices currently in the Navy inventory.

ARMY

Observed Fire Simulators

We recently installed six Invertron, UK designed artillery Observed Fire Simulators. It is a second generation simulator that has proven to be extremely effective in training indirect fire observers. Users are very positive about its value and during the first year of use at the Artillery School in Gagetown, New Brunswick, ammunition savings of $1.3M were made.

Leopard Tank Training Devices

With the acquisition of the Leopard Tank, trainers began to realize the importance of cost effective modern training devices. Currently we have:

1. Drivers Instructional Cab (German);
2. Turret Classroom Instructional Models; and
3. TALAFIT (Tank, Laying, Aiming and Firing Trainer) (Belgium).

We are in the process of improving the armoured training system to include gunnery crew simulators, tactical simulators and driver simulators. One concept is the TICS (Turret Interaction Crew Simulator). This is similar to the UCOFT (Unit Conduct of Fire Trainer for the US Battle Tank M1).

Staff Training Tactical Simulator

Although no acquisition project is currently underway for an Army Staff Tactical Training Simulator, we have completed development of a system that economically solves the displayed map, line of sight and movement problems on an automated battle board. We are now in a position where we can build on this capability to provide automated command and staff training from unit to corps level.

AIR FORCE

Long Range Patrol Aircraft - CP 140 Aurora

By combining the better features of the USN P3 and S3 trainers along with our own ideas utilizing the state-of-the-art, we have produced a package that has proven to entirely satisfy our training requirements. Trainers include:

1. The Flight Deck Simulator, designed and manufactured by CAE Industries;
2. The Operational Mission Simulator; and
3. The Integrated Avionics Trainer, and six other part task trainers

which represent major sub systems for maintenance training purposes.

These trainers/simulators have been in service for one year and both trainers and trainees are extremely enthusiastic.

CC130 Hercules

Approved for procurement is an up-to-date CC130 Operational Flight Trainer which will include a state-of-the-art digital computer generated visual system. As well, we are in the process of replacing six analogue basic jet trainer simulators with state-of-the-art visual computer generated systems. We are also preparing the documentation necessary for approval to procure a tactical helicopter simulator.

Sea King Helicopter

We have completed the replacement of the analogue tactics portion of the Sea King Helicopter and are in the process of similarly replacing the analogue flight and engine simulators with state-of-the-art systems and will be procuring entirely new simulators when the Sea King is replaced.

CF18 Hornet

In support of the new CF18 aircraft we have a contract with CAE Ltd for two Operations and Flight Tactic (OFTT) trainers which include state-of-the-art computer generated systems and a weapons systems trainer in which the basic OFTT will be augmented by the latest air combat manoeuvring systems. In addition, the project includes the procurement of two HOTAS (Hands on Throttle and Stick) trainer, a kit of maintenance trainers and a host of Computer Assisted Learning (CAL) stations.

E3A AWAC

DND in conjunction with Canadian Industry has been responsible for the design, development and manufacture of an E3A (AWAC's) Operational Flight Trainer and this trainer is in the final stages of acceptance testing; to be installed in Germany for NATO AWAC's aircrews.

CONCLUSION

As you can see the Canadian Armed Forces is dedicated to the philosophy of simulation as a means of improving training while creating a hedge against rising training costs and energy conservation.

In return for the generous way you have shared information with us and in hosting many visitors at your various training establishments, I would like to extend a warm invitation to you to visit any of our training bases and see any of these, or other training devices in operation. We of course would welcome any joint development suggestions and perhaps at some time should consider some sort of body where matters related to training development/simulation, etc, can be mutually shared.

ABOUT THE AUTHOR

Commodore Gordon L. Edwards, a Naval Officer, is currently serving at National Defence Headquarters as the Director General Military Plans and Operations. His main responsibility includes the development and implementation of Canadian National and International military plans.

THE NATIONAL TRAINING CENTER
A TOTAL EXPERIENCE TRAINING CENTER

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This paper has been prepared with the cooperation, assistance and concurrence of the National Training Center TRADOC System Manager's Office, Headquarters, U.S. Army Training and Doctrine Command, Fort Monroe, Virginia.

ABSTRACT

Now more than ever the U.S. Army must be prepared to survive and win in battle. This paper discusses this necessity and how the Army is meeting this need by the development of the National Training Center. An overview is presented on the training, evaluation, and control concepts of the National training Center and how these concepts have been implemented by the NTC Instrumentation System.

BACKGROUND

The Need - The Necessity To Be Ready To Win

"The Army's primary objective is to win the land battle - to fight and win in battles large or small, against whatever foe, wherever we may be sent to war..." "We must assume the enemy we face will possess weapons generally as effective as our own. And we must calculate that he will have them in greater numbers than we will be able to deploy, at least in the opening stages of a conflict." "...We can expect very high losses to occur in short periods of time. Entire forces could be destroyed quickly if they are improperly employed."*

In order to accomplish its objective, the U.S. Army must train in peacetime as it will fight in war. Terrain utilization and and weapons employment are skills that the Army's leaders must have honed to perfection through training. Maneuver and support units must be able to move, emplace and shoot quickly. Night operations must be as familiar as day operations. All units must be able to survive and accomplish their missions in the hostile nuclear, biological and chemical environments as well as that of electronic warfare. Only through peacetime training can these skills be acquired so that the confidence to deal with the heightened challenges of war may be developed.

The Army has structured its training to meet this challenge. The ARTEP provides a collective training program for experiential training based on a TRAIN-EVALUATE-TRAIN model. Yet virtually everywhere it is stationed, the U.S. Army is hard pressed to provide complete resources for such training. Modern weapon systems have changed the tempo, lethality and size of battle areas. The same land area which was once ample for training divisions is now inadequate for exercising brigades. As Army units train for war maneuver areas which are now too small constrain the realism of their training. Manning of a realistic opposing force and an effective control and assessment structure is, for battalion level exercises, beyond typical resources.

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*Operations FM 100-5 (Washington, DC, HQDA, 1 July 1976) p. 1-1

Civilian communities adjacent to installations limit the Army's ability to fully utilize electronic warfare and close air support consistent with a realistic battlefield environment.

The foregoing realities and technological advances have laid the foundation for conducting realistic large unit training in a cost-effective manner to help meet the current and future Army training needs.

Historically, as combat units first take up their role in a war, the losses of those units have been very high, compared to the losses the same units suffer later in combat. Intuitively one would expect a combat-experienced soldier or unit to suffer fewer casualties and to be more effective than those without such experience. Certainly, officers and men of all services can look back at their participation in World War II, Korea, and Viet Nam to find validation for such intuition. Moreover, the statistics of units in those wars bear out the conclusion that combat experience improves both the survivability and the performance of units.

Over the years, many attempts have been made to realistically duplicate the combat experience during training when the cost of learning is measured in dollars rather than in lives. Infiltration courses with live machine gun fire only a few feet above the ground and the use of live artillery fires, live close air support and naval gunfire during exercises have been employed.

No training can completely capture the danger - and the associated fear - that is generated by real combat. However, each of the techniques used in the past has been intended to provide some part of the sounds and feel of combat so that in the future, the soldier, sailor, or airman entering combat would not find it completely new and foreign to him.

A major contribution to the technological advancement of training has been the Air Force RED FLAG activity at Nellis Air Force Base. Here the combination of carefully trained and equipped "enemy" aircraft, a highly sophisticated and instrumented airspace, and the ability to capture and replay the aerial combat for the participants has created the type of experiential learning that can approximate air-to-air combat and increase the capability of U.S. pilots to survive and be successful in the early phases of combat.

The Army at the Training and Doctrine Command Combined Arms Test Activity, Combat Developments Experimentation Center, and other test ranges has used modern simulation technology to attempt to create realistic combat conditions, not with the goal of training personnel and units but of testing concepts and equipment under conditions as near combat as possible. These agencies have taken advantage of the capabilities of the laser, the computer, radar and other technologies to reach levels of accuracy and realism that had not before been possible. These tests, however, were designed primarily to provide the realism for the equipment or mechanical function and were limited to small units. The training for combat survival of the individuals involved during these experiments has been of secondary importance.

The Army is now using laser simulations for direct fire weapons to increase the realism in training. For the first time, opposing forces can realistically engage each other in mock combat, inflicting simulated casualties and damage as a direct result of the engagement and not from the use of slow and arbitrary means (i.e., judgemental decisions by umpires).

How NTC Meets The Need

In a statement before the House Appropriations Committee, General Rogers, former Army Chief of Staff, made the point that "the worst thing that can happen is for a soldier and a unit to find themselves on a battlefield, fighting in anger for the first time and never to have experienced anything like it before."

Recognizing the increasing inadequacy of training facilities, the Secretary of the Army and the Chief of Staff stated in their 1978 joint posture statement to Congress that:

> "The Army foresees one or more National Training Centers, large military reservations which can support the kind of combined arms training needed to ready the total Army for battle in Europe."

The National Training Center (NTC) is a facility where highly realistic, comprehensive and intensified training will be conducted. Troops will be transported to this facility periodically to become proficient in critical tasks that cannot be accomplished at home stations. Since combat conditions are duplicated with great fidelity at the NTC, it can also be used as a combat proving ground. Battle realism, evaluation and feedback in this environment require engagement measurement and monitoring and control instrumentation coupled with data processing and display capabilities to provide objective assessments and analyses of unit performance with sufficient detail and timeliness to ensure maximum learning. A beneficial by-product of such instrumentation is the ability to answer critical questions of aggregate force readiness trends and effectiveness of doctrine, organizations, equipment and training techniques.

The NTC, with its mixture of various forms of instrumentation and simulations, and with its ability to capture data for later use, offers a training environment that closely resembles real combat while concommitantly providing the ability to rapidly analyze the events that occur during the exercise, to evaluate the general state of a unit's training, to assess their deficiencies and to provide in-depth near-real-time feedback.

It is this concept of using modern technology available to train units by creating a near combat environment that makes the NTC unique. The NTC concept is to train so realistically that the soldier's reactions to combat are learned so well he will act intuitively and decisively in real combat. This process, known as experiential learning, is the goal of the NTC.

The Training and Doctrine Command, in its analysis of the NTC training environment, has developed an array of seven significant training elements to be stressed in the NTC development:

- Battalion Task Force (BnTF). A combined arms team with a staff and a critical task of coordinating combat power on the battlefield.
- Opposing Force (OPFOR). A dedicated unit, sized and equipped to operate against the BnTF in realistic numbers, using Soviet tactics and signatures and operating as part of the control force to ensure proper balance in combat operations. This OPFOR must think and act like Soviets, including less concern for casualties and more for results.
- Electronic Warfare (EW). The use of jammers against U.S. communications and electromagnetic devices in a manner expected of the Soviets in Europe.
- Close Air Support (CAS). The opportunity to plan and execute joint air-ground operations.
- Live Fire (LF). An imaginative use of portable, instrumented targets to provide a realistic threat, both offensively and defensively, to the BnTF under conditions that permit the BnTF to coordinate and control live fires.
- Weapon Engagement Simulation (ES). The use of lasers and computers to simulate fires on the battlefield, including a realistic and believable assessment of casualties.
- Instrumentation. The use of sensors, computers, and data communications to tie together the whole NTC activity and to capture that activity in a manner which permits effective training feedback and assessment.

Together, these elements provide a training environment where Army maneuver battalions can undertake essential combined arms training which cannot be accomplished at home station due to physical limitations and the prohibitive cost for providing an NTC type environment. In addition to this training role, the NTC also provides an environment to gather data about simulated battlefield performance and the effectiveness of U.S. Army organizations, doctrine, procedures, tactics and weapon systems under realistic simulated combat conditions.

NTC PHASE I CONCEPT - AN OVERVIEW

The National Training Center (NTC) is being implemented in Phases of which Phases I and II have been defined. Phase I, when implemented, will provide a place where Army units can undertake essential combined arms training that cannot be done at home stations because of limitations, or the prohibitive total cost of providing a NTC Phase I type environment at all or selected division installations.

The Training Environment and Concept of NTC

The elements of the training environment for the NTC Phase I include:

- Battalion Task Force (BnTF). The basic building block of mounted warfare is and will be the cross-reinforced tank or mechanized company team or battalion task force. After corps and division commanders have set in motion the necessary concentration of power, they must turn over the immediate direction of the battle to brigade and battalion commanders. The brigade and battalion commanders then must fit the forces to the ground, maneuver against the enemy as the battle develops, and coordinate the concentration of firepower. The battalion task force will be the element that the NTC training environment is designed to train as the initial goals of Phase I. Initially, one battalion engagement exercise will be conducted at a time. Later in Phase I, expanded instrumentation capabilities will allow two simultaneous battalion level exercises.

- Opposing Force (OPFOR). A realistic "enemy" force will be provided by a dedicated unit, sized to achieve force ratios of at least 3 to 1 against a U.S. battalion during defense missions. The OPFOR will use Soviet tactics and signatures, with the vehicles and weapons capabilities of Soviet type motorized rifle regiment replicated. The OPFOR will consist of approximately 1000 men and 230 tracked vehicles equipped with silhouette replicas (VISMOD kits).

- Electronic Warfare (EW). Jammers will replicate ground based threat communication jammers, capable of 1.5 kW operations, on a narrow electromagnetic band targeted against those communications nets found in battalion and brigade. Additional equipment, to be supplied by the Air Force, will duplicate a representative air defense threat in the vicinity of the FEBA.

- Close Air Support (CAS). This will be provided from George AFB and RED FLAG operations at Nellis AFB. It may also encompass Marine and Navy air support from Twenty Nine Palms or China Lake. This NTC Phase I will offer opportunities to practice the joint planning necessary for air-ground operations at the battalion task force level with a real-time casualty assessment system supported by instrumentation.

- Live Fire (LF). This will be conducted at realistic engagement ranges and target arrays, with all elements of direct and indirect fire integrated. Minimum restrictions commensurate with safety will be applied. Targets will be portable and have sufficient instrumentation to provide input for after action review. Targets will respond to live fire hits or laser fire from DRAGONS and TOWS.

- Engagement Simulation (ES). The MILES system will be used down to individual weapon level. Engagement simulation data provided by MILES will be reported by telemetry on selected weapons.

- **Instrumentation**. The NTC instrumentation components include time-space position location, key event recording, voice and video recording, and appropriate analysis and playback facilities.

Training at the NTC Phase I will be based upon the TRAIN-EVALUATE-TRAIN model with detailed feedback after each mission and a final diagnostic After-Action-Review (AAR) and Take-Home-Package to serve as a basis to guide subsequent home station training programs. The training will focus on improving performance in the five levels of activity within the battalion task force: execution, control, coordination, support and planning.

The NTC Phase I training should be viewed as an extension of and building on home station training with heightened realism in battlefield conditions and objective standards. The NTC Phase I will concentrate on minimum constraint operations at the combined arms task force level and will provide command and staff exercise opportunities at the brigade level.

The NTC training scenarios will be tailored for each unit based on:

- Current status of collective training - proficiency based on ARTEP,
- Resources at home station,
- Contingency plans,
- Training goals, and
- Task organization.

The training experience will be based upon a European analogue. Units will exercise emergency deployment plans; move to and draw POMCUS-like prepositioned equipment; deploy to field positions similar to European defense plans; and execute scenarios of appropriate tactical missions. By 1984 brigade headquarters will be responsible for battle management of a mix of one real and up to two notional battalions. Battalion commanders and their staffs will be exercised in a realistic command environment using CPX role-playing techniques similar to those used in the Combined Arms Tactical Training Simulator (CATTS). Each CONUS armor/mechanized battalion commander and staff will then train at Fort Irwin twice each 18-month period, once without troops on the notional battle facility, and once with the entire battalion.

Evaluation Concept

The evaluation function of the TRAIN-EVALUATE-TRAIN model at the NTC Phase I will concentrate on the phases of the command and control process at the battalion task force level: collection of information, planning, issuing orders, assessing and supervising the progress of operations.

At the NTC Phase I, the primary target of evaluation and corrective training will be the battalion's ability to orchestrate the application of its combat power. A Take-Home-Package for home station training will provide the opportunity for review and remedial training. The evaluation concept is designed to provide:

- An increase in proficiency of battalion combined arms teams as they execute a series of missions.
- A comprehensive assessment of unit training to serve as a basis for subsequent home station training.

The evaluation concept will be based on a determination of what should be collected and measured; what will be the information feedback levels, critique audiences and frequency; and what the evaluation packages are used for.

Instrumentation and Control Concept

The instrumentation and control system has been designed to support the objectives outlined in the training and evaluation concepts. The system will collect and report data during performance of unit tasks; enhance overall realism and control of the exercise; record and process collected data, and provide computer generated imagery or graphic displays for assessment and control of the exercise. Data collection and processing will be objective and primarily based upon instrumentation. Some actions within the levels of activity upon which the training and evaluation will be focused are not suitable for direct instrumented collection. These shall be collected and processed relying on controllers. The instrumentation system will, however, be structured to support and expedite these controller inputs.

The design of the instrumentation system and the mix of instrumented and controller functions will be based on the system's ability to support the TRAIN-EVALUATE-TRAIN model. The analysis of the evaluation/instrumentation system's ability to support the NTC Phase I will be built around four basic issues:

- What should be collected and measured?
- What can be collected and measured and at what level?
- What are the methods and frequency of feedback presentation?
- What will the data be used for?

The instrumentation system, collection methods and playback techniques are described in the NTC Development Plan published by the Army Training and Doctrine Command.

The Training Mission and Its Implementation

The unique aspect of a National Training Center (NTC) is the total emersion of a battalion task force in a realistic battle environment. The NTC training will be as realistic as technology and safety will permit. Equally important, an instrumented NTC will allow the transparent collection of hard analytical data from which objective battlefield performance effectiveness can be derived.

Training Objectives

The NTC training objectives are designed to fill the gap between home stations unit training and combat. They are intended to serve as a basis for NTC training and evaluations. These specific objectives are:

- Increase the proficiency of brigade and battalion commanders and staffs to plan and exercise command and control of their forces while executing combined arms tactical missions in a realistic threat environment.

- Increase the proficiency of brigade and battalion task forces to coordinate and apply all types of fire and terrain modification to increase force effectiveness and decrease unit vulnerability.

- Increase the proficiency of the battalion task force to employ and coordinate organic and supporting direct and indirect fires, combat support and combat service support systems against a realistic opposing force in a free play exercise.

