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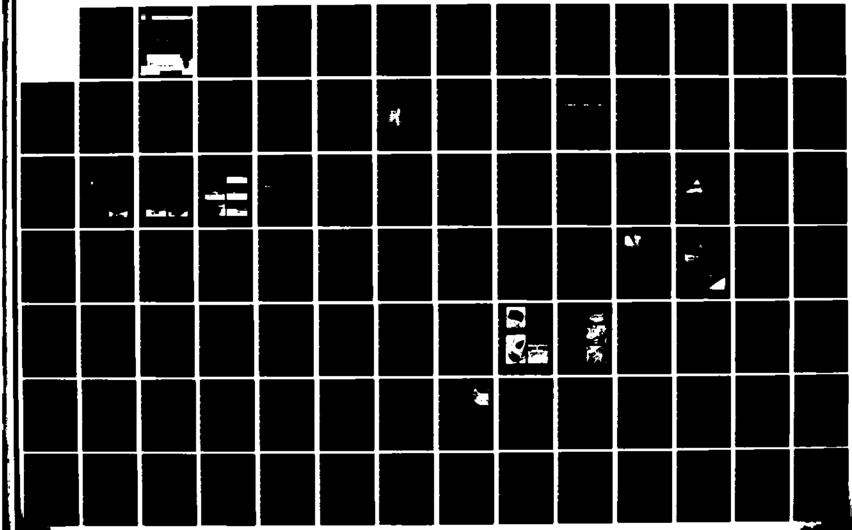

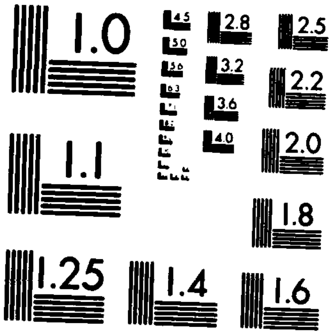

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VOLUME I

PROCEEDINGS

November 14 - 16, 1983

5th

INTERSERVICE INDUSTRY TRAINING EQUIPMENT CONFERENCE

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FOREWORD FROM THE CONFERENCE CHAIRMAN

Some years ago, several far-seeing members of the military services and the training equipment industry recognized the need for a more effective technical interchange between military procurement agencies and the industry developers of training equipment. An annual Interservice/Industry Training Equipment Conference was established with the help of the American Defense Preparedness Association and the National Security Industrial Association. Over the past five years, the scope of this Conference has been expanded to include consideration of management issues and views from the training equipment users in the field, as well as the continuing exchange of technical information. These annual conferences have been further broadened by providing an opportunity for both government and industry to exhibit their latest innovations in the field of training equipment and technology. Conference sites for these expanded Interservice/Industry Conferences have ranged from Salt Lake City, Utah to Orlando, Florida and, this year, to the Nation's Capitol, Washington, D.C.

These Proceedings of the 5th Interservice/Industry Training Equipment Conference ~~continue to~~ present a record of technology interchange, training management issues, and user views from what has become the premier annual military/industry training conference. Key decisionmakers at all levels of the government and industry will be meeting again to consider vital issues related to the training of our Nation's Armed Forces. "Increased Readiness Through Training" is the theme of the 1983 Conference, and this can be made reality through the cooperative efforts of all government and industry Conference participants.

Credit for success of this year's conference must go to the hundreds of persons who have contributed so generously and willingly of their time and effort. Members of the Conference Committee have been tireless in their pursuit of excellence and their efforts deserve the thanks of all who are privileged to attend this Conference.

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A WIDE FIELD-OF-VIEW CRT PROJECTION SYSTEM WITH OPTICAL FEEDBACK FOR SELF ALIGNMENT

Paul Lyon
Evans & Sutherland Computer Corporation
580 Arapeen Drive
Salt Lake City, Utah 84108

ABSTRACT

Evans & Sutherland has developed a multi-channel CRT projection system. This system uses microprocessor technology with optical feedback to provide self-alignment for color-hue, intensity, color-convergence, geometry, and focus. By replacing drift-prone analog correction circuits with digital circuits and D/A converters, system drifts are limited to gain and offset errors. These errors are optically detected and corrected in "real time" by the microprocessor. Geometry drifts can be detected and corrected to within 1/4 of a pixel. Because this projection system is CRT based, image generator, lens, and projection angle induced distortions as large as 30% can be corrected by the projector's digital electronics. The projection system self-alignment capabilities together with edge matching make possible the tiling of multiple channels. This facilitates improved brightness and resolution over wide fields-of-view. A six channel system, with 30 degree by 30 degree fields-of-view for each channel, using a 12 foot radius screen of unity gain yields 7 ft-lambert brightness with better than 3 arc-minute resolution.

INTRODUCTION

Wide field-of-view projection systems are an important part of visual simulation. Such systems should provide wide-angle viewing of scenes without noticeable image discontinuities and should project enough brightness and resolution for a degree of realism. Other qualities, such as ease of initial-alignment, stability after alignment, geometric adaptability and ruggedness are important for a projector to accomodate various applications and endure the tortures of a motion platform. We have developed a multi-channel CRT projection system with these qualities. In brief, the projection system can do the following:

(1) Display a wide field-of-view due to its modular design.

(2) Be initially aligned through a computer terminal.

(3) Prevent color-hue, intensity, color-convergence, geometry and focus drifts by keeping itself in alignment.

(4) Accomodate a wide range of optical and off-axis projection distortion.

(5) Project a bright, high-resolution image.

The projection system consists of a correction electronics cabinet (CEC) and several projector heads. The CEC is located by the computer image generator (CIG), and the projector heads are mounted on the motion platform. Figure 1 shows how the CEC receives signals from the CIG and sends signals to the projector heads via cables. Small optical sensors are placed on the screen just outside the field-of-view. These microprocessor-controlled sensors provide feedback information for self-alignment.

DRIFT COMPENSATION

Analog circuits inherently drift with temperature and time. As a result, display devices utilizing these circuits must be periodically re-aligned. Alignment can be a time consuming process especially if there are multiple potentiometers (some being interactive), capacitors, inductors and delay lines to be adjusted. Frequent alignment procedures are expensive so drifts should be minimized.

A common method of correcting geometric distortion and color misconvergence in a display is to generate a correction polynomial that is a function of the x and y deflection signals. Such a polynomial function might have the form:

$$f(x,y) = \text{Offset} + Ax + By + Cxy + Dx^2 + Exy^2 + Fx^3 .$$

Each term of the polynomial is a different type of correction. For example: Cxy is a keystone correction and Exy^2 is a pincushion correction. The signal f(x,y) is summed with the deflection signal to produce a reasonably converged and undistorted image. Figure 2(a) shows how correction terms such as: x, y, xy, x^2, xy^2 and x^3 can be generated and summed together in the analog domain. When this