- Increase the tactical proficiency of the maneuver elements and leaders within a battalion task force in the conduct of their combat missions in a realistic hostile environment, to include: (1) use of tactics, terrain and terrain modification to maximize combat power at critical times and places; (2) employ unit gunnery skills in conjunction with supporting direct and indirect fires in a near-real-combat environment to acquire and service targets representative of an appropriate threat force at realistic ranges and dispersion; (3) increase soldier and leader confidence in their proficiency of maneuvering company team and higher units in close proximity to live fire; (4) exercise EW and NBC counter measures necessary to survive and function on a "dirty" battlefield; and (5) integrate air cavalry and attack helicopters into the scheme of maneuver and to perfect the control and coordination techniques unique to those resources.

- Create an opportunity for brigades and battalions to plan and execute realistic combat service support operations.

In addition to the training objectives discussed above, the NTC will also meet the following evaluation objectives:

- Provide a measure of the increase in combat effectiveness of all elements of combined arms task forces achieved during training at the NTC.
- Provide real-time player feedback which makes possible the compilation of an accurate objective record of tactical performance that can be used in After-Action-Reviews (AARs) for all levels during the NTC training period and after units return to home station.
- Assist in the evaluation of present tactical doctrine, tables of organization and equipment, and training doctrine at the brigade and battalion level.

Units trained at the National Training Center (NTC) will be required to perform a large number of defensive and offensive tactical missions. These tactical missions are listed below.

- Movement to contact
- Hasty attack
- Deliberate attack
- Defend in sector
- Defend from a battle area
- Hasty defense
- Delay in sector
- Disengagement
- Counterattack
- Defend a battle position
- Deliberate defense
- Reconnaissance and security
- Create and defend a strong point

A series of tactical mission analyses and support packages will be prepared for each of the above missions and will be used to conduct and control the exercises.

NTC PHASE II - PRELIMINARY OVERVIEW

Building on the experiences of Phase I it is anticipated that Phase II will move beyond Phase I as the state of the art in training and instrumentation moves to meet the NTC requirements. It is expected that Phase II will include:

- Increase in the number of player units that can be monitored and controlled.
- Upgrading of the MILES system to include new weapons and target acquisition capabilities.
- Improved techniques and instrumentation to address indirect fire, air defense and U.S. Air Force close air support simulation.
- Improved After-Action-Review (AAR) techniques to include development of special presentation methods.

Similar to Phase I, NTC Phase II will provide an order of magnitude increase in the proficiency of the Army's tactical forces through effective and realistic training. It will provide the experiential base which will allow our forces to fight outnumbered and win the first and subsequent battles of any conflict.

NTC INSTRUMENTATION SYSTEM OVERVIEW

Key Requirements - The Design Drivers

Out of the NTC training concept which drove the evolving structure of the NTC Instrumentation System a number of imperative requirements became the bases for the hardware and software designs:

- Future growth must be supported without causing significant redesign and recoding of software;
- Instrumentation must be as transparent as possible;
- The historical data collected must be capable of being recalled and portions selected by training analysts during the course of the exercise for subsequent After-Action-Review (AAR) presentations;
- Instrumented data collection must be supplemented with voice recordings of radio nets, video picture input from the exercise area, and field/observer controller inputs, and
- Technical, schedule and cost risks will be minimized.

System Description

In order to minimize interface complexity, and correspondingly reduce technical risks, a system architecture has been synthesized that consists of three major subsystems: (1) Core Instrumentation Subsystem (CIS), (2) Range Data Measurement Subsystem (RDMS), and (3) Range Monitoring and Control Subsystem (RMCS). This system architecture is presented in Figure 1 along with the allocation of functional areas to all subsystem components (Figures 1A-1C).

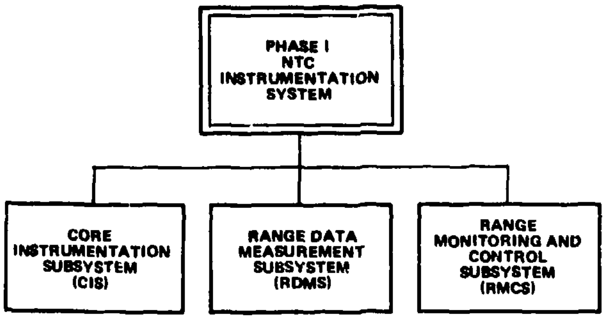


FIGURE 1 NTC PHASE I INSTRUMENTATION ARCHITECTURE

Range Data Measurement Subsystem (RDMS)

The RDMS provides real-time position location and engagement event data on all instrumented players in the Engagement Simulation (ES) and Live Fire (LF) exercises. As shown in Figure 1A, the RDMS is composed of three major components: (1) Tracking and Communication Component (TCC), (2) Computational Component (CC), and (3) Player Unit Component (PUC). The RDMS Player Unit Component includes the Transponder Component (TC) and the Weapon Engagement Simulation Component (WESC) which is the Army's MILES system.

The remote, unmanned Central Station (CS) within the TCC selects the transmission path to Player Units (PUs), provides a two way digital data link to Player Units (PUs) and collects range data. Event messages and slant range data received by the Central Station (CS) are time tagged then relayed to the CC. The CC computes PU position, decodes event data for validity and transmits the position and event data to the Core Instrumentation Subsystem (CIS). Commands from the CIS are relayed to the player unit through the CC and TCC.

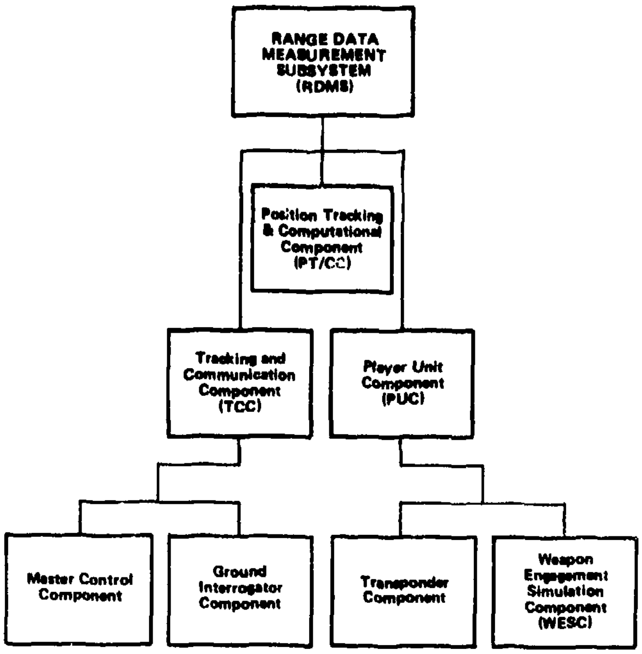


FIGURE 1A RANGE DATA MEASUREMENT SUBSYSTEM (RDMS) SYSTEM ARCHITECTURE

The Tracking and Communications Component (TCC) consists of a number of Micro A and Micro A/D stations located at known surveyed points. The Micro A and Micro A/D stations measure range to the selected player unit and in addition provide a digital data link between the Central Station and the Player Unit. The Micro A/D station acts as a relay to Micro A stations that are not in radio line of sight of the Central Station. The system remains in a quiescent state until a command from the Central Station triggers a ranging interrogation command.

A Player Unit (PU) includes a discretely addressable Micro B unit that serves as a range transponder and communications link. Additionally, a PU contains an Input/Output (I/O) device, and a Transponder Component (TC), attached to a Weapon Engagement Simulation Component (WESC) unit. A PU can receive and store engagement messages from the I/O and TC/WESC, and transmit the data to the CS upon TCC request. Initial operational capability will be 125 player units with expansion to 500 player units occurring later in Phase I.

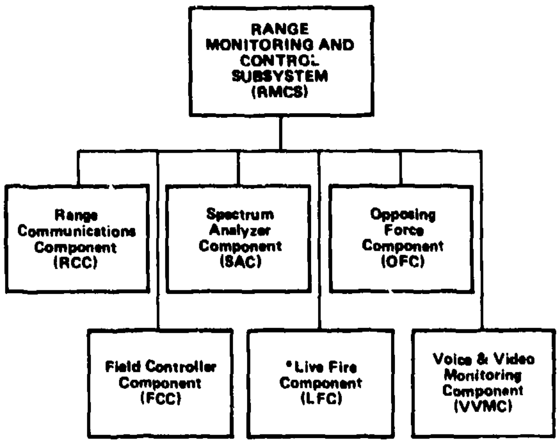
The Weapon Engagement Simulation Component (WESC) simulates direct fire weapons effects in support of a free play engagement simulation between battalion TF OPFOR elements. Functions performed by WESC include: simulation of direct weapon firing cues, computation of direct fire casualty and damage, implementation of direct fire effects, generation of firing and weapon effect engagement events and hand-off of this data to the I/O through TC for ultimate transmission to the CIS.

The Computational Component (CC) consists of a multiple-CPU processor and software necessary to compute PU Position Location (PL) data. Initial loading and realtime operations control of the TCC remote, unmanned Central Station (CS) is accomplished by the CC.

Range Monitoring and Control Subsystem (RMCS)

The RMCS provides the means to monitor and control all activities on the NTC Engagement Simulation (ES) and Live Fire (LF) ranges. These capabilities include automated and human sensors and a backbone communications component to tie these sensors together and connect them with the CIS.

As shown in Figure 1B, the RMCS consists of six major components: (1) Range Communications Component (RCC), (2) Spectrum Analyzer Component (SAC), (3) Live Fire Component (LFC), (4) Voice and Video Monitoring Component (VVMC), (5) Field Controller Component (FCC), and (6) Opposing Force Component (OFC).



*Growth Option

FIGURE 1B RANGE MONITORING AND CONTROL SUBSYSTEM (RMCS) SYSTEM ARCHITECTURE

The Range Communications Component (RCC) provides voice, digital and video communications between RMCS components and the CIS. Specifically, voice communications are provided between the CIS operators and their counterparts in the VVMC, FTFC, FCC and OFC components. Digital communications are provided between the IDCC in the CIS and the SAC and LFC components. Video communications are provided between the IDCC and VVCEC components in the CIS and the VVMC and FTFC components.

The Spectrum Analyzer Component (SAC) provides the means to measure, record and transmit all relevant NTC EM emissions which may interfere with other NTC or non-NTC (i.e., GOLDSTONE) operations. The SAC, under control from the CIS, will continuously monitor an assigned frequency range at an assigned rate. Whenever an emission is detected which exceeds a threshold value set by the CIS, the SAC will report this occurrence (time, frequency and value) to the CIS.

The Live Fire Component (LFC) provides a realistic, simulated, combat environment for NTC Live Fire exercises. Specifically, the LFC simulates a dynamic OPFOR target array and engagement scenario; generates live fire effects cues from the OPFOR; scores and records live fire results (events); and transmits all live fire event data to the CIS.

The Voice and Video Monitoring Component (VVMC) provides both fixed and mobile video recording elements to record key engagement simulation and live fire events. The unmanned fixed video element will be controlled directly from the VVCEC within the CIS. Mobile video teams will be directed from the VVCEC component within the CIS in response to missions assigned by EMC or TAF operators.

The Field Controller Component (FCC) provides nonintrusive observation of the battalion TF during both Engagement Simulation (ES) and Live Fire (LF) exercises. Specific functions performed by the FCC include: enforcement of the rules of engagement; assessment of indirect fire casualties; implementation of indirect fire weapon effects cues (fire marking); assuring range safety and the recording and communication of battalion TF activities based on human observations. This component will be manned by Army personnel.

The Opposing Force Component (OFC) simulates the opposing force in the free play Engagement Simulation (ES) between the battalion TF and the OPFOR. Specific functions performed by OFC include: the simulation of all OPFOR operations (C^3, maneuver, fire, administration, log, etc.); the observation of battalion TF activities and the communication of these observations to the CIS personnel; and execution of CIS specified OPFOR scenarios to achieve the desired training missions and goals. This component is also manned by Army personnel.

Core Instrumentation Subsystem (CIS)

The CIS provides all real-time data processing and interactive display capabilities needed to monitor, command, and control all NTC Engagement Simulation (ES) and Live Fire (LF) exercise activities. The CIS also provides data processing, interactive display, voice and video editing and training material production capabilities needed to synthesize and present near-real-time After-Action-Reviews (AARs), both in the field and in the CIS AAR theater, and to produce take-home training packages. Finally, the CIS provides the data processing and interactive display capabilities required to support Training Developments (TD) and Combat Developments (CD) research at the NTC.

As shown in Figure 1C, the CIS consists of six major components: (1) Digital Interface Component (DIC), (2) Computational Component (CC), (3) Interactive Display and Control Component (IDCC), (4) Voice/Video Control and Editing Component (VVCEC), (5) Field Training Feedback Component (FTFC), and (6) the Environmental Protection Shelter (EPS). The IDCC is further decomposed into four major functional elements: (1) Exercise Monitoring and Control (EMC), (2) Training Analysis and Feedback (TAF), (3) Command Battle Simulation (CBS) and (4) Experimental Test Bed (ETB).

The Digital Interface Component (DIC) provides the single input/output (I/O) interface for all digital data communications between the CIS and the RDMS and RMCS subsystems, respectively. The DIC implements digital communications protocol between the CIS and external subsystems. It reformats and provides data buffering for all CIS digital I/O. In short, the DIC centralizes all digital I/O data communications for the CIS and preprocesses these data to transform them into the proper format required by the CIS. The DIC performs a similar function for data output from the CIS to the RDMS and RMCS subsystems.

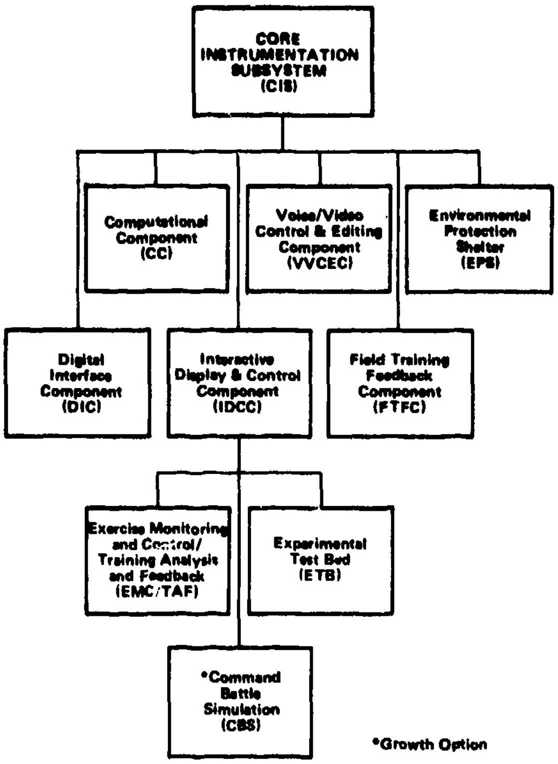


FIGURE 1C CORE INSTRUMENTATION SUBSYSTEM (CIS) ARCHITECTURE

The Computational Component (CC) performs the mainline computation in support of all CIS exercise monitoring, command, control, and training feedback activities. Specific computational processing performed by the CC include: (1) state estimation for all instrumented players in the exercise, (2) real-time casualty assessment for all direct and indirect fire weapon engagements (those not performed or only partially performed by the WESC), (3) real-time statistical analyses to provide training assessment, (4) spectrum management analyses, and (5) range operations analyses.

The Interactive Display and Control Component (IDCC) provides the real-time interactive data display and control facilities required for CIS controllers to direct all aspects of the NTC training exercise and provides near real-time training data feedback. Specifically, the IDCC provides a digital background map, selectable tactical symbology, engagement event data, statistical performance data, and function key, keyboard and interactive menus to interactively control all aspects of the CIS subsystem. As shown in Figure 1C, the IDCC implements the CIS display and interactive control operations of: Exercise Monitoring and Control (EMC), Training Analysis and Feedback (TAF), Command Battle Simulation (CBS) and Experimental Test Bed (ETB).

The Voice/Video Control and Editing Component (VVCEC) provides all facilities needed to record, archive, edit and replay relevant voice and video data obtained by monitoring battalion TF and OPFOR field operations. Specifically, the VVCEC provides the means to record, edit, and replay BLUEFOR tactical communications. It also provides an interactive software system to assist tactical communications monitors to manually input key COMMO event data. Finally, the VVCEC provides similar recording, editing and replay facilities for all video data collected in the field by a fixed video camera remotely controlled from the CIS and by five mobile video cameras operated by the field video teams directed from within the CIS.

The Field Training Feedback Component (FTFC) provides a self-contained mobile display capability to present field After-Action-Reviews (AARs). The FTFC will provide display capabilities similar to those available within the CIS AAR theater including a large screen display and color monitors. The FTFC display will be generated using TAF capabilities in the CIS under the direction of the field AAR director using voice communications provided by the Range Communications Component (RCC) within the RMCS.

The Environmental Protection Shelter (EPS) provides the operational environment for all CIS personnel and equipment. Specifically, the EPS provides physical security, conditioned power, light, air conditioning and operational and maintenance facilities, equipment and supplies.

Subsystem Interfaces

As discussed the NTC Instrumentation System (NTC-IS) has been divided into three major subsystems (CIS, RDMS, and RMCS) with functions allocated to each subsystem to assure that the functional and physical interfaces between them are simple and straightforward. The system interface diagram for the NTC Instrumentation System (NTC-IS) is presented in Figure 2. As shown, data generally flows from the RDMS and RMCS into the CIS where it is processed and displayed for decision making. Control, on the other hand, tends to flow from the CIS to the two other subsystems (RDMS and RMCS).

Notice that all digital data interfaces are implemented by the Digital Interface Component (DIC) within the CIS. In this design, the DIC provides all hardware and software capabilities to assure data and physical compatability between subsystems. That is, the DIC performs all electronic signal and data transformations required to implement the needed interface thereby decoupling all other data processing functions internal to the respective subsystems. This design approach has provided the flexibility required to carry on development of each of the subsystems in parallel and also provide for future growth.

The digital interface between the RDMS and CIS has been successfully demonstrated during the NTC I-ALPHA Test where the General Dynamics Electronics RMS II and Xerox WESC systems were used to implement the RDMS. Because of this, all data formats are clearly defined (based on well known RDMS capabilities) and the physical interface can be implemented using standard off-the-shelf inter-computer communications equipments similar to those used in I-ALPHA.

CORE INSTRUMENTATION SUBSYSTEM OPERATIONS OVERVIEW

The CIS functions as the NTC Exercise Operations Center during an exercise. Therefore, an operational overview is useful in gaining an understanding of how the engagement will be monitored and controlled.

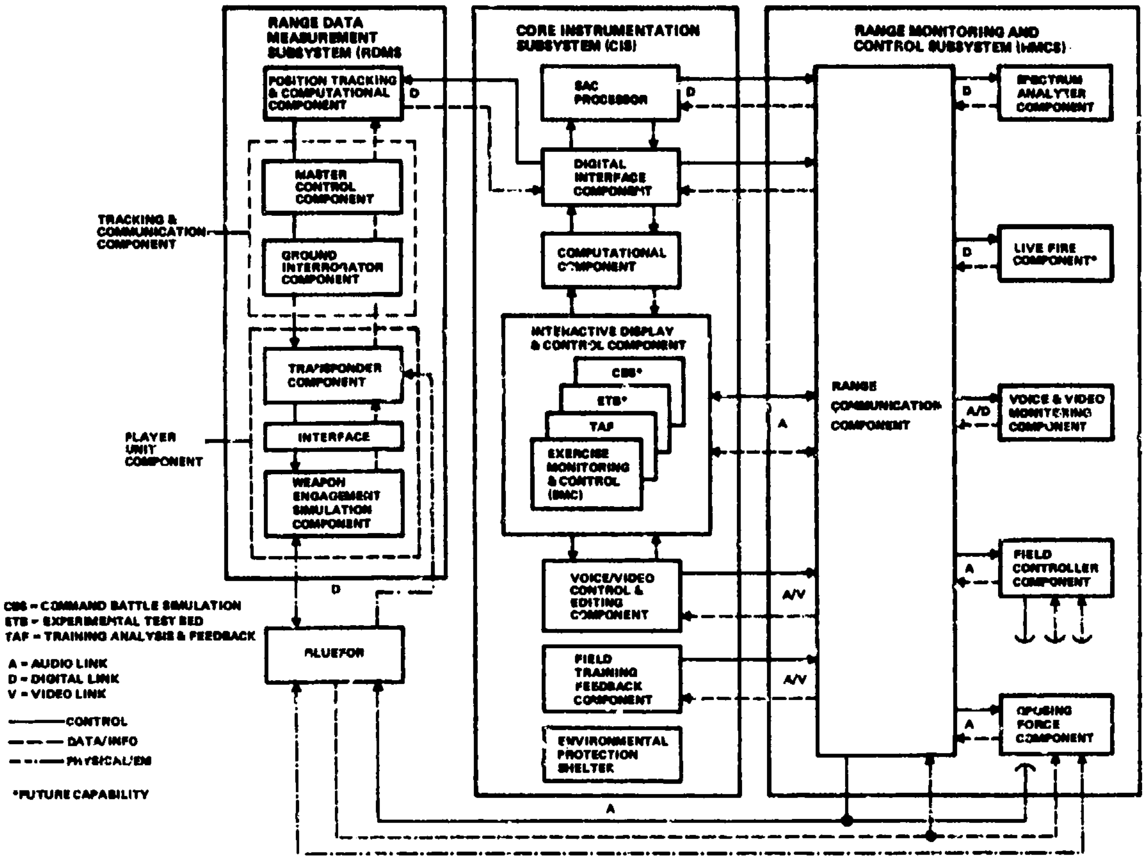


FIGURE 2 NTC INSTRUMENTATION SYSTEM INTERFACES

The heart of CIS operations are the functions performed within Exercise Monitoring and Control (EMC) and Training Analysis and Feedback (TAF). It is therefore useful to explore the functions of the EMC/TAF controller stations and the activities performed within the EMC/TAF Operations Center.

As shown in Figure 3 the EMC/TAF Operations Center is located in the Environmental Protection Shelter (EPS) where the data from the Range Data Measurement Subsystem (RDMS) and the voice radio and video inputs interface with the CIS.

EMC/TAF Operations Center Layout

Figure 4 presents the layout of the operator stations within the EMC/TAF Operations Center. As indicated, there are eight operator stations, each assigned unique functional responsibilities.

STATION 1: TAF OPERATIONS

Operators at this station are allocated the responsibility to analyze exercise data to extract important training feedback data in order to meet the training objectives specified for each exercise segment. The Training Analysis and Feedback Officer (TAFO) and his assistants structure an After-ActionReview (AAR) and build material to fill out this AAR structure during an ongoing exercise segment.

STATIONS 2, 3, and 4: COMPANY OPERATIONS

Operators at these stations are allocated the responsibility to monitor and analyze the activites of each of the three BLUEFOR line companies and their subordinate platoons.

STATION 5: EXERCISE OPERATIONS

Operators at this station are allocated the responsiblity to monitor and control the training environment. These responsibilities include directing the Field Observer/Controllers (FOC), fire marker teams and monitoring the status of the NTC-IS instrumentation hardware and software.

AAR - After-Action Review
A/V - Audio/Visual
CBS - Command Battle Simulation
EMC/TAF - Exercise Monitoring & Control Training Analysis & Feedback
ETB - Experimental Test Bed
PL/ERS - Position Location/Event Registration Subsystem

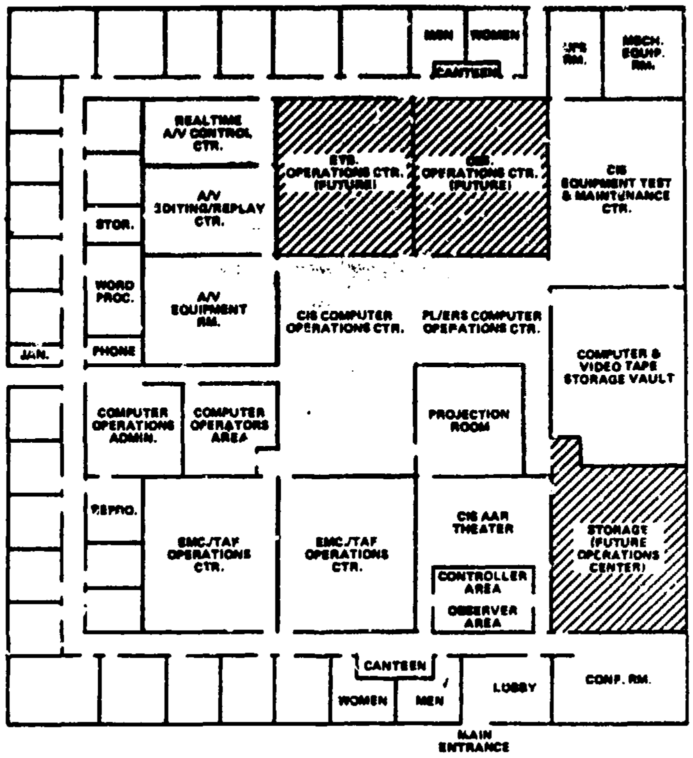
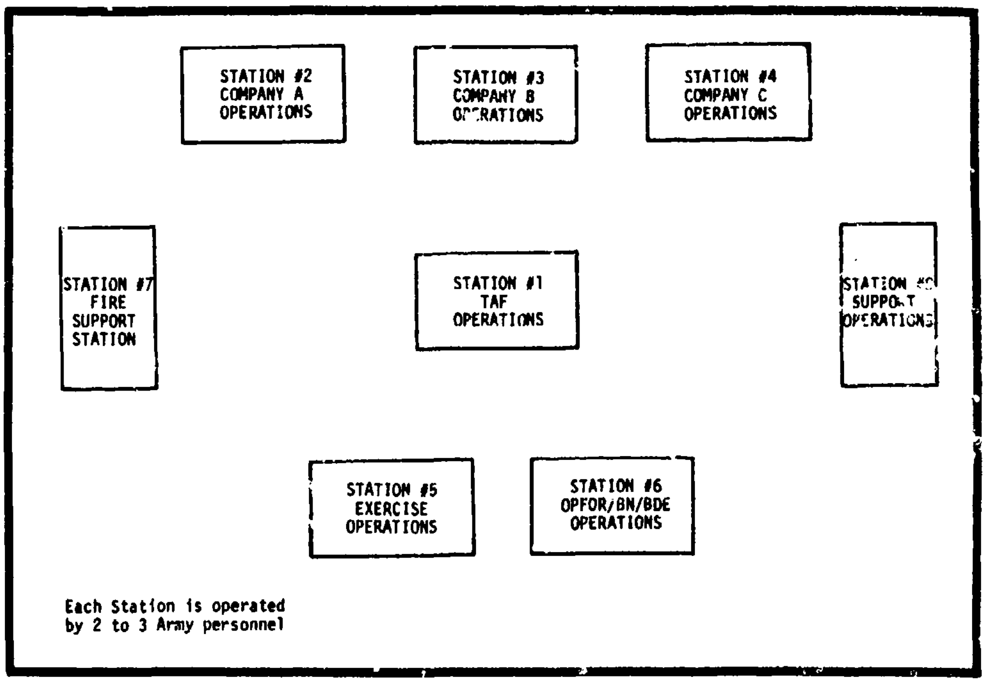


FIGURE 3 FLOOR PLAN CIS ENVIRONMENTAL PROTECTION SHELTER (EPS)



Each Station is operated by 2 to 3 Army personnel

FIGURE 4 EMC/TAF OPERATIONS CENTER LAYOUT

STATION 6: OPFOR, BN and BDE OPERATIONS

Operators at this station are assigned the responsibility to direct the opposing forces (OPFOR) and monitor the battalion TF and brigade (BDE) tactical and intelligence operations. When nuclear, biological or chemical (NBC) effects are played, the NBC operator is accommodated at this station.

STATION 7: FIRE SUPPORT OPERATIONS

Operators at this station are assigned the responsibility to monitor and direct the simulation of indirect fire operations for both the battalion TF and OPFOR.

STATION 8: SUPPORT OPERATIONS

Operators at this station are assigned the responsibility to monitor and analyze all battalion TF combat support and combat service support operations.

Using the controller station capabilities previously described, the EMC/TAF operators are able to perform their particular function in the CIS by monitoring the appropriate radio nets, tagging event data collected by the field instrumentation, directing and prompting the operation and information input of the Field Observer/Controllers, diecting the OPFOR operations, directing and editing the activities of the field video teams and selecting the data and video displays to emphasize and demonstrate specific training objectives for AAR sessions.

SUMMARY AND SCHEDULE

Summary

The National Training Center (NTC) then has been designed to provide to the members of each battalion a total experience which cannot be duplicated at their home stations. The Instrumentation System will provide the means by which the training experience can be controlled and the means by which the data can be collected, recalled and presented so that units will have an appreciation of their state of readiness for combat and can develop a training program to eliminate their weaknesses.

Not only will the NTC provide the opportunity for the units that pass through the 14-day period to improve their training but it will provide an opportunity for the Army to identify better training methods. It will provide a system which will allow a unit's performance to be judged objectively in a realistic combat environment. Home station training will become more effective as a result of units experiences at NTC and as a result of the periodic reviews of their NTC performance by use of their Take-Home-Package of recorded material. The net result will be that over time the performance of battalions at NTC will improve as they learn to train more effectively at home stations.

Schedule

Initial operational capability - 125 player units -	31 Jan 82
Expanded player unit capability -	Oct 82
Phase II implementation -	Incrementally from mid to late 1980's

ABOUT THE AUTHOR

Mr. Richard C. Dickson is a 1956 graduate of the University of Wisconsin. Prior to his retirement from the U.S. Army in 1979 he directed the operational development of the Combined Arms Tactical Training Simulation (CATTS) at Ft. Leavenworth, Kansas. He is currently the System Engineering Manager, National Training Center Project Office, Science Applications, Inc.

PIERSIDE COMBAT SYSTEMS TRAINING WITH THE 20B4

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ABSTRACT

Pierside combat systems training is a way to supplement the shore based training facilities and the at-sea exercises which are so necessary to keep a combat team at a high level of proficiency. This paper presents how pierside training is being accomplished with the use of the Device 20B4, Mobile Combat Systems Trainer. The 20B4 provides the capability for conducting individual operator and team training on the crew's ownship through stimulation of the installed operational equipment. The user can develop, modify, expand, and replay training exercises quickly through a combination of real-time and off-line software routines. The system presents a total electronic warfare environment to a wide range of sensors with a cost effective adaptability to the sensors and threats. The mobility of the 20B4 enables the system to be moved wherever the ships are located to achieve improved fleet readiness through realistic training and checkout.

INTRODUCTION

The classic problem in warfare is to ensure that the Military personnel and equipment are organized, trained, and ready to handle a wide variety of combat situations. This is particularly true for naval ships where complex team operations, actions, interactions, and decisions are required. The precision and speed involved in threat detection identification, engagement, and weapons deployment are critical to the survival of combat ships. The coordination of these activities in a battle environment is complicated and crew proficiency is difficult and expensive to maintain during peacetime. To achieve a high level of proficiency, without being in battle, is the goal of all training activities.

Until recently, coordinated combat systems team training was provided to varying degrees at land-based training facilities, and through at-sea exercises which involved the use of operational aircraft and ships. As with any training situation, there were limitations to what could be accomplished under these conditions. The problem was to fill the gaps, bring training to the fleet, and accent the coordination of the combat systems team. Among alternatives considered to supplement the shore based facilities and at-sea exercises, was that of a pierside combat systems trainer. This device would create a realistic threat environment, directly stimulate shipboard sensors, and interact with the operation of these sensors.

The result would be a training system that permitted on-ship training of combat systems teams using their shipboard equipment and training scenario coordination provided by knowledgeable Fleet training personnel. The Device 20B4 Mobile Combat Systems Trainer (MCST) is one such device.

DESCRIPTION OF THE 20B4

Functional Description

The 20B4 MCST is a completely mobile unit, with all equipment contained in an air-conditioned semitrailer which has an air-cushioned suspension system. (See Figure 1, Picture of 20B4 Van.)

The software programs and peripheral devices compute all target and vehicle dynamics for any training exercise. Three-dimensional landmass and weather formations are stored on easily accessed magnetic tape and disc cartridges. Among the other software programs are those for data entry, radar parameter tables, Electronic Warfare emitter tables, and hardware diagnostics for ease of maintenance. (See Figure 2, the 20B4 MCST block diagram.)

Data from the computer is passed to high speed electronic modules designed specifically for the 20B4. Each module performs a designated task, such as target attenuation. This modularization permits easy fault isolation, and correction by module replacement. The combination of many elements of target characteristics data is generated in the proper format for application to various types of radar systems (such as pulse Continuous Wave, pulsed doppler, chirped pulse, coded pulse groups, Frequency Modulation, Continuous Wave, or others). This signal is provided to the appropriate radar channel from the 20B4 van. Fire control radar types may be of the conical scan, Conical Scan Receive Only scan, simultaneous monopulse using 1, 2, or 3 channel receiver systems, with or without sidelobe cancellation features.

The signals are transmitted to the ship through 1-inch diameter cables (normally, one per sensor), which terminate in sensor interface units. The attache-case sized interface units further condition and distribute the signals through a harness which is configured to permit quick, temporary connection to the sensor. (See Figure 3, Interface Kit). Stimulation of the radars is done at the Intermediate Frequency of the radar to use as much of the radar system as reasonable, and to achieve realistic interface for effective Electronic Counter Measures interactions. A side benefit of this approach is that it serves as a systems level device to generally assess the operability of the radar. EW equipment interface is provided at the RF level for the same reasons.

In its present configuration, the 20B4 simultaneously stimulates up to seven radar sensors and various Electronic Warfare equipments. The radars typically include a short range surface search, a long range air search, a three-dimensional air search, and four missile or gun fire control radars. These radars are selected from the list of 23 different radars currently interfaced by the 20B4. The Electronic Warfare equipment stimulated include countermeasures sets, deception repeaters, Direction Finder Sets, countermeasures receivers, and threat identifiers. The 20B4 also stimulates Identification Friend or Foe (IFF) and ownship motion equipment.

The threat environment of the 20B4 presents up to 32 independent targets simultaneously, such as ships, aircraft decoys, and missiles. In any given scenario, hundreds of targets can be presented over time. These are accompanied by appropriate signatures, landmass, weather, sea state, Electronic Counter Measures and chaff. Each threat or environment parameter output results in presenting the shipboard equipment with the static or dynamic features which would be associated with real conditions. Three-dimensional landmasses from around the world are available, and aircraft features include size, aspect, turn rate, speed, and acceleration, among others. Missiles employed in the training scenarios feature appropriate elements such as Electronic Warfare emissions, range, altitude, and velocity characteristics. Jamming conditions can be automated or activated by operators during exercises. Targets that fly behind the landmass mountains are masked as in real life, and targets which are successfully engaged are removed from the displays when they are destroyed.

The Electronic Warfare Simulator (EWS) of the 20B4 will present up to 32 simultaneous threats in the upper bands (A through J). Again, in any scenario, hundreds of Electronic Warfare targets can be presented over time. Each Electronic Warfare threat may be assigned a unique pulse repetition interval and pulse code, and there are no restrictions placed on the number of threats in any particular band. Each emitter may have any of 10 basic scan patterns (circular, spiral, raster, palmer, etc.) generated from one of 16 hardware stored antenna patterns. Disc storage provides for 250 emitter signatures for scenario preparation and implementation.

Sixteen independent, programmable jammers are available for simultaneous use. Hundreds of these may be employed during the course of any given scenario. They provide selectable features such as carrier and amplitude modulation, range or angle gate steal, blink and angle deception. Chaff drops are also programmable and up to 16 simultaneous drops may be made at any time.

The 20B4 stimulates the AIMS MK X or MK XII IFF systems at the radio frequency level. All modes are stimulated, although mode 4 is simulated to avoid exercising crypto-secure circuits.

Ownship motion is provided for any one of the 10 classes of ships currently in the 20B4 library. The overall gaming area is 1,024 by 1,024 nautical miles which permits a great deal of flexibility in scenario preparation.