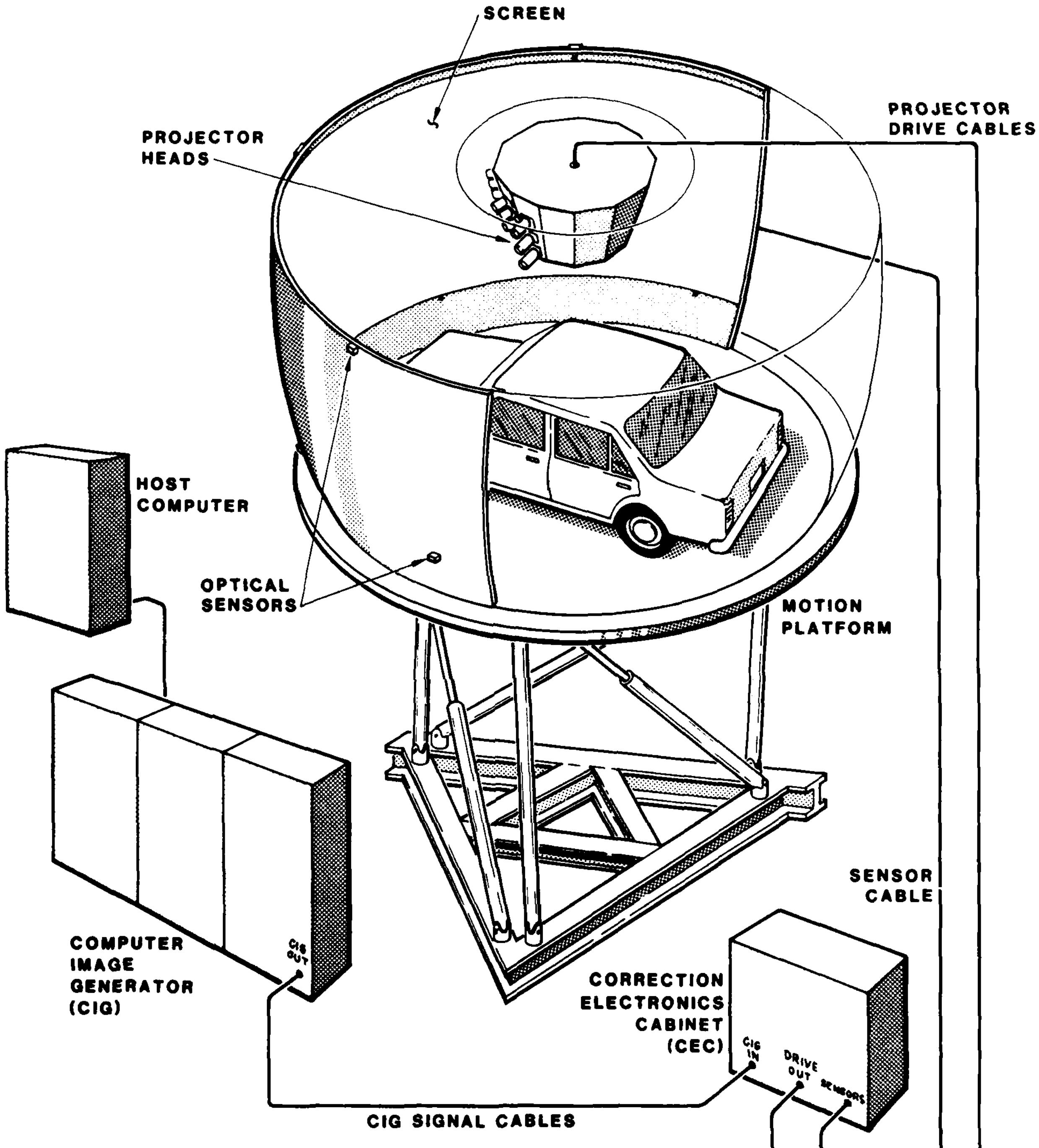


Figure 1. Integration of the Projector System with a CIG and a Motion Platform

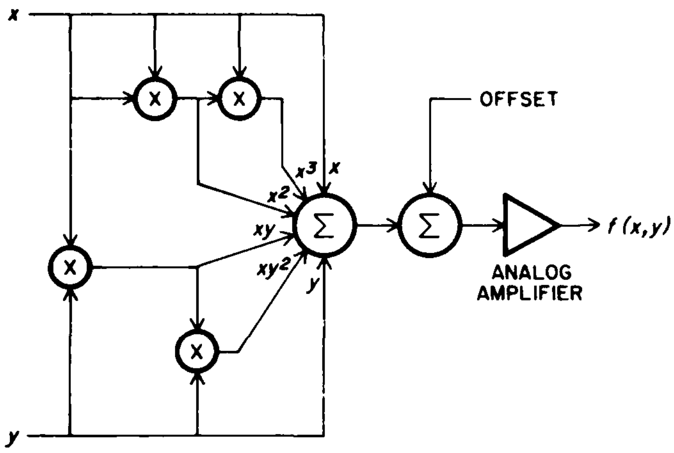


Figure 2(a). Analog Correction

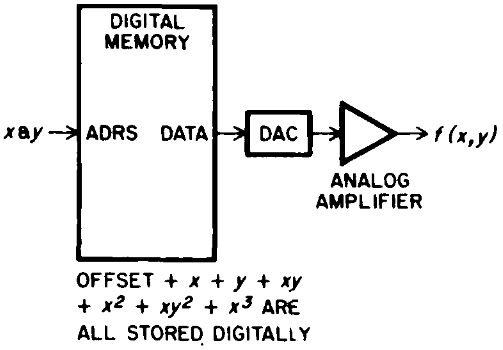


Figure 2(b). Digital Correction

approach is used, a separate potentiometer is necessary to adjust the weighting of each product term as it applies to the overall correction function. Because these potentiometer-controlled circuits (which are the terms of the correction function) can drift independently, it is very difficult to determine and correct drift-induced errors.

Digital generation of the correction signal offers a superior method of drift control. Figure 2(a) and 2(b) show analog and digital techniques for computing the correction function f(x,y). By locking various product terms together in a digital memory there can be no independent drift in the product terms. This does not eliminate drift completely since the necessary digital-to-analog converters and analog amplifiers still can drift, but it does simplify the problem because drift can only occur in gain and offset.

Gain and offset errors can be easily detected and resolved. This is the fundamental premise that permits a "closed loop" system around drift. Optical sensors located on the projection screen (or alternatively sensors fiber optically coupled to the CRT faceplate) sense the drift induced errors. Figure 3 is a simplified block diagram of the hardware necessary to detect and correct drifts. By "closing the loop" or feeding back around the imagery, important visual parameters are automatically compensated by the feedback electronics. Good edge-matching between channel boundaries is assured by controlling the color-hue, intensity, and geometric alignment of adjacent channels.

HARDWARE

The cathode-ray tubes, the lenses, the projection screen, and the electronics of a projector must carefully be considered when designing a high-performance projection system.

Cathode-Ray Tubes

The cathode-ray tubes (CRTs) used in the projector heads were specifically designed for high brightness. They have seven-inch faceplates with high-brightness phosphors. The green phosphor is P53, the red phosphor is P56, and the blue phosphor is similar to a P4 silicate blue. The tubes operate at a 40 kilovolt anode voltage and use liquid cooling to allow continuous operation at high-brightness video levels. The 4 mil maximum spot size can comfortably accomodate a 1024 line per channel resolution.

Lenses

The lenses used in the projector heads have the following properties:

(1) Small and light weight to minimize the moment-of-inertia on a motion platform.

(2) More uniform brightness over the entire aperture of the lens to minimize intensity rolloft at the edges of a projection channel.

(3) 1024 raster line resolution over the entire viewing area.

These parameters were intentionally designed into the lenses to improve the overall system performance. Figure 4 is a photograph of one projection head with the lenses attached.