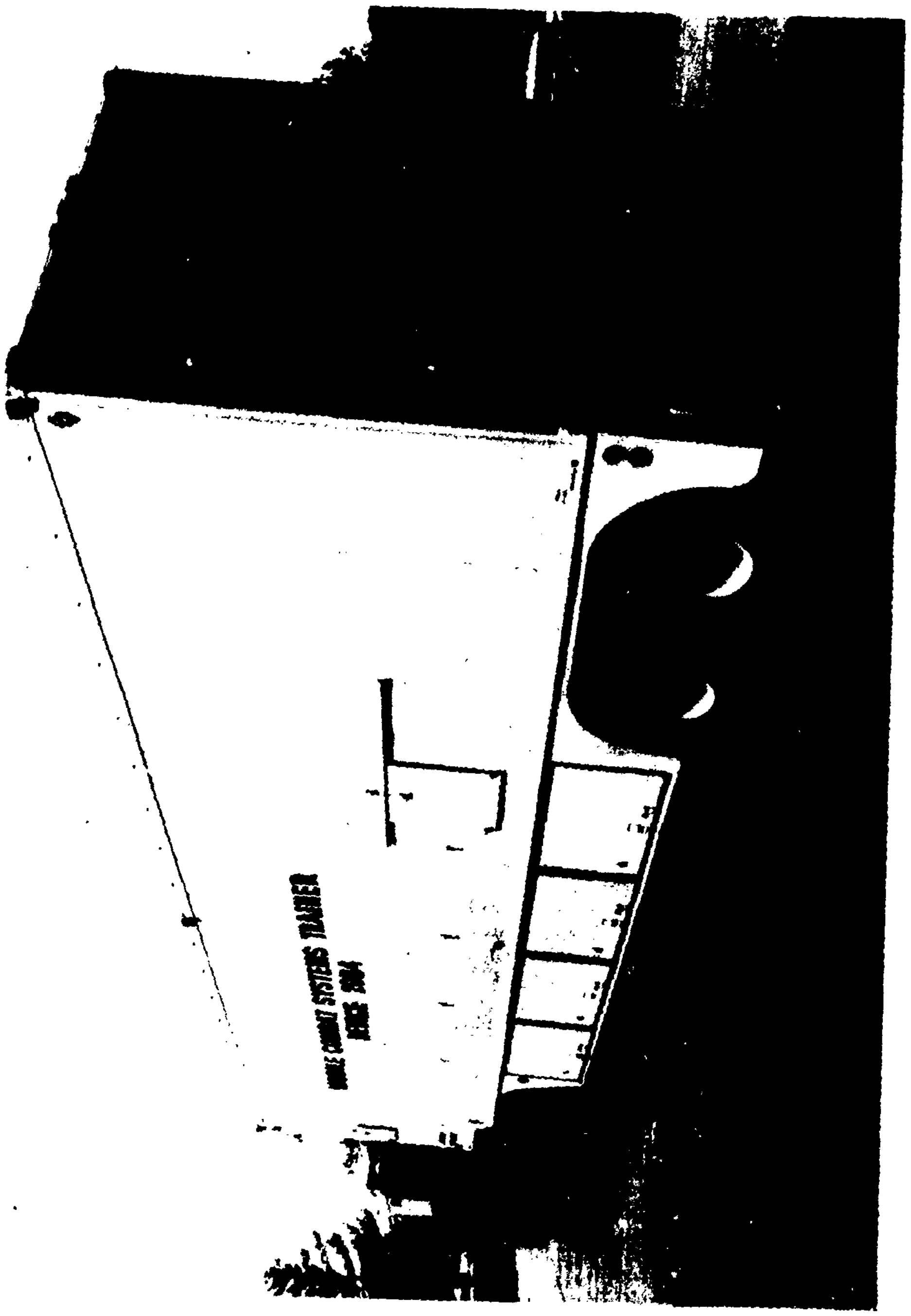
Pre-operating Features

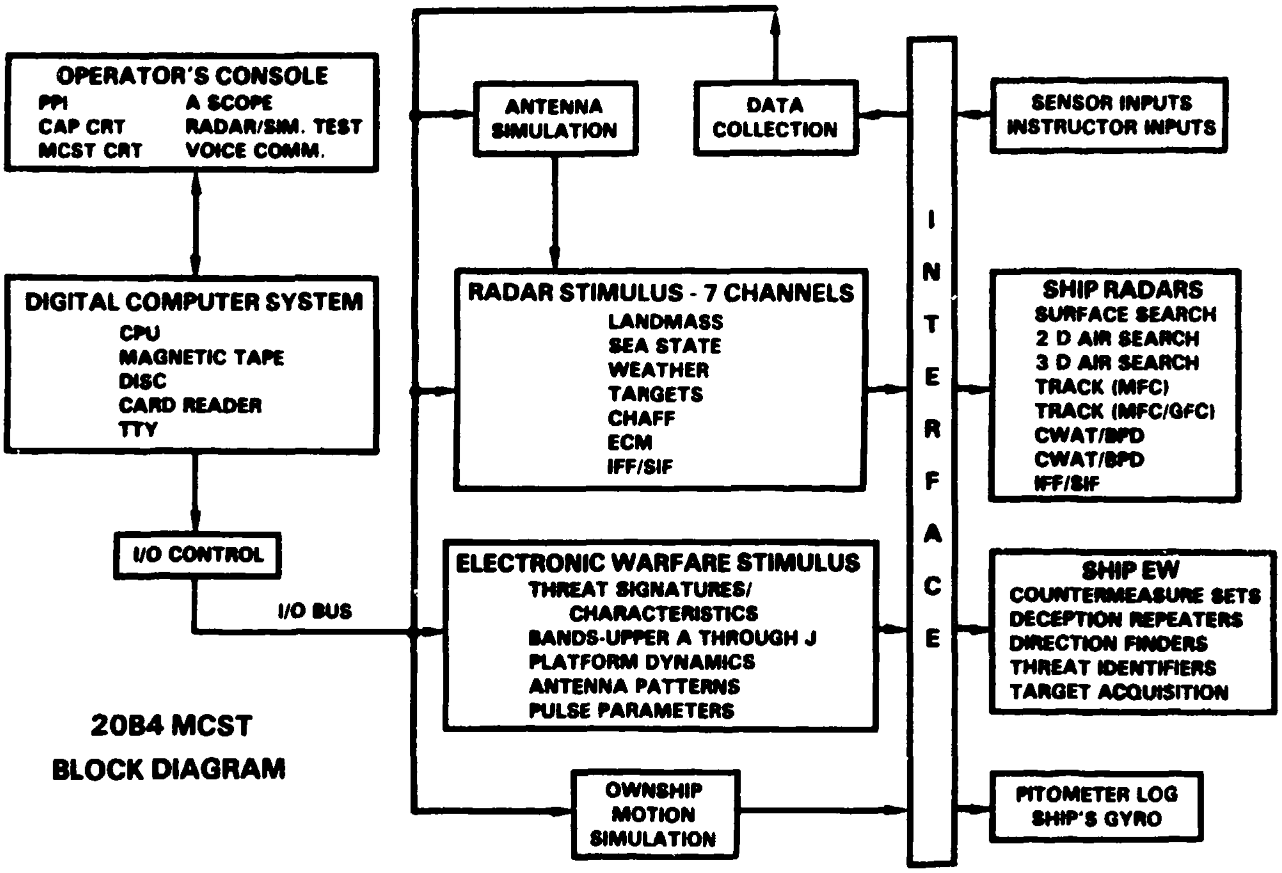
All information used to prepare an exercise is entered via the Operator Console of Device 20B4. (See Figure 4, Operator Control Console.) Two cathode ray tube displays with keyboards allow the instructor to create targets, activate jammers, start and stop scenarios, change weather conditions, or alter any other factors that would affect the ship's sensors. A Plan Position Indicator is provided to show the actual display being presented to the ship's radars. Also, an A-scope and patch panel including an intermediate frequency amplifier-detector allow the instructor to monitor pertinent signals such as radar sync, ranging, video, and error signals.

The importance of realistic training scenarios cannot be overstressed, and the 20B4 permits scenario preparation by the user, based on his training objectives. These can be prepared off-line through use of the scenario compiler, and instructions are entered in time, target or object, function, and value format. The resultant data is stored on magnetic tape (or cards) and a hard copy output may be obtained from a line printer installed in the van. Scenarios may also be generated on-line through Instructor Manual (Keyboard) operations and automatically recorded. Scenarios may be created for simple or complex missions, to emphasize some specific training goal or for a variety of other uses.

Interface with the ship is through the Interface Kits previously mentioned. These are electronically keyed and automatically alert the 20B4 Instructor if the cable interconnections are incorrect.

After the interface is completed and verified, the 20B4 and ship sensors must be correlated through alignment. This is done in


MOBILE COMBAT SYSTEMS TRAINER



20B4 MCST
BLOCK DIAGRAM

Figure 2.

a step-by-step procedure from the 20B4 Instructor position and includes such elements as azimuth and elevation angle offsets. Depending on the type of ship and number of sensors to interface, this overall interface task can be done in as little as 1 or 2 days. All data for a given ship is recorded on disc, so that it is readily recalled for that ship when training is conducted at a later time.

The final step is to initialize the training program. This is done by selecting the scenario, landmass map, weather map, and weather height. This may be done from the Operator's position. The Operator then selects the appropriate mode of operation, NORMAL or RECORD. The RECORD mode is used to generate a scenario on-line.

Operation

Following interface and alignment, the 20B4 may be used to run as many scenarios as training time permits.

Operation in the NORMAL mode consists of starting a prerecorded scenario and monitoring the sensor operator action and responses. For greater realism, there is a second Operator position from which the Combat Air Patrol (CAP) simulated aircraft is controlled. Due to the dynamics of the CAP interactions with the ships' Air Intercept Control personnel, both target control and communications are handled by this Operator. Both positions for the 20B4 and CAP instructors are identical, and each has access to all displays as well as the capability to manually intervene to modify the scenario, if desired. The use of the prepared scenarios thus minimizes the operating functions to be performed, but the system offers the potential to modify the scenario during training as desired. Further, the use of standardized, repeatable scenarios can provide relative personnel training assessments or evaluation of combat systems capabilities of various classes of ships.

Data Collection and Evaluation

During the training exercises (and keyed to the specific scenario), there are a number of important events that are recorded. These are automatically obtained from flagged scenario data, sensing points in the interface or from inputs derived from hand-held keysets controlled by Instructor/Observers positioned at critical locations aboard ships. The data recorded includes administrative information such as the date, ship, time, as well as other inputs. Electronic Warfare data which can be recorded includes emitters presented, identified correctly, engaged correctly and the time to detect high priority threats. Radar target data which can be recorded includes targets presented, engaged, and killed by threat class, average detection time, average target assignment time, as well as Search and Track radar summary information. This data may be used to identify specific problem areas, debrief ships crews and officers, or assess overall effectiveness for readiness evaluation. Due to the complexities of evaluation, the data collection use is strictly up to the user.

20B4 MCST Expandability

Although the 20B4 currently supports a defined set of sensors, additional units can be stimulated with very little modification. The 20B4 provides stimulation for many types of radar, as well as Electronic Warfare signatures within the radio frequency spectrum from 0.2 to 18 GHz. To stimulate a new sensor, the general technique is to develop a new interface or modify an existing one.

The capability to provide anti-submarine warfare training has been taken into account in the basic 20B4 design. Should there be a requirement for this training mission to be assigned to the 20B4, there is enough physical space and system computing time to accommodate it.

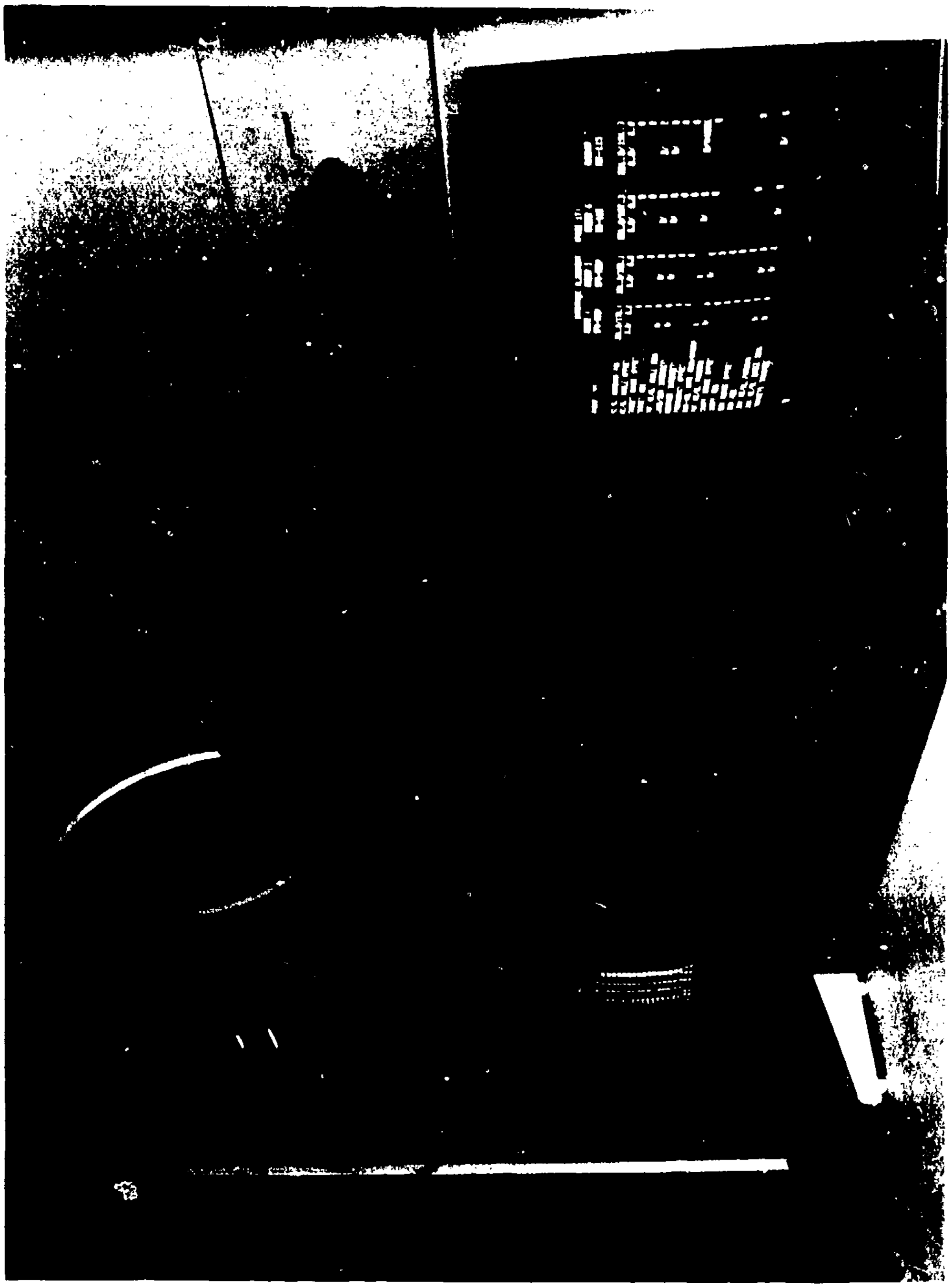
Conclusion:

Pierside combat systems training is an important element in the present training concept for Navy shipboard personnel. The strong point of pierside training is that it brings the environmental control of the classroom to the actual shipboard equipment and combat teams. The 20B4 has been used successfully as a cost effective means of maintaining combat crew proficiency for a number of ship types including aircraft carriers, cruisers,destroyers, and frigates during the past two years at a number of east coast Naval bases.

Experience to date indicates that ship's crews welcome the training experience because they are integrated as combat crews into composite training exercises in which these crews are given an opportunity to interrelate and cooperate under psuedo-combat conditions to successfully complete a training mission.

Additional 20B4 MCST units are currently being fabricated and deployed at selected locations throughout the world for more widespread economical proficiency training.

The Device 20B4 is not limited to pierside combat systems training. It is a general purpose radar and EW stimulator/ trainer and is a natural extension of the AN/MPQ-T1 Nike Hercules Radar Simulator previously designed by AAI. (The AN/MPQ-T1 trainer is a trailer mounted system which can be readily moved from missile site to missile site to provide training to the weapon system operators.) With the addition of new interface kits, the Device 20B4 could provide individual or team training to almost any radar or Electronic Warfare systems. This could include air, land, or sea based electronic sensing platforms.



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FIRING BATTERY TRAINER

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ABSTRACT

A fundamental problem in the training of artillery crews is the cost of ammunition, fuel and range facilities used in live fire training. Current dry fire training is slow and monotonous because error sources can only be detected by stopping the exercise after each weapon laying and visually inspecting the various sighting and ammunition preparation functions. Clearly, there is a need for a training device which provides for a real-time assessment of weapon laying and ammo preparation errors and which is compatible with current live and dry fire training techniques. This paper describes the AAI Firing Battery Trainer, a device capable of training each crew member of a firing battery in the weapon-laying and ammo preparation operations

INTRODUCTION

The Firing Battery Trainer (FBT), developed by AAI under the direction of the Human Engineering Laboratory, provides the equipment necessary for instruction and practice in development of the skills necessary to operate the howitzer effectively in either a dry or live fire environment. The FBT is a system that is installed on the crew's assigned M109's, thereby developing the realism that cannot be achieved otherwise.

The FBT is configured to permit the training of an entire battery simultaneously. A single instructor or battery commander can monitor the speed and accuracy of each gun crew from a single instructor's console. Any number of weapons from one to eight can be connected to the system. A detailed display of any one gun crew's error data is available to the instructor on his console, and a complete printout is available at the completion of the exercise.

BACKGROUND

There are two groups of laying errors which affect laying accuracy. They are: 1) deflection errors and 2) quadrant errors. Deflection errors are errors in the azimuth of the gun tube committed by the gunner. Quadrant errors are errors in the elevation of the gun tube committed by the assistant gunner.

In laying the weapon in azimuth, there are four operations to be performed. Two of the operations have a direct effect on gun tube placement. They are: 1) entering the commanded deflection into the sight, and 2) rotating the turret to the entered deflection. An error of one mil in either of these operations results in a one mil error in gun tube azimuth. The remaining two operations, 3) levelling and 4) cross-levelling, have a second order effect on gun tube azimuth.

In laying the weapon in elevation, there are three operations to be performed. Two of the operations have a direct effect on gun tube placement. They are: 1) entering the commanded quadrant into the sight, and 2) elevating the gun tube to the entered quadrant. An error of one mil in either operation results in a one mil error in gun tube elevation. The remaining operation, 3) X-levelling, has a second order effect on gun tube elevation.

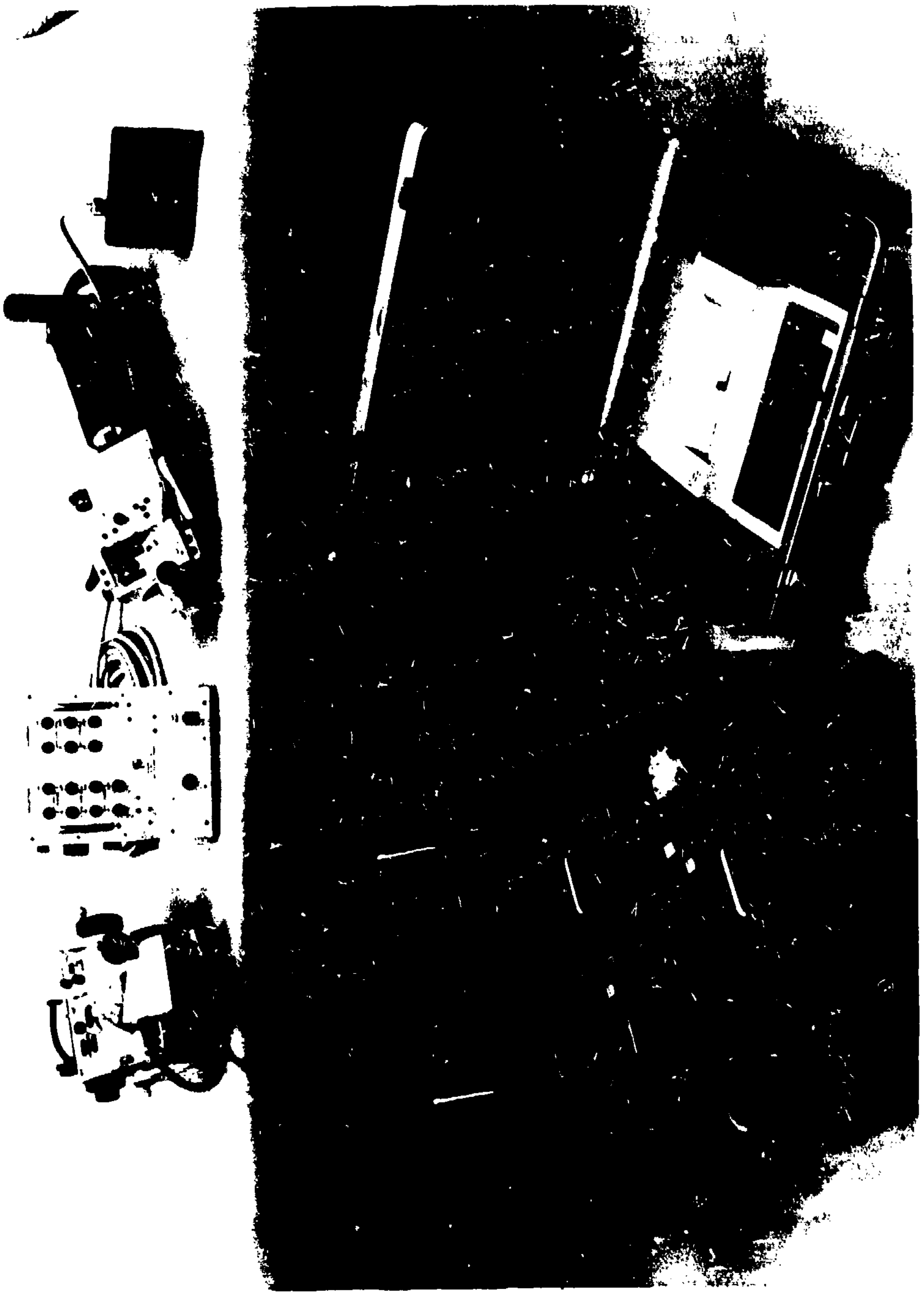
In preparing the ammo, there are four operations to be performed. They are: 1) projectile type selection, 2) fuze type selection, 3) fuze time entry, and 4) charge number and charge color selection. With the possible exception of fuze time, ammo preparation errors will result in a significant change in the kill-capability of a given artillery round.

DESCRIPTION OF THE FBT

The FBT system has the capability of being used for either live fire or dry fire. All weapon-mounted equipment is capable of withstanding both the shock associated with howitzer fire and vibration associated with howitzer travel. Other components are designed to withstand abusive treatment resulting from the use of the equipment in the field. For dry fire training, the howitzer and trainer can be used in a "parking lot" environment. See Figure 1.

Weapon Mounted Components

The FBT is basically a measuring device with feed-back. Its function is accomplished by instrumenting the M117 pantel and M15 quadrant and providing a hand operated unit to indicate ammo preparation errors, all connected to an instructor's console for control of the training exercises. The pantel is modified by adding sensors to detect the azimuth entered value, sight pattern, level and cross-level and by adding hi/low lights to provide feed-back if an error exists. The quadrant is likewise modified to detect entered value, level and cross-level and by adding hi/low lights. Ammunition preparation activity is detected by observing the crew and entering error/no error on the hand held monitoring unit. Possible errors are projectile type, fuze type, fuze time and charge. Each of the above items is connected to a weapon-mounted interface unit for



signal processing and transmission to the instructor's console. In addition, the interface unit provides the Chief of Section with a summary of the seven laying errors.

Instructor's Equipment

The instructor's console is composed of two sections, the error display unit and the control unit. The display is located in the lid of the console and the control unit in the base. The display provides a complete summary of all laying and ammo errors, along with the commanded values, for one weapon. The error data is displayed real time, i.e., as the gunner and assistant gunner perform their operations, the error display will show the movement of the sights, turret, and gun tube. All laying errors are displayed with an accuracy of 0.1 mils, except the sight pattern error which has an accuracy of 0.2 mils.

The control section of the instructor's console permits the instructor to control 1) the training mission, 2) the input of command data, 3) the display of information on the error display, and 4) the display of the on-carriage hi/low error lights. Prompting provides the instructor with all options available to him for each data input.

The printer unit serves two functions. First, it contains the power conditioning system for the entire weapon trainer system. The system operates from 115vac 60 Hz 10 amps (standard house power in the USA). The second function is to house the printer unit. The printer is used to provide instructor and students with a record of their performance.

Technical Description

The FBT contains sensors or devices to measure a total of eleven error sources from each howitzer. They are:

(A) Deflection Entered Value
(B) Deflection Sight Pattern
(C) Deflection Level
(D) Deflection XLevel
(E) Quadrant Entered Value
(F) Quadrant Level
(G) Quadrant XLevel
(H) Projectile Type Selection
(I) Fuze Type Selection
(J) Fuze Time Setting
(K) Charge Preparation

The measurement of these error sources is accomplished by four different measurement techniques. They are:

(A) Level/XLevel Measurement (Quadrant and Deflection)
(B) Entered Value Measurement (Quadrant and Deflection)
(C) Sight Pattern Measurement
(D) Ammo Preparation Errors (Projectile Type, Fuze Type, Fuze Time, and Charge)

The four level/Xlevel error sources listed above are measured and processed in a similar fashion, utilizing the same type of sensor and signal processing techniques. The sensing devices, or inclinometers, are gravity referenced devices which provide a bi-polar analog DC voltage output which is proportional to the angle of tilt. The sensors used on the pantel and quadrant are essentially the same, differing only in their physical size, weight, and output range. Once digitized, the sensitivity of both sensors is 0.1 mil per LSB.

The two entered value sensors are optical shaft angle measurement devices of the incremental type. The sensors used on the pantel and quadrant are essentially the same, but because the two sights have different internal gearing, the sensors must have correspondingly different resolutions in order to provide the same 0.1 mil per bit error resolution.

The sight pattern sensing system consists of an optical image processing system followed by an IR detector. The signal from the detector, when digitsed and processed by the computer system, provides a 0.2 mil accuracy determination of turret azimuth.

The computer system, which consists of the computer and I/O controller is the control element of the FBT. All data communications between sensors, displays, and keyboards are controlled by the computer system. Memory mapped I/O techniques are used for all computer system interfaces, except the printer interface which is via an RS-232 link. All software was written in assembly language in order to minimize memory requirements and optimize operating efficiency. The FBT software is divided into two subsystems: initialization software and training mission software. The initialization software is written as an off-line system, while the training mission software is an interrupt driven real-time system.

OPERATION

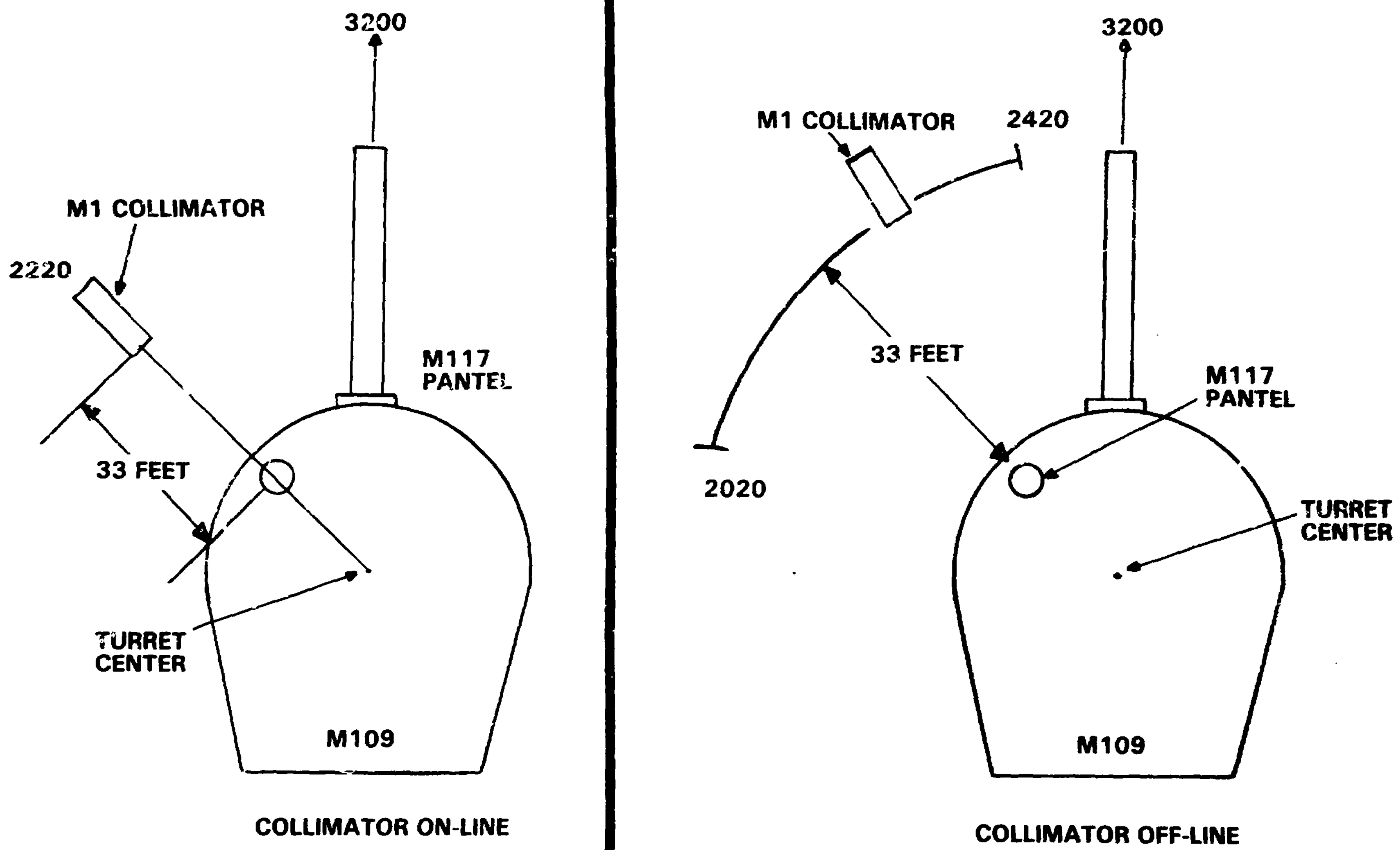
Prior to the start of a training exercise, the FBT must be set up and initialized. Either the one-step or the two-step initialization procedure may be selected. Once initialization has been completed, the training exercise can begin.

Initialization

FBT System initialization falls into two categories: first, FBT system initialization, and, second, sensor initialization. System initialization consists of entering the sight initialization values, day, and time of day.

The FBT sensors can be initialized by following either of two procedures depending on the placement of the collimator. See Figure 2. Each procedure has its own merits and limitations. Placement of the collimator "on-line" is more difficult, but enables FBT initialization to be accomplished with a simple one step procedure. Placement of the collimator "off-line" is easier but requires a more time-consuming two-step FBT initialization procedure.

The one-step initialization procedure can be used if the collimator is emplaced at 33 feet and on the extension of the line connecting the pantel and the turret center-of-rotation. While on-line emplacement might be difficult or impossible, due to the local terrain variations, it is the only



COLLIMATOR ON-LINE

COLLIMATOR OFF-LINE

FIGURE 2

collimator location which will permit 360 degrees turret laying.

After orienting the battery with the M2 aiming circle and emplacing the Ml collimator, the pantel and the quadrant is set at 3200 and 0300. The Chief of Section must depress his "COS Ready" switch to complete FBT sensor initialization.

The two step initialization procedure was developed to permit greater flexibility in the placement of the collimator. With this procedure, the collimator can be placed at any angle between 2020 and 2420 mils at 33 feet. Turret rotation is limited when the collimator is placed off line, but the FBT sight pattern detector system has the same field of view as the pantel; i.e., the FBT will be able to measure the sight pattern at any turret angle at which the gunner can see it.

The two step procedure requires that the weapon be laid to two deflection commands, 3200 and 2100 mils for the M109. The first lay, 3200/300, is automatically performed when the gun is oriented with the aiming circle. The second lay, 2100/300, is equivalent to a lay command at the indicated values. All critical parameters (levels, Xlevels and entered values) are monitored to assure that they are within the required tolerance. If any one parameter is out-of-tolerance for either step, then the FBT will inform the instructor. The gun crew must then correct this parameter before that initialization step can be completed. At the completion of each step, the COS must depress his "COS Ready" switch in order to proceed.

Operation

Once initialization has been completed, the system is ready to begin a training mission. The pace and format of a training mission is under the complete control of the instructor. All firing commands are entered by the instructor, and he selects the format (fixed target/moving target, on carriage prompting lights on/off, rapid fire/slow fire, etc.) with the Mission Keyboard.

Due to memory limitations in the FBT computer, a maximum of ten lay commands may be issued for any one mission. This mission may be set up as either a fixed target or moving target mission. A fixed target mission is a "fire when ready" format. Just prior to firing the round, the COS must depress the "COS Ready" switch on his COS interface unit in order to signal the FBT (and the instructor) that the weapon is laid. In order to implement a fixed target mission, the instructor 1) depresses the "Enter New Command" button of the Mission Keyboard 2) enters the commands via the Data Keyboard, 3) depress the "Issue Command" button of the Mission Keyboard, and simultaneously, 4) issues the commands to the gun crews. At this point, the FBT monitors the laying operation and awaits the COS ready signal from the gun crew. This signal indicates that the round has been fired ("shot out") for fixed target missions. When the signal is received (or when the 59 second time out has been reached), the instructor can either enter a new set of commands by depressing the "Enter New Command" switch and then repeating the above procedure, or end the mission by depressing the "EOM" switch. The instructor may issue as many as ten commands during any one mission.

For moving target missions, there is a "Fire On Command" order given. This means that the weapon is not fired until a separate fire order is given by the instructor. To implement a moving target mission on the FBT, the procedure is identical to the fixed target procedure discussed above, with one exception. Upon receipt of the COS ready signal, the instructor may either fire the round or issue another set of lay commands. To fire the round, the instructor depresses the "Fire" button on the Mission Keyboard and, simultaneously, gives the fire order to the gun crew. To issue another set of lay commands, the instructor depresses the "Enter New Command" button on the Mission Keyboard and then follows the same procedure followed for fixed target missions above. The decision to fire the round or issue another set of lay commands is based on lay time and is under the control of and at the discretion of the instructor.

When starting a new mission, the instructor has the option of enabling the on-carriage indicators and setting the threshold at which they come on. These indicators provide the gunners with immediate feedback and prompting of their errors. To enable these indicators, depress the "On-Carriage Indicators" switch of the Mission Keyboard. When the built-in light is illuminated, the function is enabled.

The "pace" of the training mission is set by the rate at which the instructor issues commands. The print-out contains the "Start Mission" and "End of Mission" times, which provides an indication of the pace of the mission.

SUMMARY

It is possible to incorporate the FBT into a number of training scenarios which permit more interesting and cost-effective training. The FBT provides tangible, documented goals which each gunner can strive to achieve. The ability to train with the FBT in both the live fire and dry fire environment allows the gun crews to be exposed to both the realism of live fire while maintaining proficiency with cost-effective dry fire scenarios. In addition, the FBT permits the instructor to develop various "games" to maintain the crew's interest. Games such as "beat the clock" and "competition among crews" provide both valuable training and increased interest. Future potential for the FBT includes integration of the trainer with larger system trainers. Such a training system could pinpoint poorly trained troops in realistic battlefield scenarios.

The FBT, having completed its development cycle, is now awaiting its first field evaluation.

EFFICIENT, ACCURATE WEAPON SCORING AGAINST MOBILE THREATS IN THE REAL-TIME SIMULATED COMBAT ENVIRONMENT

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ABSTRACT

With the advent of real-time interactive combat simulation on the Advanced Simulator for Pilot Training (ASPT), a requirement for determining weapon effectiveness against moving threats was established. Traditional methods either required an excessive amount of computer memory or were restricted to low fidelity approximations. An innovative approach to this problem was developed for ASPT. An iterative approach utilizing both an aerodynamic model, based upon the weapon ballistics, and the threat position time history serves as a framework for this method. An exact determination of weapon impact or miss can be made through the use of kinetics and calculus. This method allows real-time interactive scenarios that include evasive maneuvers and ECM tactics, yet requires very little computer memory and execution time. This capability is essential for effective and realistic combat simulation.

INTRODUCTION

Background

Flight simulators are being used more and more to train pilots in weapons delivery both on the conventional range and in the hostile environment. A means of scoring the weapon projectile is essential in order to evaluate pilot performance. If the target is fixed on the terrain, scoring is relatively simple. When the bomb or bullet is released, the flight path and point of impact with the terrain can be determined, and a miss distance can be obtained that is independent of time. However, when the target is moving, real-time scoring becomes much more difficult. A time history of the target and the weapon projectile is needed so that the distance between projectile and target may be evaluated as a function of time. Depending upon the fidelity of the model used to create this time history, massive amounts of computer memory and execution time may be required.

The most common method currently in use involves updating the weapon projectile position on each iteration. This method is very accurate but requires a large amount of computer memory and execution time, especially when the weapon is a stream of cannon shells, because each round must be updated on every iteration. Even when the weapon and target position are known for each iteration, interpolation must be used to find the position between iterations. This interpolation and the techniques used for scoring the time histories of the weapon projectile and target require still more computer memory and execution time.