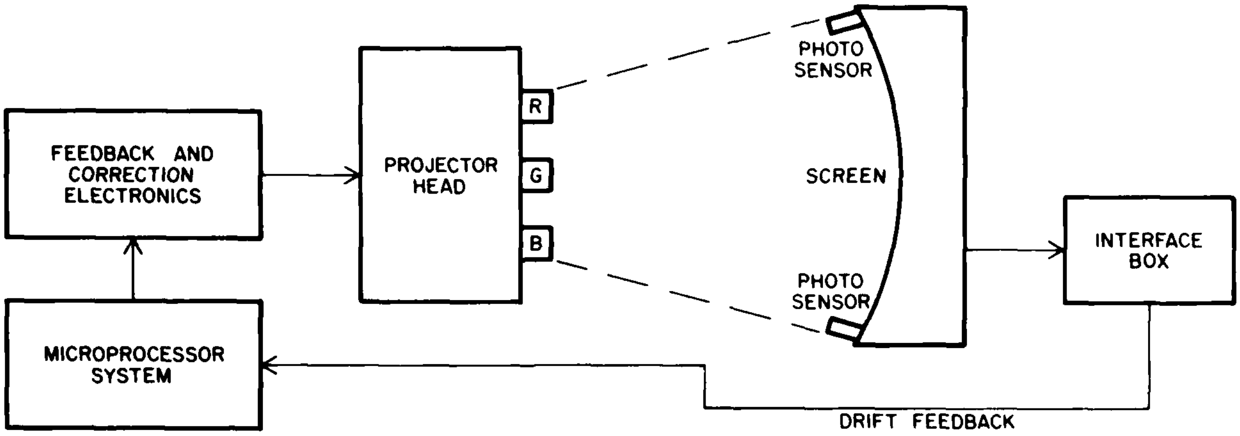


Figure 3. Optically "Closing the Loop" Around Drifts

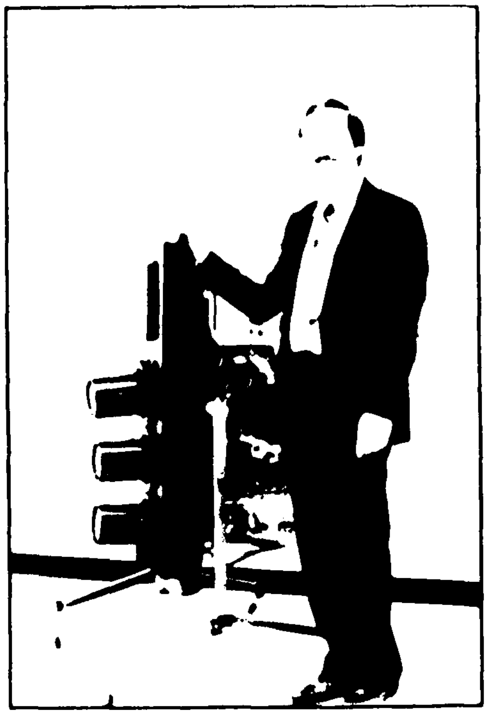


Figure 4. Projector Head and Lenses

Projection Screen

The gain of the projection screen has an important impact on overall system performance. If the screen gain is too low, the projected images will appear dim. If the gain is too high, sensitivity to screen defects is increased and the exit pupil (the area from which the image can be viewed) becomes smaller. Also, color separation at the fringes of the exit pupil may become noticeable.

Wide field-of-view screens are curved to optimally direct the light from the projector into the exit pupil. The radius of curvature for this projector was chosen to be approximately 12 feet. Twelve feet is a trade-off among exit pupil size requirements (one or two observers), eye accomodation, acceptable off-axis viewing distortion, and a size compatible with a motion platform. A screen gain of 3 was selected as the optimal trade-off among projector brightness capability, cross illumination minimization, and reasonable screen surface tolerances.

Electronics

The electronics of this projector combine a variety of technologies. Analog, digital, electro-optical and microprocessor designs interact to form a system that can be initially aligned through a computer terminal, keep itself in alignment with optical feedback and diagnose its own hardware problems. Figure 5 is a simplified system block diagram showing how the electronics interact.

The system electronics are physically partitioned into three sections: the projector head, the correction electronics cabinet (CEC), and the CEC interface box. The "projector head" houses the CRTs and lenses. It also contains the video, deflection, and correction amplifiers. The "correction electronics cabinet" houses the digital correction and microprocessor related hardware. The "CEC interface box" contains the sensor hardware for sending feedback information to the correction electronics cabinet. It also buffers the maintenance signals sent from the microprocessor to the projector heads.

The projector heads and CEC interface box are mounted on the motion platform and the correction electronics cabinet is

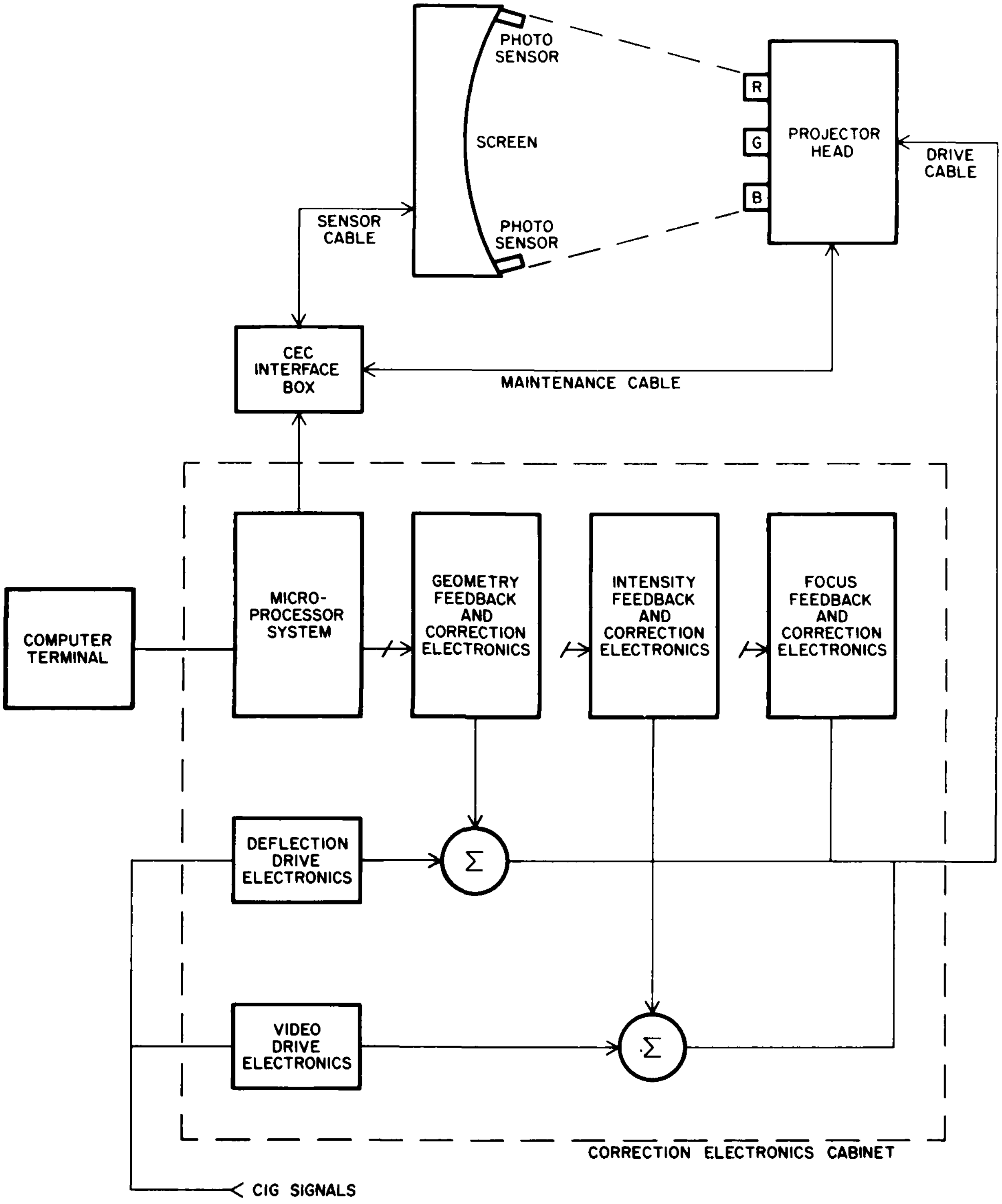


Figure 5. System Block Diagram

located next to the image generator. One correction electronics cabinet and CEC interface box will support up to eight projector channels.

Following is a brief discussion of each major section of hardware.

Microprocessor System

The microprocessor system operates in one of four modes. The first mode is the "normal operating mode" in which the projector accepts signals from the CIG and displays images. In this mode the microprocessor controls the projector's self-alignment procedures and performs real-time diagnostic tasks between action fields. The second mode is the "initial-alignment mode". In this mode a user can align the projector from a terminal using the built-in pattern generator. The third mode is the "diagnostic test mode". In this mode the host computer talks to the projector and executes board level diagnostic tests. The fourth mode is the "local system mode". In this mode a ROM resident debugger/operating system controls the projector. A user can probe and control the individual sections of the projection system from a terminal.

Digital Correction Electronics

Digital correction signals are generated for intensity, geometry, and focus. The microprocessor calculates what the correction functions need to be and stores them in the "correction memories". The data in these memories are operated on by a digital transfer function and fed into digital-to-analog converters.

Deflection Drive and

Video Drive Electronics

The deflection drive electronics receive the horizontal and vertical sync signals from the CIG and generate the signals required to drive the deflection amplifiers in the projector head. These signals are digitally generated by a "state-machine" which is a slave processor to the microprocessor system.

The video drive electronics receive the video signals for red, green, and blue from the CIG and modulates them with the required intensity correction and edge matching signals. This modulated video is sent over cables to the video amplifiers in the projector head.

Projector Head Electronics

The projector head houses the video, deflection and correction amplifiers. These are linear amplifiers that only drift in gain and offset. The bandwidth of these amplifiers varies depending on the required system resolution.

Phosphor protect circuitry in the projector head senses the loss of horizontal or vertical sweep, power supply failures, and excessive anode current. If such a failure is detected, the beam current and the anode supply are immediately turned off to prevent CRT phosphor damage.

The maintenance cable extends the microprocessor system into the projector head. Memory-mapped analog-to-digital converters allow tests on the analog circuits, and digital ports can be accessed to observe the status of parameters like: phosphor protect, high-voltage and cable continuity. Also, video threshold (G2) and static focus are controlled in the projector head digitally via this microprocessor interface.

Feedback Sensor Electronics

Photo sensors are placed between adjacent channels slightly outside the field-of-view. These sensors are optimized in size and sensitivity to detect sub-pixel positional drifts and slight changes in image intensity. This analog information is converted to a digital value and read by the microprocessor system.

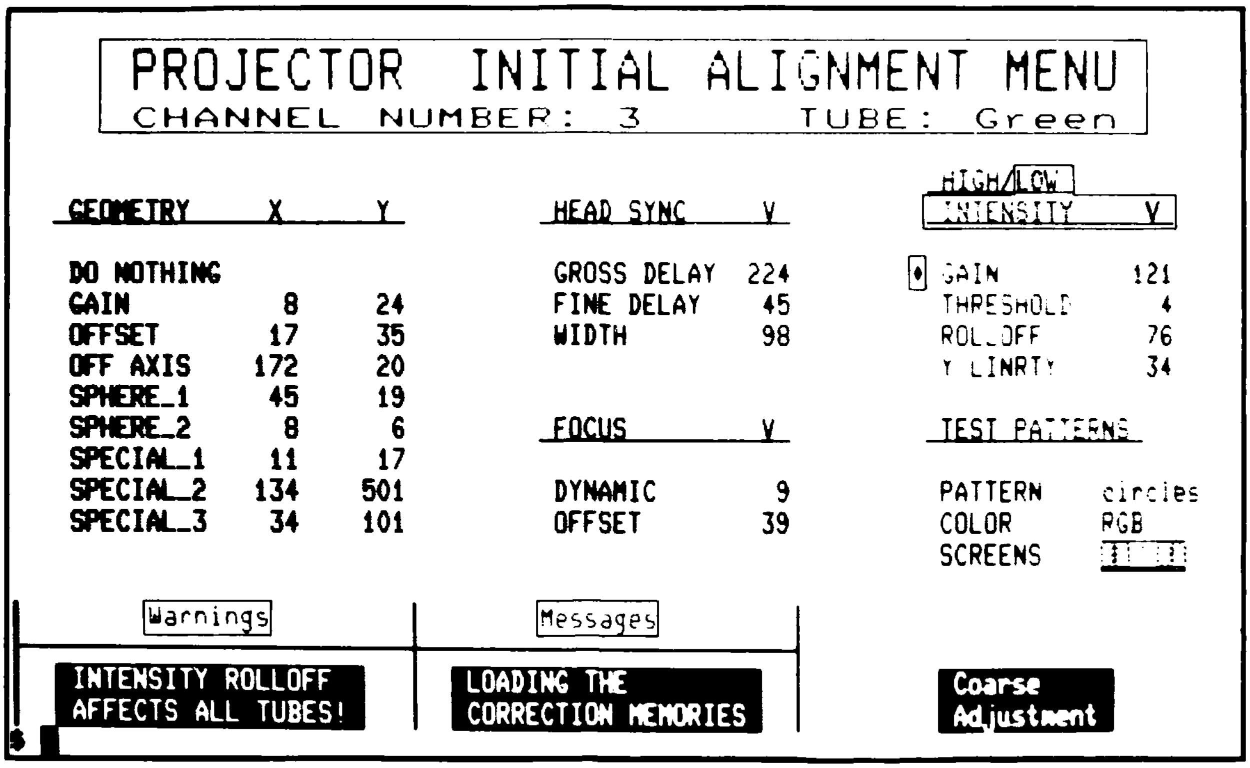
ALIGNMENT

There are two types of alignment in the projection system, initial-alignment (IA) and self-alignment (SA). Initial-alignment is the process of converging the projected image and correcting any geometric distortions. Self-alignment is the process by which the system "closes the loop" around important visual parameters to prevent the projected image from drifting away from the initially aligned condition.

Initial Alignment

The projector is placed in the initial-alignment mode when an interrupt command is generated by the alignment terminal. The system software will currently support either a Digital VT100 terminal or a hand-held Termiflex HT-12 terminal. During alignment this terminal is temporarily located on the motion platform so the user can see the projection screen while aligning the system.