Statement of Problem

In a real-time, high fidelity threat environment, computer memory and execution time are at a premium. Yet, in this same environment, an accurate weapon scoring algorithm is essential. The ability to determine weapon effectiveness against stationary and mobile targets is a requirement if aircrew training or survivability are to be evaluated. Scoring against stationary targets is a straight forward evaluation of weapon ballistics. The problem of weapon scoring against mobile targets is one of finding an accurate method that requires very little computer memory or execution time. An innovative approach to the problem of mobile target scoring has been developed for use on the Advanced Simulator for Pilot Training (ASPT).

METHOD

Scoring constitutes a measurement of the distance from the target to the weapon projectile. The ASPT weapon, whether it is a bullet or a missile, is treated as a point in space located at the front edge of the projectile, and the target is treated as a sphere whose diameter is approximately the wingspan of the target (or other appropriate cross-sectional dimension depending upon the object) with the center of the sphere located at the target center of gravity. Consequently, the issue is whether the weapon (point) penetrates the target (sphere). At the present time, ASPT does not require fidelity to the degree of determining exactly where the weapon strikes the target. However, this could be found by applying the target Euler angles (roll, pitch, yaw) to the target sphere and redefining the sphere as a three-dimensional object that has the same size and shape as the target.

Scoring Algorithm

The method for ASPT mobile target scoring determines whether the target sphere is penetrated by the weapon. The calculations involved determine the exact time the weapon projectile is closest to the target and the distance between them at that time. These calculations are the same regardless of the weapon that is used.

The distance between the weapon and the target at any given time can be found by subtracting the target position from the bullet position. These positions and the difference are treated as vectors in three-dimensional space.

Equation #1: $\overline{D} = \overline{P}_{weap} - \overline{P}_{targ}$

$\overline{D}$ is distance

$\overline{P}_{weap}$ is weapon position

$\overline{P}_{targ}$ is target positon

The weapon and target position at any time can be found using Equation #2. This equation assumes a constant velocity, an assumption that will be discussed in more detail later.

Equation #2: $\overline{P} = \overline{P}_0 + \overline{V}T$

$\overline{P}$ is position at time T

$\overline{P}_0$ is position at time T = 0

$\overline{V}$ is velocity

T is time

Substituting Equation #1 into Equation #2 and expressing in terms of the coordinates of three-dimensional space yields:

Equation #3a:

$$D_x = (P_{ox} + V_xT)weap - (P_{ox} + V_xT)targ$$

Equation #3b:

$$D_y = (P_{oy} + V_yT)weap - (P_{oy} + V_yT)targ$$

Equation #3c:

$$D_z = (P_{oz} + V_zT)weap - (P_{oz} + V_zT)targ$$

The total distance can be found by applying the theorem that states the magnitude of a vector squared is equal to the sum of the components squared.

Equation #4: $D^2 = D_x^2 + D_y^2 + D_z^2$

Before substituting Equation #3 into Equation #4, it would be helpful to rewrite Equation #3 as follows:

$$D_x = (P_{ox_{weap}} - P_{ox_{targ}}) + (V_{x_{weap}} - V_{x_{targ}})\ T$$

$$D_y = (P_{oy_{weap}} - P_{oy_{targ}}) + (V_{y_{weap}} - V_{y_{targ}})\ T$$

$$D_z = (P_{oz_{weap}} - P_{oz_{targ}}) + (V_{z_{weap}} - V_{z_{targ}})\ T$$

Now let:

$$P_{ox} = (P_{ox_{weap}} - P_{ox_{targ}}),\quad V_x = (V_{x_{weap}} - V_{x_{targ}})$$

$$P_{oy} = (P_{oy_{weap}} - P_{oy_{targ}}),\quad V_y = (V_{y_{weap}} - V_{y_{targ}})$$

$$P_{oz} = (P_{oz_{weap}} - P_{oz_{targ}}),\quad V_z = (V_{z_{weap}} - V_{z_{targ}})$$

With these substitutions, Equation #3 becomes:

Equation #5a: $D_x = P_{ox} + V_xT$

Equation #5b: $D_y = P_{oy} + V_yT$

Equation #5c: $D_z + P_{oz} + V_zT$

Combining Equation #5 and Equation #4 gives:

Equation #6:
$$D^2 = (P_{ox}^2 + P_{oy}^2 + P_{oz}^2)$$
$$+ (2T)\ (P_{ox}\ V_x + P_{oy}\ V_y + P_{oz}\ V_z)$$
$$+ (V_x^2 + V_y^2 + V_z^2)\ (T^2)$$

This is a second order equation in time whose first derivative, when set equal to zero, will give a point of minimum or maximum. The equation for the first derivative is as follows:

Equation #7:

$$2\ (P_{ox}\ V_x + P_{oy}\ V_y + P_{oz}\ V_z) + 2\ (V_x^2 + V_y^2 + V_z^2)\ T = 0$$

Whether the point is a minimum or maximum can be determined by looking at the sign of the coefficient of the T term. This is always a positive number so the point will be a minimum. By solving for T, the time when the distance will be smallest can be found.

Equation #8:

$$T = \frac{-\ (P_{ox}\ V_x + P_{oy}\ V_y + P_{oz}\ V_z)}{(V_x^2 + V_y^2 + V_z^2)}$$

Taking the time found in Equation #8 and substituting it into Equation #6 gives the miss distance, the closest the weapon ever gets to the target. These equations are based on the assumption that the target and weapon projectile are under no acceleration. This assumption is obviously not valid for all time; however, for a very short time period, it can be considered valid. In the next section, this assumption as it applies to the target will be investigated. Following that discussion, the gun and missile applications will be reviewed and particular characteristics of these systems addressed.

Target

A no-acceleration assumption is valid when a sufficiently short time period is used. For a time period to be "sufficiently short," it must be short enough so that any normal acceleration the target would undergo could not have a significant effect on the location of the target at the end of that time period. Table 1, found in the Appendix, shows the effects of airspeed and G-loadings (acceleration) on target displacement for varying time periods.

Taking one line from Table 1 as an example, enter the table with 500 knots true airspeed (KTAS). At this airspeed, we will assume the aircraft is limited to approximately 7 Gs by either structural limits or aerodynamic stall. Using a value of 7 Gs and choosing a time period of one-tenth of a second, the lateral displacement is 1.126 feet. That means the difference between where the target would be located if it were accelerated for one-tenth of a second, and where it would be if it were not accelerated for one-tenth of a second is 1.126 feet. (See figure 1.)

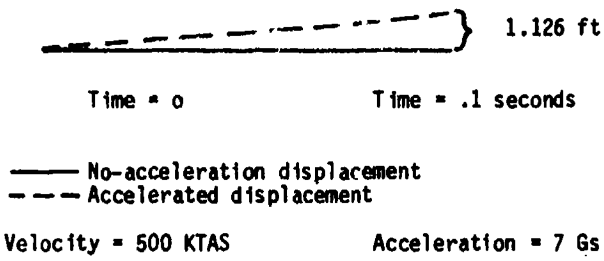


FIGURE 1 TARGET DISPLACEMENT

Based on the data in Table 1, a time period of one-tenth of a second is adequate as the boundary on a zero-acceleration assumption. Before the scoring algorithm is used, it must be determined when the weapon is within one-tenth of a second of time of impact or closest miss. Also, it must be determined if one-tenth of a second is a short enough time period for the no acceleration assumption on the weapon projectile. ASPT uses two methods at this point. Each method used is based upon the weapon involved, i.e., gun or missile.

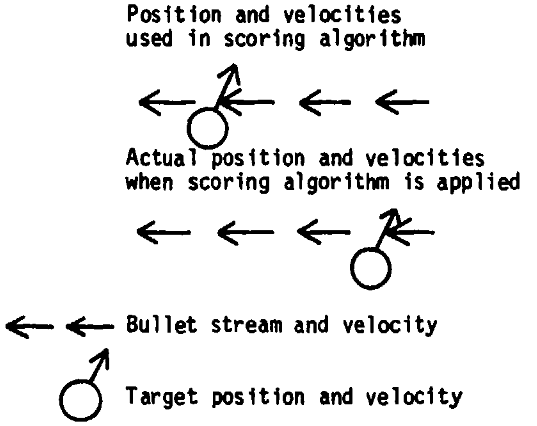
<u>Gun</u>

Scoring with the gun must take into account the fact that a large number of bullets can be fired, each with the potential to hit the target. Evaluating each bullet individually on every iteration would require massive amounts of computation time; or storing the plotted flight path of each bullet would require a large memory capacity.

ASPT uses an innovative approach to this problem. As the bullet is fired, a bullet time of flight until impact, based on the range to the target, is determined. This time of flight is used to predict a new target position at that time of predicted impact by using existing target position, velocity, and acceleration. The new target position is used to calculate a new range, and the process is repeated. This iterative process provides an accurate, predicted impact point. Based upon the predicted range, a predicted time of flight until bullet impact is found. Using this time of flight and equations that model the bullet flight characteristics, bullet position and velocity for the predicted impact are found. These values (time of flight, Pox, Poy, Poz, Vx, Vy, Vz) are stored as a row in an array. If the predicted range is greater than the effective range of the gun, it is assumed the bullet will miss, and no data is stored in the array. It is interesting to note that any form of ballistic model may be used as long as bullet position and velocity can be determined at the predicted impact point. Another interesting point is that the rate of fire on most aircraft cannons is greater than most simulation iteration rates. For example, the A-10 30 mm cannon fires at 70 rounds per second and the F-16 20 mm cannon fires at 100 rounds per second. Therefore, it must be assumed that each bullet value that is stored is not one bullet but actually a stream of bullets. The values stored are the values for the midpoint in the stream.

One of the data values stored is time of flight. This time of flight is used to determine when to apply the scoring algorithm. One iteration's worth of time (based upon the simulation used) is subtracted from the time of flight value on each iteration. The time of flight remaining is then checked to see if it is within one half of an iteration of zero. When the time elapses to within one half of an iteration of zero, that row of the array is evaluated. By using the stored bullet position and velocity and the actual target position and velocity in the scoring algorithm, a miss distance can be determined.

The scoring algorithm is based upon knowing the weapon's and target's position and velocity at the same point in time. But, it is unlikely the time of flight would be an exact multiple of the iteration rate (causing time of flight to subtract to exactly zero). This means the weapon's and target's position and velocity values are probably not for the same point in time. However, the time difference would be small, less than one half of an iteration. This dilemma can be resolved by referring back to the assumption about the bullets being a stream. The velocity at any position along that stream can be considered constant for a short time period. Therefore, the bullet position and velocity values can be assumed to be valid at the time used to determine the target position and velocity. (See figure 2.)



Hit occurs in both cases but at different points in the bullet stream.

FIGURE 2 BULLET AND TARGET POSITION AT IMPACT

After a row of the array has been evaluated, it is zeroed out and not checked again unless it is reused with the values for a new bullet. By using this method, only the bullets that were predicted to hit the target on a given iteration will be evaluated on that iteration. Therefore, each bullet does not need to be evaluated on each iteration; however more than one bullet may be evaluated on a particular iteration.

The ballistic equations that account for bullet flight need only be evaluated once for each bullet. These equations are run at the time of firing, and they provide the position and velocity values at the predicted impact. Massive memory is not required since bullet position and velocity are saved for only one instant of time. The memory required on ASPT is a local array 60 X 7 in size (32 bit words). The "60" dimension is based upon ASPT's 30 Hertz (Hz) iteration rate and the fact that the maximum effective range of the bullet is always reached within two seconds; therefore, only 60 rows would be needed at any one time. Also, this method should ensure the bullet is within one-tenth of a second of impact on the target. Since the maximum time of flight for the bullets is two seconds, (based upon effective range at the gun) it is impossible for a target to maneuver in such a way that it could pass through the bullet flight path with a potential for being hit without being quite close to the predicted impact point. (See figure 3).

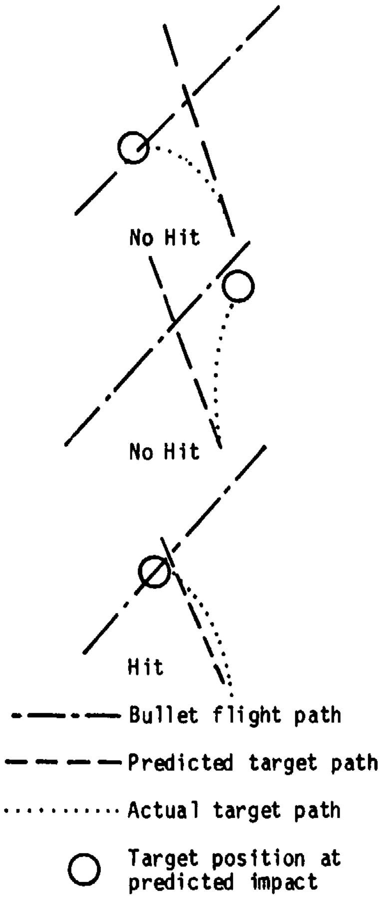


FIGURE 3 POSSIBLE BULLET AND TARGET POSITIONS

Now that the time to apply the scoring algorithm has been determined, the question remains how short a time period (based upon bullet ballistics) is required for the no acceleration assumption to be valid.

There are two primary forces which cause accelerations that affect a bullet's flight path. The first force is gravity, which acts perpendicular to the earth's surface. Over a short time period (one-tenth of a second), the gravity effect can be disregarded. The second force is supersonic drag, which acts parallel to the bullet flight path. Table 2 in the Appendix, shows the effects of drag on bullet displacement and velocity over a 1.5 second time period.

Using the .5 sec line from Table 2 as an example, we find that at .5 seconds, bullet velocity is 3140 ft/sec. The distance the bullet has traveled when using ballistic equations that account for drag is 1725 feet. If no acceleration had been assumed during the previous one-tenth of a second, the distance traveled would be 1734 feet. The difference of nine feet is not significant if we remember that the bullet is actually a stream of bullets extending in front of and behind the bullet point (See figure 2). Therefore, when the weapon used is a gun, the one-tenth of a second time period is short enough to assume no acceleration based upon the data in Table 2.

The last point to be addressed in this section is how the one-tenth of a second time period is used when applying the scoring algorithm. Recall that the scoring algorithm is applied when the time of flight to the predicted impact point has been reduced to zero. When the scoring algorithm is applied, the first thing found is the time when the minimum miss distance will occur. This time is limited to an absolute value of one-tenth of a second, the time period for the no-acceleration assumption. This means the bullet must penetrate the target sphere within one-tenth of a second from the time of the predicted impact if it is to be recorded as a hit.

Missile

A missile presents a slightly different problem. Since the missile is often fired at long range, the target aircraft will have time to perform some maneuver that will cause it to be significantly displaced from its predicted position. Also, because of its maneuvering capability, the missile's flight path is unknown ahead of time. However, only a few missiles can be active at one time, so on ASPT, each missile can be updated on every iteration without requiring excessive execution time and memory capacity.

Since both the missile and target are maneuvering, it is impossible to set a predetermined time to evaluate the miss distance. Therefore, a different technique is used. The range between missile and target is determined for each iteration. Once the missile has reached its maximum velocity, if the range between successive iterations decreases, the missile will be allowed to continue tracking the target. As soon as the range increases, it is assumed the missile just passed the target. Therefore, on the first iteration that shows an increase in range, the scoring algorithm is applied using current target and missile positions and velocities. The scoring algorithm then becomes the method used to interpolate between target and missile positions on the current iteration and the preceding iteration. ASPT runs on a 30 Hz iteration rate, therefore, the maximum time period that no acceleration is assumed is one-thirtieth of a second (one iteration). This time is well within the one-tenth of a second time period that was established for the target. The only possible problem with the no-acceleration assumption on the scoring algorithm would be the missile's own maneuvering capability. Table 3, in the Appendix, shows the effects of airspeed and G-loadings on missile displacement for a one-thirtieth of a second time period. Even for the worst case of a missile traveling 2000 knots with the capability to pull 30 Gs, the displacement due to acceleration over one-thirtieth of a second is only .536 feet. Based on Table 3, the no-acceleration assumption is valid for the missile when the time period is one-thirtieth of a second or less. The procedure for a missile, then, is to update both the target and missile positions on every iteration. When the missile stops converging on the target and first shows an increase in range, the scoring algorithm is applied using current values of position and velocity. The maximum time for the no-acceleration assumption then becomes one thirtieth of a second.

CONCLUSION

The ASPT method of scoring against a movable target allows real-time scoring using actual target and weapon positions. This method requires a minimal amount of computer memory and execution time while producing a high fidelity means of determining weapon effectiveness against mobile targets.

APPENDIX A

DISPLACEMENT TABLES

TABLE 1
TARGET DISPLACEMENT FOR VARIOUS TIMES

Airspeed (Knots)	Acceleration (Gs)	Time Period (Sec)	Displacement (Feet)
300	5	.05	.201
300	5	.10	.804
300	5	.15	1.809
500	7	.05	.282
500	7	.10	1.126
500	7	.15	2.534
700	9	.05	.362
700	9	.10	1.448
700	9	.15	3.257
900	11	.05	.442
900	11	.10	1.769
900	11	.15	3.981

Displacement is measured in feet. It is the lateral difference between where the zero-acceleration velocity vector would put the aircraft during the time period, and where the accelerated velocity vector would put the aircraft during the same time period.

TABLE 2
BULLET DISPLACEMENT AND VELOCITY

Time of Flight (Sec)	Velocity (Ft/Sec)	Distance Traveled With Acceleration (Feet)	Distance Traveled Without Acceleration (Feet)
0	3806*	0	0
.1	3678	373.2	380.6
.2	3542	731.2	741.0
.3	3404	1076	1085
.4	3270	1407	1416
.5	3140	1725	1734
.6	3014	2030	2039
.7	2894	2323	2331
.8	2777	2604	2612
.9	2664	2874	2882
1.0	2555	3133	3140
1.1	2450	3381	3389
1.2	2347	3619	3626
1.3	2248	3846	3854
1.4	2152	4064	4071
1.5	2058	4273	4279

*Muzzle velocity plus true airspeed.

This data is based upon the F-16 20MM cannon; the data is valid for an aircraft at 10,000 MSL and 300 KTAS. The maximum effective range of this gun is 4000 feet. The "Distance Traveled Without Acceleration" column is based upon no acceleration during the previous one-tenth of a second, not for the entire time of flight.

TABLE 3
MISSILE DISPLACEMENT
DURING ONE THIRTIETH OF A SECOND

Airspeed (Knots)	Acceleration (Gs)	Displacement (Feet)
500	15	.268
500	20	.357
500	25	.447
500	30	.536
1000	15	.268
1000	20	.357
1000	25	.447
1000	30	.536
1500	15	.268
1500	20	.357
1500	25	.447
1500	30	.536
2000	15	.268
2000	20	.357
2000	25	.447
2000	30	.536

Displacement is measured in feet. It is the lateral difference between where the zero-acceleration velocity vector would put the missile during the time period, and where the accelerated velocity vector would put the missile during the time period.