With the projection system in initial-alignment mode, an "alignment menu" appears on the terminal. The alignment menu is optimized for the most "user friendly" interface. Figure 6 shows an alignment menu for a VT100 terminal. The user can select a parameter and modify it interactively. The value of the alignment parameters can be observed by



PROJECTOR INITIAL ALIGNMENT MENU
CHANNEL NUMBER: 3 TUBE: Green

GEOMETRY	X	Y
DO NOTHING		
GAIN	8	24
OFFSET	17	35
OFF AXIS	172	20
SPHERE_1	45	19
SPHERE_2	8	6
SPECIAL_1	11	17
SPECIAL_2	134	501
SPECIAL_3	34	101

HEAD SYNC	V
GROSS DELAY	224
FINE DELAY	45
WIDTH	98

FOCUS	V
DYNAMIC	9
OFFSET	39

HIGH/LOW

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Warnings

INTENSITY ROLLOFF AFFECTS ALL TUBES!

Messages

LOADING THE CORRECTION MEMORIES

Coarse Adjustment

Figure 6. Initial Alignment Menu

pressing the appropriate keys on the terminal keyboard. "HELP" and other useful screen menus are also provided to simplify the alignment process.

The most significant feature of the initial-alignment control is its programmability. Any correction function that can be defined mathematically, can be implemented to facilitate user interaction during alignment for the particular geometry involved. As a result, complex corrections such as off-axis and spherical distortion are easy to contend with. The time it takes to align a projector channel is small because the "user friendly" terminal interface makes complicated functions easy to manipulate. For instance, compound terms can replace common correction terms like: tilt, linearity, and keystone. Quasi-automatic and even totally automatic methods of initial-alignment are possible extensions of this technology.

The "speed of the microprocessor" lets the user observe real-time changes on the projection screen as the correction control is manipulated. For instance, if a keystone distortion is to be introduced, the user can press an increment or decrement key on the terminal and watch the projected image change smoothly in keystone, just as though he were turning a keystone potentiometer. This immediate visual feedback is essential for a workable human interface.

The projector utilizes optical feedback to automatically match color-hues between adjacent projector channels. The user aligns one channel for the desired color tempeature or "white level" and the microprocessor sets the video parameters of all the other channels to match. This saves time on a multi-channel system since only one channel requires careful color alignment.

The expected correction function (which is the best average correction determined at the factory) can be preloaded in the correction memories during initial-alignment. This expected correction serves as the starting point, so only slight modifications are required to achieve the final alignment.

When initial-alignment is completed all the alignment parameters are stored in a non-volatile memory and used as a reference by the self-alignment software. When the projection system is powered down and then powered up again, it can return to the latest initial-alignment state by retrieving this non-volatile information.

Self-Alignment

When the projection system is in the "normal operating mode" self-alignment is continuously operating. Self-alignment refers to the process of optically "closing the loop" around system drift.

Drifts in color-hue, intensity, color-convergence, geometry, and focus are automatically detected and corrected. There are three phases to the self-alignment process: data collection, data analysis, and feedback-correction.

During data collection the microprocessor controls the projection of test information (during vertical retrace) in the vicinity of the photosensors. The test data is slightly outside the field-of-view so system users won't notice it. Different types of test data are used to check for geometry, intensity, and focus drifts. The collected data are stored for data analysis.

During data analysis the microprocessor must analyze the collected data and determine what has drifted. It also needs to separate gain drifts from offset drifts. This is done by comparing reference data from initial-alignment with the collected data and processing the differences. The result is transformed into a feedback-correction signal.

Once the collected data are analyzed and a system drift has been identified, a signal is sent to the proper feedback-correction circuit. This is the final step in "closing the loop". A system drift has been compensated.

The rate at which the microprocessor can perform data collection, data analysis, and feedback-correction must track the maximum rate of drifts in the system. This system has been designed to correct for thermal and temporal drifts.

"Closing the loop" around the real visual scene instead of beam-current or some other parameter has advantages. Phosphor degradation is automatically compensated since the CRT phosphor is included in the closed loop system. Also, the color-hue of all the projector channels can be made uniform by monitoring one channel and setting the other channels' video-parameters to match.

During self-alignment, system drifts are continually being corrected. Because of the digital nature of the feedback signal, corrections will occur in quantized steps. The minimum size of these correction steps are selected so the "eye" cannot distinguish them. For geometry the minimum step is +/- 1/8 of a pixel.

MAINTENANCE

The mechanical packaging of the projection system was designed to permit easy access to all individual components. Boards in the correction electronics cabinet plug into a backpanel, and sections of the projector head are modularized to permit easy maintenance and replacement.

When the projector is in the "normal operating mode" real-time diagnostics (RTD) are being performed. The microprocessor continually monitors every part of the system for hardware and software problems. When a problem is identified a message is sent over a serial interface to the host computer. During real-time diagnostics the microprocessor merely reports problems and makes recommendations but does not try to discover the cause of the problem. By so doing, the operator can decide whether to continue operation in a partially failed condition or shut down for repairs.

If the microprocessor reports a problem and a hardware/software failure is suspected, the projector can be placed in the "diagnostic test mode". In this mode board level diagnostic programs are run. The host computer selects the tests by sending messages over the serial interface to the correction electronics cabinet. The microprocessor runs the test and reports back over the same interface whether it passed or failed.

SYSTEM CONFIGURATION

Figure 7 shows the projection system under development. This configuration typifies the off-axis spherical projection schemes that are possible. Six projector channels are used to fill a 30 degree vertical by 180 degree horizontal field-of-view. The screen has a gain of 3 which yields a nominal brightness of 20 foot-lamberts. The line resolution is approximately 3 arc-minutes.

CONCLUSIONS

This projection system represents a viable approach for solving the wide field-of-view, high-resolution, high-brightness projection problem. The wide range of distortion correction allows off-axis projection on curved surfaces and the multiple channels provide high-resolution and high-brightness with existing projection devices. The microprocessor controlled initial-alignment, self-alignment, and diagnostics make such a system operationally practical.

ABOUT THE AUTHOR

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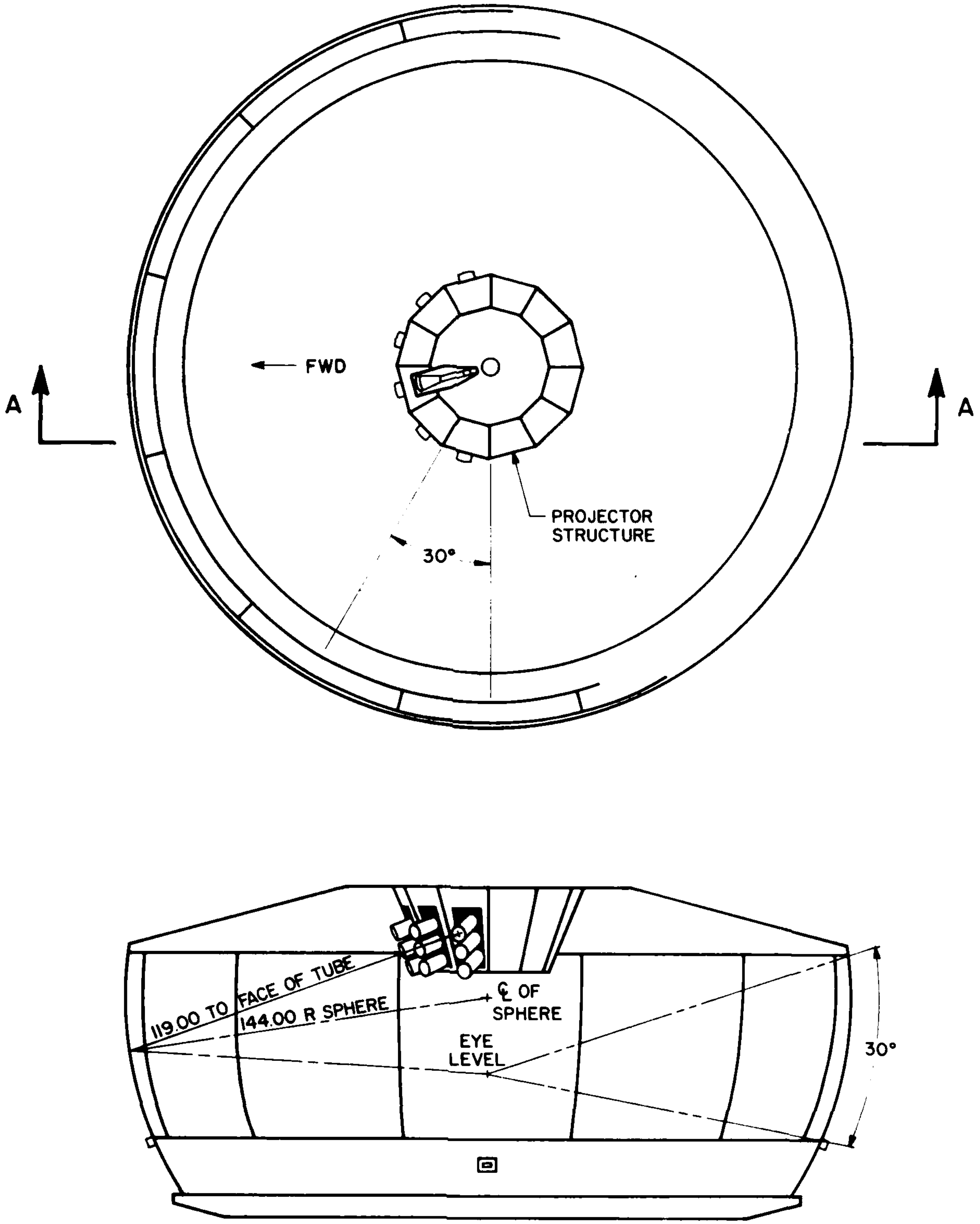

SECTION A-A

Figure 7. Top and Side View of the Projector System Configuration

CLOSING THE GAP BETWEEN AIRCRAFT AND SIMULATOR TRAINING WITH LIMITED FIELD-OF-VIEW VISUAL SYSTEMS

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ABSTRACT

A limited field-of-view (LFOV) visual system for the F-15 flight simulator (FS) - developed and built by Goodyear Aerospace Corporation - would greatly increase the already proven training capability of the FS. The current F-15 FS, having no visual system, readily handles all its assigned instrument and emergency procedure training tasks. The LFOV system - capable of adapting to cost parameters - will enhance the overall training capability of the F-15 FS by adding out-the-window visual cues. The overall training capability, particularly in the visual air-to-air and air-to-ground modes, is expected to be significantly improved by the addition of the LFOV system. The data base for the LFOV system is intended to support air-to-ground, air-to-air, and normal airfield operations. Air Force instructor pilots will evaluate the LFOV for a three-month period by following specific evaluation plans and by using strict grading procedures.

BACKGROUND

Flight simulators have been for many years major contributors to effective aircrew training. Likewise, it has been recognized that the addition of a visual system to a simulator can significantly expand the types and increase the quality of training scenarios. However, a complete visual system which offers total combat mission training can be cost prohibitive. A dedicated evaluation of aircrew training programs might discover it more cost effective to train some tasks in aircraft and, consequently, select a visual system that may be limited but which fits both cost and training parameters.

A USAF Operational Test and Evaluation (OT&E) report(1) in 1979 cited the lack of a visual system as being the number one operational deficiency/limitation of the F-15 Flight Simulator (FS) - in operation by the Air Force for over six years. Three years before the OT&E, the need for a visual system was established as an official requirement(2) for the F-15 FS. This requirement still remains unfulfilled because a cost-effective approach to visual system attachments has not been developed.

In 1978, it was determined that a visual system coming from USAF project number 2360 would satisfy the requirements for the F-15 FS. This proposed visual system was to provide visual cues necessary to train the full tactical mission. Due to budgetary constraints, this project did not meet its goal.

The Air Force restarted the effort in 1982 with a requirement from HQ TAC(3) to pursue acquisition of state-of-the-art limited field-of-view visual systems for the A-10, F-15, and F-16 simulators. This requirement prompted Goodyear Aerospace Corporation (GAC) to initiate a study to assist the Air Force in specifying the requirements for a LFOV visual system which would satisfy most of the training task objectives.

DESCRIPTION OF THE F-15 SIMULATOR

The F-15 FS was designed to support initial, continuation, and instructor pilot training associated with the F-15 weapons system. It provides training in normal and emergency systems operations in the instrument flight regime. Fully operational offensive and defensive systems permit integrated training against a variety of airborne and surface targets, but only under simulated instrument flight conditions. The simulator, designed and built by Goodyear Aerospace Corporation (GAC), Akron, Ohio, incorporates a five-degree-of-freedom G-seat, G-suit, and a wide variety of aural cues for a realistic training environment.

ANALYSIS OF F-15 TRAINING REQUIREMENTS

Training task requirements in references 1, 2, and 4 were analyzed in an attempt to specify the field-of-view (FOV), FOV orientation, and other characteristics of a LFOV visual system best suited to satisfy the training objectives of the F-15 FS.

The F-15 FS OT&E(1) is the most authoritative signal source of F-15 FS training task requirements, listing 99 tasks covering transition and air-to-air phases. The F-15 FS trains all 60 of the 99 tasks assigned to it, including cockpit checks, engine operation, instrument approaches, climbs/descents, autopilot operation, afterburner operation, emergency procedures, radar operation, armament operation, and scramble procedures. In addition, nine other tasks are considered partially trainable in the F-15 FS. The 30 remaining tasks, such as taxiing, takeoffs and landings, overhead patterns, aerodynamic braking, basic fighter maneuvers, attacks against bogeys, formation flight, "G" exercises, and flight controls, are classified as nontrainable in the F-15 FS, but most of these may become trainable with the addition of a LFOV system.

Another source of training task requirements is the combination of the minutes of a LFOV working group at Eglin AFB(4) and the LFOV visual system requirements document(2). Most of the tasks in this combined list also appear in the OT&E task list; however, the combined list includes several air-to-ground tasks not found in the OT&E list.

Using these references, it is readily apparent that the FOV requirements for air-to-air and air to ground tasks vary widely. For the majority of the air-to-air tasks, FOV requirements are symmetrical in both azimuth and elevation, with FOV requirements as high as 140 degrees in elevation and 220 degrees in azimuth. In nearly all cases, the FOV requirements for the air-to-ground tasks are skewed off to one side, requiring about 120 degree by 20 degree azimuth and 120-degree elevation. These FOV requirements were calculated largely by geometric analysis and by recording canopy migrations of targets utilizing the F-15 FS and experienced fighter pilots. These results do not vary widely from results of a study done by the USAF$^{(5)}$ using the Simulator for Air-To-Air Combat (SAAC) and the Advanced Simulator for Pilot Training (ASPT). (Table 1.)