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ABOUT THE AUTHOR

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THE M58A1 TRAINING AID, PERSONAL DECOMTAMINATION KIT

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ABSTRACT

The M258A1 Kit is a personal decontamination system which provides to the individual soldier the capability of decontaminating skin areas exposed to chemical agents. The M58A1 Kit is specifically designed for training troops in the use of the M258A1 Kit. The original design of the kits contained shortcomings and deficiencies: (1) difficulty in the preparation of the chemicals for use; (2) lack of a facial decontamination capability; (3) availability of only one complete decontamination per kit; (4) unreasonable amount of training required for proficiency. Studies indicated that these deficiencies could be overcome by repackaging the chemicals into a towelette configuration hermetically sealed in a laminated plastic-foil packet. A product improvement effort was initiated and the product improved kit had the following benefits: (1) safer, easier, and faster to use; (2) operational equivalence to the original kit plus partial facial decon and the capability to decontaminate personal equipment; (3) three complete decontamination systems per kit; (4) reduced costs.

INTRODUCTION

Early and effective decontamination of toxic chemical agents on skin can prevent loss of combat effectiveness or preclude death. Therefore factors that expedite onset of decontamination are as relevant as rates of chemical decontamination or differences of cleansing methods. Testing conducted by the U.S. Army Biomedical Laboratory has shown that it was more important to get the decon solutions on the skin in order to neutralize the agent effects than to attempt to physically remove the agent. In April of 1980, the function of the personal decontamination kit was expanded to include the decontamination of personal equipment items such as the M-16 rifle and rubber gloves. This report summarizes a program to field an improved decontamination kit which is substantially easier to use, and considerably faster to deploy.

The M258 Decontamination Kit

The M258 kit is a personal decontamination system containing materials to allow the individual soldier to decontaminate skin areas exposed to chemical agents. The M58 is the training kit. The M58 training kit is identical to the M258 decon kit except the active chemicals have been replaced by inactive simulants; the chemicals in Solutions I and II are replaced with a 50% propanol and water solution, and the chloramine B is replaced by sodium chloride crystals.*
The M258 decontamination kit is composed of the following:

- four gauze pads
- two plastic sticks
- two plastic capsules containing the active decontaminating solution
- a water proof plastic container to package the above items.

The number I capsule of decontaminating solution (solution I), capable of decontaminating GD and thickened GD, contains 40 ml of:

- sodium hydroxide 5%
- phenol 10%
- ammonia 0.2%
- hydroxy ethane 72%
- water remainder.

The number II capsule of decontaminating solution (solution II), capable of decontaminating HD (mustard) and VX agents, contains 53 ml of:

- hydroxy ethane 44%
- zinc chloride 5%
- deionized water, remainder
- a sealed glass ampoule containing Chloramine B, 17 gm.

Use of the M258 Kit

A step-by-step procedure is specified for use of the M258 kit: (1) open the decon kit; (2) use a gauze pad from the kit to soak up any liquid contamination that is on the skin; (3) if the contamination is sticky or greasy and will not soak up into the gauze, the red plastic scrapers are used to scrape the contamination away; (4) using the spike on the container cover, punch a hole in the side of capsule I; (5) soak a fresh gauze pad with the decon solution from capsule I and swab or wipe contaminated areas of skin with solution I wetted pad for one minute; (6) break the glass ampoule that is inside capsule II by hitting the wide side of the capsule with a solid blow against a hard surface (boot heel, weapon, rock, etc.); (7) shake capsule II hard twelve times so that contents are well mixed; (8) punch a hole in the side of capsule II using the spike on the container cover; (9) soak a fresh gauze pad with decon solution from capsule II and then swab or wipe contaminated areas of skin with the solution II wetted pad for two to three minutes.

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*For clarity, we will generally restrict ourselves to discussing the M258 decon kit, however, identical improvements of the M58 training kit are implied.

Shortcomings and Deficiencies of the M258 Kit

The present M258 kit contains several shortcomings and deficiencies: (1) inadvertent ampoule tip breakage (leading to rapid breakdown of chloramine B and loss of decontamination capability; (2) difficulty of breaking the glass ampoule inside capsule II; (3) knowing under dark conditions whether glass ampoule is broken; (4) inadvertent breaking of capsule II while attempting to break the glass ampoule, leading to a loss of decontamination capability; (5) spike in container lid (used for breaking the plastic capsules) can break off or can cause damage to rubber glove or injury; (6) uncertainty under dark and gloved conditions whether capsule was broken with the spike and whether the gauze pad was properly wetted; (7) no capability for facial decontamination; (8) only one complete decontamination; (9) unreasonable amount of training time.

Improving the M258 Kit

Mine Safety Appliances Company (MSA) under contract to the Chemical Systems Laboratory (CSL), had a one-year effort (1977-1978) to investigate improving the decontamination kit. The objectives of the program were to prove the feasibility of using the components of the M258 kit (Decon I and Decon II solution) on equipment; and design a suitable, compact, individual package/dispenser for these solutions using compatible component materials, and demonstrate the feasibility and utility of this design.

An experimental program was conducted which examined packaging materials; and performed shelf-life tests, storage tests, permeation tests; and the effects of temperature, decontamination procedures, and decontamination tests with candidate materials. Finally, a design study culminated in ten proposed prototype kits.

The following conclusions resulted from this program. (1) Capsule I from the M258 kit could be repackaged in a foil pouch with a premoistened wipe. This concept is similar to the individual moistened hand wipes used by the airlines, etc. (2) Capsule II from the M258 kit could be repackaged in a foil pouch with a chloramine B impregnated wipe. The alcohol/water solution is delivered to the wipe from a single crushable glass ampoule which is also in the pouch and which is encapsulated in 100-mesh propylene screen that effectively retains 100% of the glass. (3) Repackaging the components of the M258 kit in foil pouches provides a kit which is equal or better in decon efficiency, and simpler and quicker to use than the M258 components. (4) The feasibility of utilizing the decontaminating solutions (solutions I and II) on equipment was demonstrated.

This joint effort between CSL and MSA developed the basic information for a product improvement program (PIP). This effort provided data on packaging concepts and established the ultimate selection of a wipe material and laminated foil packaging material, the safety of a mesh-encased glass ampoule, and the material compatibility testing.

PRODUCT IMPROVEMENT PROGRAM

Objective

To correct the shortcomings and deficiencies of the M258 kit, the Chemical Systems Laboratory (CSL) commenced with a product improvement program (PIP). The objective of this program was to correct deficiencies in the M258 Decon Kit and M58 Training Aid Kit by repackaging the existing chemicals into a towelette configuration.

The actual PIP effort was initiated in fiscal year 1979, and was to take approximately 20 months to complete. A meeting with the Army Armament Material Readiness Command (ARRCOM) in April 1979 resulted in an expedited effort to implement the benefits of the product improved kit into a procurement action directed to purchase 1,000,000 kits. The expedited effort resulted in shortening the schedule by six months.

Benefits

The product improved kit has the following benefits: (1) safer, easier, and faster to use; (2) operationally equivalent to the current kit plus a facial decon; (3) three complete decontaminations; (4) substantially reduced costs through more efficient and effective training. It gives three times the capability at approximately the same cost.

Minimum Requirements

The U.S. Army Training and Doctrine Command (TRADOC) imposed minimum requirements for the product improved kit. These specific requirements were: (1) the kit must be placed in a box which easily fits the product into the M17 and XM29 carrying cases; (2) the kit must have a capability of face decontamination; (3) the kit must contain the maximum amount of skin decontamination towelettes (solutions I and II, and facial decons) which can be fitted into the case; (4) the title is to read "Improved Personal Decontamination Kit". (This last requirement has since been waived as it was a criterion having nothing to do with functional capability.)

Tasks for PIP

The CSL conducted, supervised and coordinated the product improvement program. Five tasks were identified:

(1) finalization of kit design;
(2) biomedical testing;
(3) environmental testing;
(4) Human Engineering Laboratory (HEL) testing;
(5) preparation of a Technical Data Package (TDP).

A contract was negotiated with Battelle Columbus Laboratories (BCL) to assist in tasks (1), (3), and (5).

Finalization of Kit Design

The objectives of this task were to enhance:

(1) night identification;
(2) packet design and guide tear feature;
(3) packet materials and marking;
(4) ampoules;
(5) plastic mesh screen;

(6) towlettes;
(7) containers;
(8) container labels;
(9) prototype PIP components and kits.

Night Identification. A method was needed whereby the soldier could distinguish between the decontamination packets 1 and 2. The soldier must be able to make this identification at night without the use of lights with or without gloves.

The fastest and surest identification may be anticipated by the use of large features or configurations. Thus, the fact that the decon 1 packet is thin and soft (or pliable) and the decon 2 packet thick and stiff (because of the glass ampoules) is one of the best distinguishing features built directly into the PIP version of the kits. The only drawback stems from the fact that identification can only occur after withdrawal of the packet from the holder (which is also the case with most other identification schemes).

An additional identification feature proposed by CSL and incorporated into the packets prepared at Battelle were tabs at the top of the packets. These tabs could serve for initial identification before the packets are removed from the holder and could also facilitate removal, especially when rubber gloves are being worn. A number of variations of these identification tabs were explored, and finally tabs of 1.27-cm (1/2-inch) base and 0.79-cm (5/16-inch) height were adopted. Higher tabs, because they must be bent over to close the lid of the container might interfere with the water tight seal if one got caught underneath the lid gasket. Shorter tabs would cause removal and identification problems with gloved fingers. (One of the changes made in labeling was to change the roman numerals I and II to the arabic numerals 1 and 2. We shall be consistent throughout the report in referring to the original M258 kit decon solutions with a I and II, and the PIP packets with a 1 and 2.)

The other concern that demanded much attention was the placement of the tabs on the top edge of the packets. Configuration A, Figure 1, shows the position of 1 and 2 tabs, respectively, for decon 1 and 2 packets at the corner of each packet, as they are to be loaded into the plastic container. Other configurations, such as indenting the tabs 1.27 cm (1/2 inch) from each corner (B in Figure 1), separating the two tabs in opposite corners (C in Figure 1), or providing one tab in the middle of one packet and no tabs on the other packet (D in Figure 1) were rejected as leading to confusion under emergency conditions. Configuration A was considered to be the most acceptable design. Subsequent efforts by MSA and CSL to optimize the mass production manufacturing producibility of the packets resulted in Configuration D for the packets. The two-tab design did not lend itself to existing mass production techniques. Final design criteria was approved on March 25, 1980, at a meeting involving TRADOC, MSA and CSL.**

The single tab available on the Decon 1 packet serves a dual purpose. It serves as an aid for night identification when the user is using rubber gloves, and is a practical means for removing the initial packet from the kit container. When this one-tab and no-tab configuration was selected, TRADOC concluded that the previously-mentioned concern for the confusion that could arise from the use of these packets would not constitute a real problem. Identification of the packets could be solved through proper personnel training.

Packet Design and Quick Tear Feature. In addition to the tab design, several decisions needed to be made to arrive at a final packet configuration. These included the rounding of corners and the placement of notches to aide in initiating the tearing open of the packets.

The rounding of all corners was done early in the program including the outside corners of the tabs. However, it was decided that the tabs would be more functional with the corners not rounded. The remaining corners were rounded to 0.64-cm (1/4-inch) radius to accomplish easier loading into the containers, to obtain a better fit with the rounded bottoms of the containers, and to avoid injury to exposed skin from the sharp corners.

Emphasis was then directed to provide a quick-tear opening mechanism. A major advantage of the PIP version of the kits is that the soldier in the field can obtain faster skin decontamination because of greater simplicity and faster access to the materials. The quick-tear open feature of the packets is an important aspect of their design. A variety of different notch placements, shapes and dimensions were investigated in conjunction with the various tab configurations shown earlier.

The initial design efforts by MSA resulted in notches placed differently on the PIP 1 and PIP 2 packets. The discussion to follow describes the progression of the quick-tear design evolving from the work performed by MSA in their original contract (1977-78). Tab design progressed concurrently. As shown in Figure 2A, PIP 1 packets were notched for opening at the sides and the PIP 2 packets required opening from the top or bottom. This design introduces two possible sources of deployment delay. It is apparent that the user may lose time while rotating packets into two different positions at 90° to each other; but also confusion might arise in distinguishing between notches up or down (PIP 2) and left or right (PIP 1), especially at night and/or gloved. A variety of different notch placements, shapes and dimensions were then investigated in conjunction with the various tab configurations.

As already discussed, CSL design contributions introduced the addition of pull tabs to facilitate identification and removal of packets from the case. As shown in Figure 2B, for the initial CSL design, notches were cut adjacent to the PIP 1 tab and between the two tabs on the PIP 2 packet.

Observations during initial human factors tests (discussed later in this report) indicated that the test participants were experiencing

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**In January 1980, MSA had been awarded a production contract from ARRCOM to produce 3,000,000 kits. Thus, MSA was involved in the final design from the point of view of mass production.

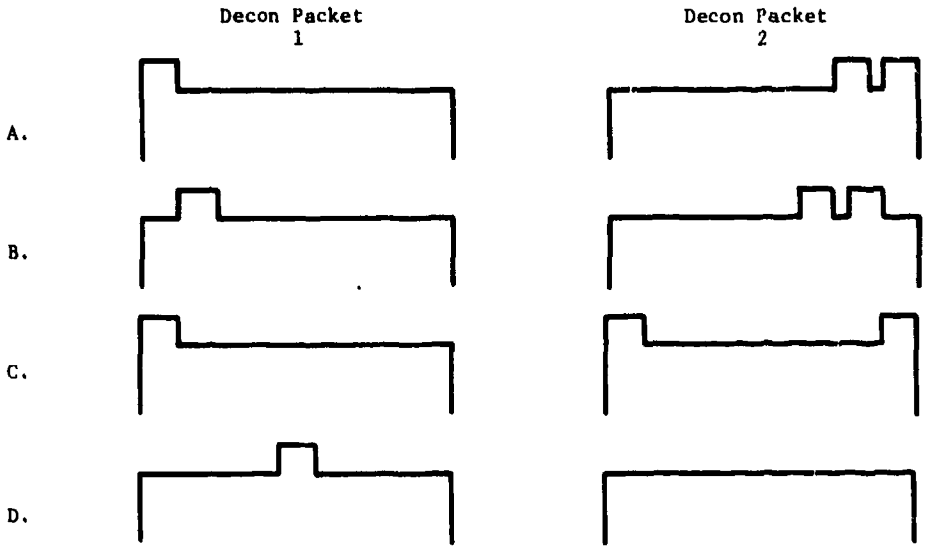
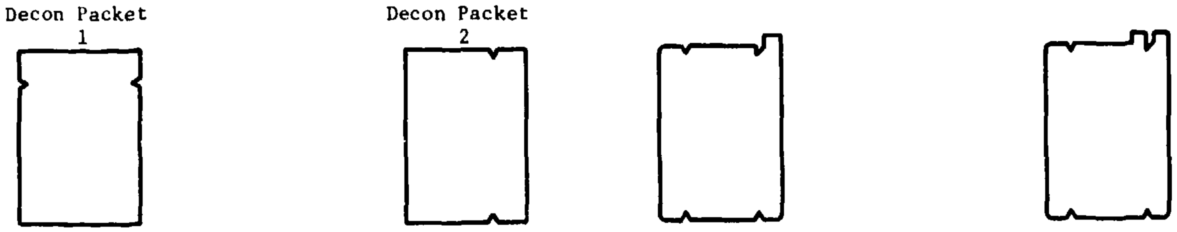
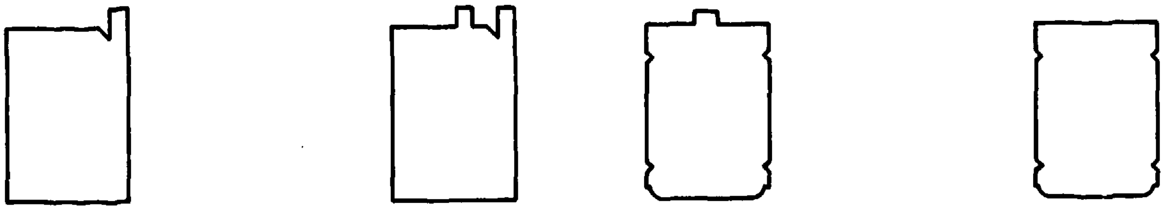


Figure 1. Tab Configuration



A. Initial MSA Design

C. Improved CSL Design



B. Initial CSL Design

D. Final Design

Figure 2. Development of Tear Notches and Identification Tab Design

difficulties with the opening of the packets. Often the corner of the packets, shown in Figure 2B, were torn off and the decontamination pad could not be removed from the packets. Configuration of the tear notches was such that the corner of the packet tended to tear off rather than the entire side of the packet.

To eliminate the problems listed above, an improved CSL design, shown in Figure 2C, was then introduced. The primary notches adjacent to the tabs were redesigned to face inward to affect tearing towards the middle of the packet. In addition, partial notches, i.e., nicks with the apex pointed parallel to the sides, were introduced at the opposite corner and at two locations at the bottom to serve as a secondary means to opening the packet should the primary notches fail. Unfortunately, occasional tears at the corners of the packets were still experienced.

At the previously referenced producibility design meeting (March 25, 1980), this problem was presented which led to the final design, shown in Figure 2D. The notches were placed along the side to cause tearing with the grain of the laminated foil packet material and also minimize the length of the tear.

Packet Materials and Marking. Candidate packet materials which had been selected in the previous MSA effort were verified through permeation and environmental studies that are reported later in this report. The packets consisted of laminated retort pouch material of 0.5-mil polyester or nylon outer layer, 0.35-mil aluminum foil middle layer and 3 to 4-mil modified polyethylene or polypropylene inner layer.

Packet marking requirements were also established during the PIP. Originally an extensive message had been specified for each side of the packets. This consisted of a hazard warning and identification on one side, and abbreviated instructions for use on the other side. These messages were printed on polyester labels that were affixed to the corresponding packets. It was found that the added strength of the polyester labels inhibited the tearing of the packets. Although it was discovered that notching the label could circumvent this problem, it was decided to eliminate the label and print any message directly on the aluminum foil middle layer of the packets. The reduction of thickness (4 mil/package) aided in loading and removing of packets from the container. As mentioned before, it was also decided that the roman numbers I and II would be changed to arabic numerals 1 and 2. Results of biomedical data and Surgeon General Approval resulted in a progression of these messages.