TABLE 1 - USAF FOV STUDY RESULTS

Tasks	Field of view required Azimuth	Field of view required Elev	Azimuth Left	Azimuth Right	Elevation Up	Elevation Down
Air to-air FOV (deg):						
Low yo-yo	83	88	42	41	58	30
Immelman	86	95	56	30	76	19
Lag-roll	101	104	52	49	67	37
Hi yo-yo	108	108	75	33	50	58
Lead turn	163	132	86	77	71	61
Quarter plane	162	142	105	57	79	63
Barrel roll	299	142	161	138	94	48
Air-to-ground FOV (deg):						
10-deg dive	67	69	65	2	52	17
15-deg dive	87	114	74	13	61	53
30-deg dive	76	97	71	5	57	40
45-deg dive	86	113	74	12	56	57
Level	62	67	60	2	56	11
10-deg pop-up	70	81	64	6	57	24
30-deg pop-up	96	122	79	17	73	49

SELECTING A LFOV VISUAL SYSTEM

Based on the above results it would appear that most of the F-15 training requirements are within a FOV of 220 degrees azimuth, oriented symmetrically about the cockpit nose, and 140 degrees elevation, oriented 30 degrees down and 110 degrees up.

A LFOV visual system implies that compromises will be made in training objectives in an attempt to minimize cost. In addition to FOV, several other parameters - Display Type, Image Generator Capacity, Projection System, Trainer Impact, and Data Base Development - must be considered and can have a major cost impact on the addition of a visual system to a FS:

FOV: • Size • Orientation • Different Orientations for Different Tasks • Ability to Dynamically Track the Area-of-Interest

Display Type: • Rear Projection Infinity Display • CRT Beam Splitter • Dome Display

Image Generator Capacity: • Animation Requirements • Moving Target Requirements • Texturing Requirements • Scene Detail/Density Requirements • Shading/Color Requirements

Projection System: • Brightness Requirements • Resolution Requirements • Camera Models • Light Spot Models

Trainer Impact: • Ingress/Egress • Maintenance Accessibility • Software Enhancements • Instructor Station Considerations • Contract Data Requirements

Data Base Development: • Level of Generic Terrain Detail • Size of Specific Terrain Detail • Level of Model Detail

Most pilots generally agree even the best state-of the-art computer generated image (CGI) visual system is marginal in its ability to present enough scene detail, high resolution, and brightness to fully train all air-to-air or air-to-ground training tasks. Therefore, it might be wise not to sacrifice quality in these areas but concentrate cost savings in the areas of reduced FOV and trainer impact.

Consideration was given to ways of reducing the simulated FOV to something less than that required to satisfy the F-15 training objectives of 220 degrees by 140 degrees. The FOV of the motionless human eye has a horizontal extent of about 160 degrees and a vertical range of 70 degrees downward and 50 degrees upwards. The F-15 aircraft FOV (Figure 1) has a maximum vertical downward FOV of 40 degrees with an overall average downward FOV of about 20 degrees. Based on these conditions, a minimum desirable FOV would be about 160 degrees azimuth (oriented symmetrically about the cockpit nose) and 60 degrees elevation (oriented 20 degrees down and 40 degrees up). This FOV should be adequate for general training requirements, straight-in approaches, target identification, etc. However, the primary area of interest will often migrate outside this field-of-view when flying against a specific or designated target, such as executing a basic fighter maneuver (BFM) against a bandit, a pop-up bombing run against a ground target, or a

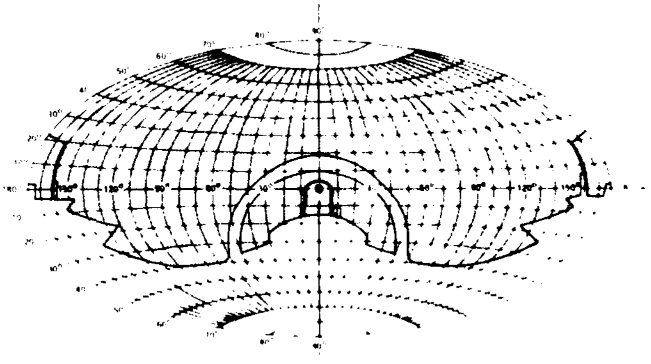

Figure 1 F-15 Aircraft FOV Plot

circling approach to a runway. Since the orientation of the primary area of interest relative to one's own ship is known, there are several ways in which the FOV area can be supplemented or the effective FOV increased. A full display dome provides the maximum flexibility for these considerations and also significantly reduces trainer modifications to provide for student ingress/egress and maintenance provisions. The primary disadvantage of the dome display over other types of infinity optics displays is that the real image is focused at a finite distance from eyepoint.

One approach to increase the effective LFOV area without adding CGI data channels is to dynamically track the primary area of interest by skewing the projectors to keep the simulated FOV area in the pilot's line of sight (Figure 2). For this to be practical, it is essential the projector displacement mechanism is simple and the projector movement does not cause distortion. As can be seen in Figure 2, if the projectors are mounted symmetrically on a horizontal platform, the platform can be rotated horizontally about the center of the dome without causing distortion. The vertical rotation, however, is a more complex operation. Each projector must be moved independently of the other to prevent distortion.

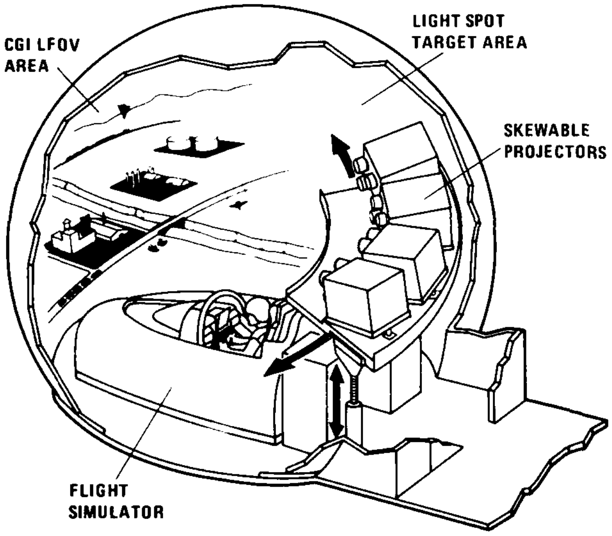

Figure 2 - Typical Dome/Projector Layout

Another approach for more effective use of a LFOV visual scene is to manually reposition the projectors as a function of the training task. For example, based on the FOV study done by the Air Force(5), the FOV required for most air-to-air maneuvers is nearly symmetrically in the horizontal but the FOV is offset to one side for most air-to-ground tasks.

Possibly the lowest cost and most desirable approach to increasing the effective LFOV area without adding more CGI channels is the use of a single light spot projected on the display surface. A simple, low-cost light spot projector (Figure 3) and associated host computer software could determine when and where the primary area of interest (target, approach end of runway, etc.) is about to migrate outside of the simulated LFOV area. At that time and location, the light spot appears on the dome surface, allowing the pilot to continue tracking the target movement until it returns within the simulated LFOV CGI visual scene.