Ampoules. The decon 2 packet serves the dual mission of neutralizing the alkalinity left on the skin from the use of the decon 1 wipe and of deactivating remaining threat agents. Upon recommendations from the Biomedical Laboratory and CSL, the volume of fluid in the decon 2 packets was to be doubled to better accomplish these dual objectives. This could be achieved by incorporating four instead of two small glass vials into the decon 2 packets. Alternatively, two large vials could be substituted for the two smaller ones.

Packets containing four small ampoules of 6.75-mm diameter each, or two large ampoules of 10.5-mm diameter each, were assembled and submitted to CSL for evaluation. It was decided to equip all decon 2 packets with four small ampoules because of better space utilization in the plastic container. However, during evaluation tests, it was determined that the amount of solution available was far in excess to the amount that could be soaked up by the towelette. This excess solution would run and drip and possibly preclude facial use. It was thus determined that the optimum saturation of the towelettes could be obtained through the use of three ampoules.

Plastic Mesh Screen. The plastic mesh screen serves the function of retaining the glass from the ampoules after crushing and not letting glass splinters injure the skin. The polypropylene mesh selected during the original contract with MSA was found quite adequate, and no further development work was done on this component.

Towelettes. An 80/20 rayon/polypropylene nonwoven fabric had been selected during the original contract with MSA. As part of the present development effort, the size of the towelette was to be increased from 7.62 x 7.62 cm (3 x 3 inches) to 7.62 x 14.0 cm (3 x 5-1/2 inches). The larger towelette can be held flat against the palm of the hand and secured at one corner by pressure from the thumb. This permits more efficient decontamination than the 7.62 x 7.62 cm (3 x 3 inch) swatch that tends to be pinched between the thumb and the finger. The larger towelette also supplies a larger quantity of chloramine B at a constant loading per unit area.

Although initial trials with unimpregnated towelettes had indicated that there was sufficient space in the packets for the larger towelettes and that three sets of decon 1 and decon 2 packets could be fitted into the container, the total bulk tended to increase considerably following impregnation of the towelettes. The fit in the container was excessively tight and both loading and removal were difficult.

To alleviate this problem, a compromise in towelette size was adopted. The size was reduced to 7 x 12 cm (2-3/4 x 4-3/4 inches) and folding into three parts instead of the original four parts was authorized by CSL. Now each packet contributed three instead of four layers of towelettes to the overall thickness of the assembly. This produced a significant improvement of the fit of the packets in the containers.

Containers. The dimensions of the polypropylene containers could not be altered, since the containers had to fit into the space of existing mask carriers. Several minor modifications of the existing containers were requested by CSL and were carried out at Battelle. These included:

(1) removal of the spike from the lid of the containers;
(2) shearing off the bulge of the spike seat in the lid of the containers;
(3) heat sealing nylon straps on both sides of the mechanical fastener.

Container Labels. The main purpose of the container labels is to identify the contents and to instruct the use of the kit. The labels were jointly arrived at by CSL and Battelle. For durability, the label stock selected was 2-mil polyester and the message was printed on the back of the label underneath the adhesive. The label was matted to avoid reflection (from the standpoint of readability as well as camouflage). Printing with a chrome yellow ink was at first specified, but since the message appeared weak against the dark backgrounds, a gold ink was finally specified.

Prototype PIP Components and Kits. Both PIP modified M258 and M58 kits were prepared by Battelle for standards testing, human engineering evaluation, display kits, etc. Since many of the methods and problems associated with this small scale fabrication will be different for large-scale manufacturing, the fabrication will not be further discussed, except that all PIP modifications essentially used "tried and proven" commercial/industrial techniques, and no major problems were anticipated for mass production.

Biomedical Laboratory Evaluations

Objective. The U. S. Army Biomedical Laboratory at Aberdeen Proving Ground, Maryland, conducted two comparative studies for the CSL. After discussion with the CSL, the comparative requirements were restated as the following two experimental studies:

(1) determine the relative decontaminating efficacies of: (a) Fuller's earth (M13 pad); (b) alcohol and water wipe (M58 training wipe

I); (c) PIP decon wipe 2; (d) sequential use of PIP decon wipes 1 and 2;

(2) determine the relative efficacies for sequential use of the PIP decon wipes 1 and 2 versus sequential use of M258 kit components according to directions for both liquid and sticky agents.

Testing Procedures. Three agents [GD, thickened GD (TGD), and VX] were applied on clipped backs of rabbits for 2.0 minutes prior to initiation of decontamination procedures, given simulated field conditions. To perform the aforementioned experimental studies, 18 LD50 determinations were required.

Testing required the use of rabbits. The required comparisons could not be performed by in vitro methods because there is no model for duplication of interactions between cleansing methods, reagents and toxic agents in the presence of circulation and biochemistry of living skin. The rabbit is the species of choice because clipped backs of rabbits are of the minimum size required for use of wiping materials and methods of decontamination proposed for human use. The value of this model is well documented.

Test Results. Mortality fractions were recorded the day following each exposure. Any animals showing severe signs were held to complete a period of 24 hours after exposure to agent. Daily parallel exposure of rabbit pairs to all experimental variables permitted use of Thompson and Weil analysis for determination of LD50 values. LD50 results for each test condition were compared with control results to produce a relative protection factor (the control results are assigned a value of 1.0; a number larger than 1.0 signifies that some protection was provided by the "decontamination" procedure, the larger the number the more effective the procedure).

The results of the Biomedical Laboratory tests are summarized in Table 1. The information above the dashed line in Table 1 can be interpreted as the relative effectiveness for facial decontamination. The overall comparison of the three facial decontamination options suggests. In the absence of significant differences against GD and TGD, the product improved decon 2 superiority against VX gives the advantage to this option. Likewise, it was demonstrated that sequential use of the PIP solution 1 and 2 is slightly more effective than the original M258 kit.

The relatively small apparent differences between factors for decontaminants of GD and TGD is strikingly different from the large factors and differences observed with VX decontaminants. This contrast is less surprising in view of the ways the physical properties of these agents affect their control LD50's. GD and TGD tend to evaporate from skin within minutes after exposures; therefore, a substantial portion of any applied dose will have evaporated or entered the skin within two minutes after exposure, whether or not decontamination is performed subsequently. [The two-minute wait to deployment was part of the skin decon kit deployment scenario.] For this reason decontamination has relatively less effect with GD than VX, which persists on the skin of controls long after decontamination is carried out on test animals.

Environmental Testing

MIL-STD-810C Tests. The evaluation of the decontamination kits prepared under the present program included the performance of a series of physical tests and of accelerated storage tests of three-month and six-month duration. The tests were conducted on the PIP kits and packets in accordance with MIL-STD-810C. Included in these tests were low pressure (altitude) testing, low temperature testing, high humidity testing, leakage (immersion) testing, and shock (transit drop) testing. The product improved kit successfully passed all these tests with a confidence level between 90 and 99%.

Vibration Tests. Vibration tests were performed by CSL. Each test consisted of a cycling

Table 1. Biomedical Test Results: Protection Factors

	Protection factors for given agents**		
	GD	TGD	VX factors
Control	1.0	1.0	1
M58 Training Wipe I (Alcohol and Water)	1.7*	2.2	56
M13 Pad (Fuller's Earth)	2.6*	1.5*	80
PIP Decon Wipe 2	2.2*	4.0	197
SEQUENTIAL WIPES			
M258 Kit	3.6	3.5	90
PIP M258 Kit (M258A1)	3.9	6.1	96

* No significant difference from control value.
** Based on clipped rabbits.

test during which there was a series of sinusoidal sweeps from 5 to 200 Hz and back to 5 Hz in 12 minutes. There were seven sweeps for 84 minutes for each axis of the container. Kits were vibrated at a high temperature of approximately 43°C and at a low temperature of approximately -34°C. Between vibration treatments at the different temperatures, the packets were opened and examined for breakage.

With one failure in 80 items, the decon 2 packet demonstrated a reliability to withstand the vibration treatments at least 97.9% at the 50% lower confidence level. With 90 items and no failure, the decon 1 packet demonstrated a reliability to withstand the vibration treatment of at least 99.2% at the 50% lower confidence level.

Accelerated Shelf-Life Stability. The purpose of this phase of the evaluation was to: (1) demonstrate the compatibility of the nonwoven fabric with the chemicals of decon solution 1 and with chloramine B; (2) monitor changes in the composition of decon solution 1 and the loss of active chloride from the chloramine B impregnated on the nonwoven fabric. The accelerated storage stability tests were carried out at 60°C and 43°C, respectively, for decon 1 and decon 2 packets.

Fabric Properties. Tensile tests were conducted on both decon 1 and decon 2 swatches to determine if the long-term exposure to the decontaminating agents would result in changes in the fabric properties. Since the fabric strength varies by approximately a factor of 10 depending on fabric orientation, the unaged swatches were tested in both directions. Ten unaged samples were tested in each direction on an Instron tensile tester using ASTM DM 7 Section 7.1.2 procedures. Eight samples in each direction were tested on the three-month and the six-month accelerated storage swatches. Due to the closeness of the average tensile values in each of the four tests, a statistical analysis was conducted. Using t-distribution statistics to estimate the true averages (with a 95% confidence level) the swatch tensile strength of the three-month and six-month tests are compared to the unaged swatches in Table 2.

Shelf-Life Stability of Decon 1 Solution. Analyses were run on the contents of packets kept at room temperature (control) packets exposed for three months and six months to 60°C, and on a sample taken from a polypropylene storage bottle of solution 1. Six samples were analyzed of the accelerated aging tests and three each of the room temperature control and of the storage bottle. The concentration of the main constituents of solution 1 [phenol, ammonia (NH_3), sodium hydroxide (NaOH), and ethanol] determined by the analyses are summarized in Table 3.

Analysis of the sample bottle of Decon 1 solution shows average ammonia and sodium hydroxide contents of 0.084 and 5.07 percent, respectively. Sodium hydroxide level is well within tolerance but the ammonia is quite low. It appears that somewhere in the process of formulating and storing the solution, ammonia is lost. It is also noted in this analysis that in packaging of the decon 1 solution, approximately 20% of both the sodium hydroxide and the ammonia is lost. This suggests the possibility of neutralization by an acid constituent either on the nonwoven fabric or on the inner surface of the laminates.

Statistical procedures were used to determine if there existed a significant difference between the aged and the control samples for each constituent. These results are summarized in Table 4. The following observations can be made:

(1) No significant difference exists in the phenol contents of the control and aged samples.

(2) The small loss of ethanol after aging three months is not significant, but the loss after six months may be of concern.

(3) Sodium hydroxide and ammonia concentrations change appreciably over time.

Stability of Decon 2 Solution, Active Chlorine Content. To analyze the stability of the free chlorine content, swatches were analyzed. Accelerated storage (43°C) at three months and six months were compared with a control (three months at room temperature). Results show a very narrow distribution of data points with small standard deviations; consequently, a t-test of the data was deemed unnecessary. The results are summarized in Table 5.

These data show an average drop in free chlorine content of 4% over the three-month storage period and of 6% over a six-month period at 43°C. These results appear favorable for the long range storage stability of chloramine B in the decon 2 packets.

Table 2. Shelf-Life Stability of Fabric

	% Change in strength	
	Decon 1 Swatch	Decon 2 Swatch
Three-month Test		
Strong Direction	0	0
Weak Direction	0	+17
Six-month Test		
Strong Direction	0	-14
Weak Direction	+19	10

Table 3. Decon 1 Solution Analyses

	Phenol	NH_3	NaOH	Ethanol
Desired Concentration and Tolerance, %	10 ± 0.5	0.2 ± 0.02	5 ± 0.5	72 ± 2.0
Bottle, Average (Std Dev)	10.13 (0.31)	0.084 (0)	5.07 (0.02)	71.71 (2.18)
Control (3 months, RT) Average (Std Dev)	9.02 (0.98)	0.067 (0.005)	4.07 (0.09)	71.22 (0)
Aged (3 months, 60°C) Average (Std Dev)	9.31 (1.68)	0.051 (0.0045)	3.74 (0.02)	70.81 (1.87)
Aged (6 months, 60°C) Average (Std Dev)	9.44 (0.12)	0.055 (0.0061)	3.61 (0.04)	66.65 (2.06)

Table 4. Statistical Comparison of Decon 1 Packet Contents of Aged Packets to Room Temperature Controls

A. 3 Months @ 60°C

Component	Degrees of freedom	Calculated t-value	t-value from table (95% confidence level)	Significant
Phenol	6	0.268	1.943	no
Ethanol	7	1.288	1.895	no
NaOH	6	9.851	1.943	yes
NH_3	7	4.822	1.895	yes

B. 6 Months @ 60°C

Component	Degrees of freedom	Calculated t-value	t-value from table (95% confidence level)	Significant
Phenol	7	0.727	1.895	no
Ethanol	7	6.14	1.895	yes
NaOH	6	6.743	1.943	yes
NH_3	7	3.184	1.895	yes

Table 5. Active Chlorine Content Versus Time

	Average	Standard Deviation
Control	14.68	0.116
Accelerated Storage		
3 months	14.07	0.116
6 months	12.77	0.231

Pouch Stability Tests. In addition to the tests being conducted by Battelle, Mine Safety Appliances Company performed analyses of the composition of stored materials. Firstly, 17 grams of solution 1 were sealed in a packet, minus the wipe, and stored. After 34 months at an elevated temperature of 60°C the total weight loss was 0.10 grams. This equates to a loss of 0.58%. Also, complete decon 1 packets (with towelette) were placed in their cases and stored. After nine months at 43°C, 0.01 grams of solution was lost, equating to a 0.058% total weight loss. The estimated shelf-life for the decon 1 packet is thus estimated at 12 years.

The stability data for the decon 2 packet are summarized in Table 6. Even though there is only 83% of the initial chloramine activity remaining after 19 months of storage at 43°C, the material is fully effective. Actually, the major loss of activity occurs initially and then tapers off. The estimated shelf-life is eight years.

HEL Testing

Objective. CSL went to the U. S. Army Human Engineering Laboratory (HEL), Aberdeen Proving Ground, Maryland, to determine if the user could operate the product improved version of the M258 Skin Decontamination Kit as well as or better than the existing M258 Kit. Additionally, the HEL was to determine if the user could distinguish between the decon solutions 1 and 2 envelopes in low-level light condition and to determine if the user could successfully manipulate the decon 1 and 2 envelopes while wearing chemical protective gloves. These tests used the M58 and the PIP M58 training kits.

Test Conditions. This test was designed to evaluate the differences in performance times and ease of preparing the pads with solutions I and II. Test participants consisted of ten U. S. Army personnel trained in the use of each kit. Each kit was evaluated and compared under three test conditions: (1) bare handed, (2) wearing chemical protective gloves, and (3) wearing chemical protective gloves and blacked-out goggles to simulate night conditions. Performance times were measured for conditions 1 and 2. However, for condition 3, only the observations and comments of test personnel were used for evaluative purposes.

In order to balance the learning effect that results from repeated training and testing trials, the ten test participants were divided into two groups of five each. Group I was tested first with the standard M58 training kit and second with the PIP training kit. The testing order of the kits was then reversed for Group II.

Results. Median performance times for conditions 1 and 2 are shown in Table 7. The only steps that are different for the standard M58 kit and the PIP kit are the preparations of the decon pads with solutions I and II or 1 and 2. As

Table 6. Decon 2 Pouch-Chloramine B Stability

	% Initial Activity
Chloramine B Crystals	
24 Months at 43°C in sealed glass ampoule	99.6
24 Months at 43°C in sealed foil pouch	99.1
Chloramine B Impregnated on Rayon/Polypropylene Fabric	
10 Months at 43°C	86
19 Months at 43°C	83

Table 7. Median Performance Times* Comparing the M58 Decon Kit and the PIP Version

Task	Barehanded		Gloved	
	M58	PIP	M58	PIP
Mask time	16	14		
Open kit	4	5	3	3
Wipe with dry pad	31	--		
Prepare pad with Solution I (1)	41	11	44	14
Wipe with pad 1	69	80		
Prepare pad with Solution II (2)	46	21	45	24
Wipe with pad 2	96	118		
Decon face	49	32		
Don gloves	23	28		
TOTAL	391	330	98	43

* Time measured in seconds

can be seen from the table, the preparation time of the decon 1 pad is shortened by approximately 75% with the PIP kit. Preparation time of the decon 2 pad is reduced by more than 50% with the PIP kit.

Preparation of a Technical Data Package (TDP)

At the conclusion of the PIP effort, drawings and specifications were prepared that could be used for competitive procurement actions. This TDP was completed and forwarded to ARRCOM and has subsequently been used in awarding a Government procurement contract.

SUMMARY

A one-year joint effort (in FY78) between CSL and Mine Safety Appliances Company resulted in an improved version of the M258 Personal Skin Decontamination Kit. In FY79, a product improvement program was launched, and completed in approximately 14 months. The PIP effort included finalization of kit design, biomedical testing, environmental testing, and human engineering testing. Finally, a technical data package was prepared. Medical approval was granted by the Surgeon General in July 1980 for the M258/M58 PIP materials.

The product improved kits obviated several safety hazards potentially available in the original M258 kits. They contain less of the active ingredients (per packet) while still providing adequate amounts for effective decontamination.

The potential for eye irritation is considerably lessened by the fact that in towelette form, without excessive fluid, the possibility of splashing liquid into the eye seems remote. When this is coupled with user instructions and training to avoid getting the materials into the eye, and that decontamination should only be conducted on the lower face, the hazard appears quite limited and acceptable, particularly considering the benefit to be gained by having an effective decontamination process for lethal CW agents.

The product improved kit was tested by Army personnel (officer and enlisted) in training exercises. Afterwards, the personnel were asked to complete a questionnaire. All participants felt that the product improved kit was a marked improvement over the standard M58 kit in all steps of operation.

Each kit contains three complete decontaminations, and it has been demonstrated that the product improved kit has operational equivalence to the M258 Kit plus also providing a facial decon. Indeed, the PIP kit, because of the pretreated towelettes and tear-away packet design, has shown enhanced effectiveness in neutralizing agent since it is easier and faster to use. It has also been demonstrated that the PIP kit can be used to decontaminate small areas of personal equipment such as rifle, gloves, etc. Finally, costs have been reduced substantially. The PIP kit can be fabricated and assembled for approximately the same cost as the old M258 kit, yet it contains three complete decontaminations as opposed to one. The PIP kit and the PIP training kit have been designated the M258A1 and M58A1, respectively.

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