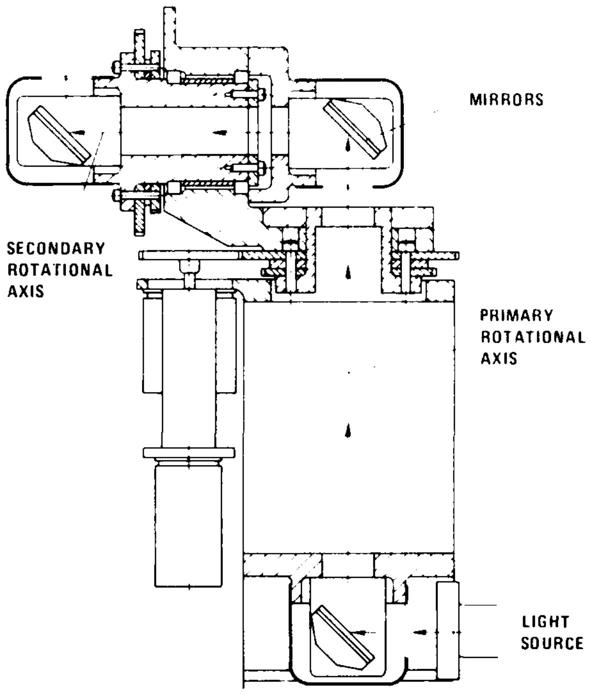

Figure 3 - Light Spot Projector

Determination of the required image generator (IG) capacity (its ability to generate realistic images, moving targets, and special effects) can best be accomplished by developing tactical mission scenarios based on specific training objectives and requirements. A typical mission scenario, based on F-15 simulator training requirements, might consist of three groups of four F-15 aircraft in the air superiority role, a large number of F-4, A-7, and F-16 aircraft in the strike role, a group of four enemy aircraft, air-to-air and surface-to-air missiles, moving ground targets, and antiaircraft (AAA) fire. The total number of moving objects (aircraft, missiles, ground vehicles) within the simulated LFOV area and within visual range will be considerably fewer than the total available at any given time. To simulate this scenario, the IG must be capable of handling between five and ten moving targets. In addition to the moving targets, the IG must be capable of generating special effects such as exploding targets, AAA tracers and flak, and smoke trails and launch flashes of missiles. These effects are important training aids because they provide immediate feedback to the student indicating performance.

THE F-15 SIMULATOR VISUAL EVALUATION SYSTEM

Because of the subjective nature of many of the parameters associated with a LFOV visual simulator system, actual training effectiveness evaluations can only be accomplished through the use of experienced pilots practicing training tasks on a LFOV visual simulator system. A LFOV visual system will be integrated with an F-15 FS and evaluated prior to the FS's delivery to the Air Force in July 1984. This effort will be undertaken by GAC in conjunction with Rediffusion Simulation Incorporated (RSI) and Evans and Sutherland (E&S). A four-channel CGI CT-5A visual system, with a 20-foot display dome and a FOV of 160 degrees in azimuth by 60 degrees in elevation, will be used for the demonstration. The projectors will be mounted on a platform which can be manually repositioned to orient the azimuth FOV from 100 degrees right and 60 degrees left to 100 degrees left and 60 degrees right. A light spot projection system will also be used to extend the FOV of the primary area of interest (Figure 4). The visual data base will encompass an area of about 90,000 sq. nm. System development began at GAC in Akron, Ohio, January, 1983, and the system will be turned over to the Air Force for evaluation for a three-month period beginning January, 1984 (Figure 5).

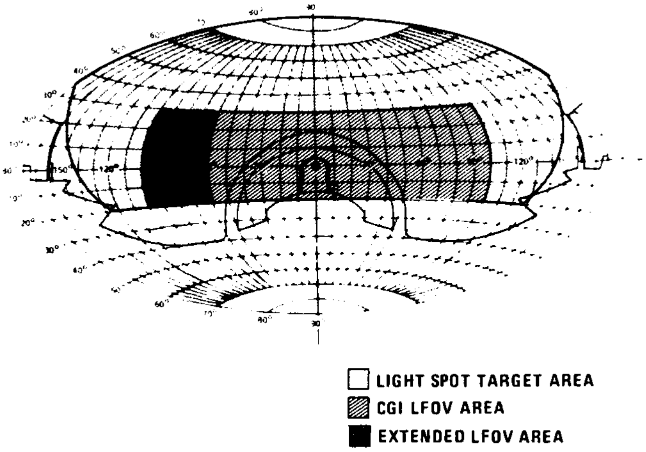

Figure 4 - Demonstration System FOV Plot

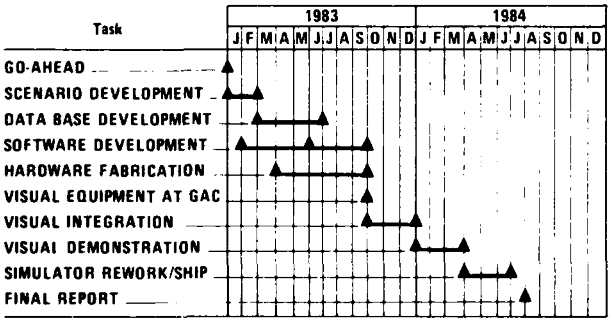

Figure 5 - F-15 Visual Evaluation Schedule

LFOV EVALUATION DATA BASE

The data base for the LFOV simulator demonstration is intended to support air-to-air, air-to-ground, and normal airfield operations. Due to this wide variety of tasks, very few of the conventional trade-offs were made because the same data base must support the entire flight regime. For example, a strictly air-to-air simulator would not require as much detail in the data base to support flight below about 5,000 feet nor would an air to ground simulator require flight above 5,000 feet.

Even during the short time frame allowed to generate the data base, Air Force personnel were utilized in the process to ensure the final data base would address the questions of the evaluation. Input from aircrews was particularly helpful and important in highly subjective areas, such as weapons effects where photographic documentation is very limited. The success of this interaction suggests that participation by aircrews should be encouraged to an even greater level.

AIR TO GROUND CONSIDERATIONS

The ground attack mission will include low-level navigation, threat avoidance, and low altitude delivery, as well as the more conventional dive-bomb delivery. To support the navigational portion of the flight, a 100-by-20 nm corridor of "real world" information is provided. The corridor begins at the Seymour-Johnson AFB and ends at the Dare County, N.C., practice bombing range (Figure 6). Because this entire area is relatively flat, a region of generic hills has been added to the north of the corridor. These hills (Figure 7) are intended to evaluate the system's capabilities for following visual,

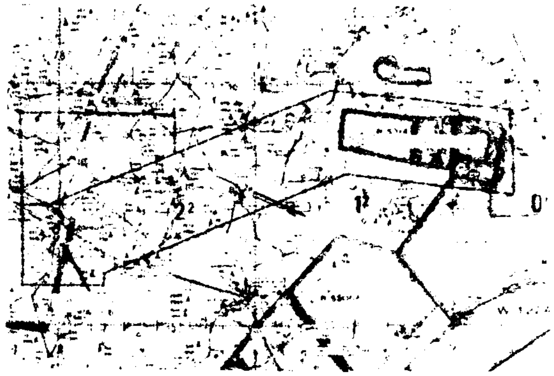

Figure 6 - Dare County Practice Range

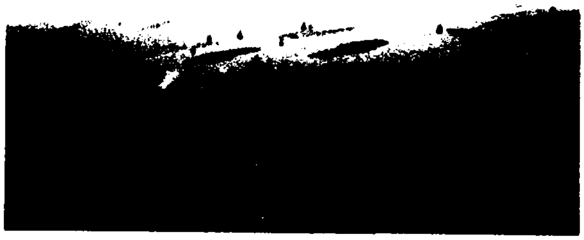

Figure 7 Generic Hills

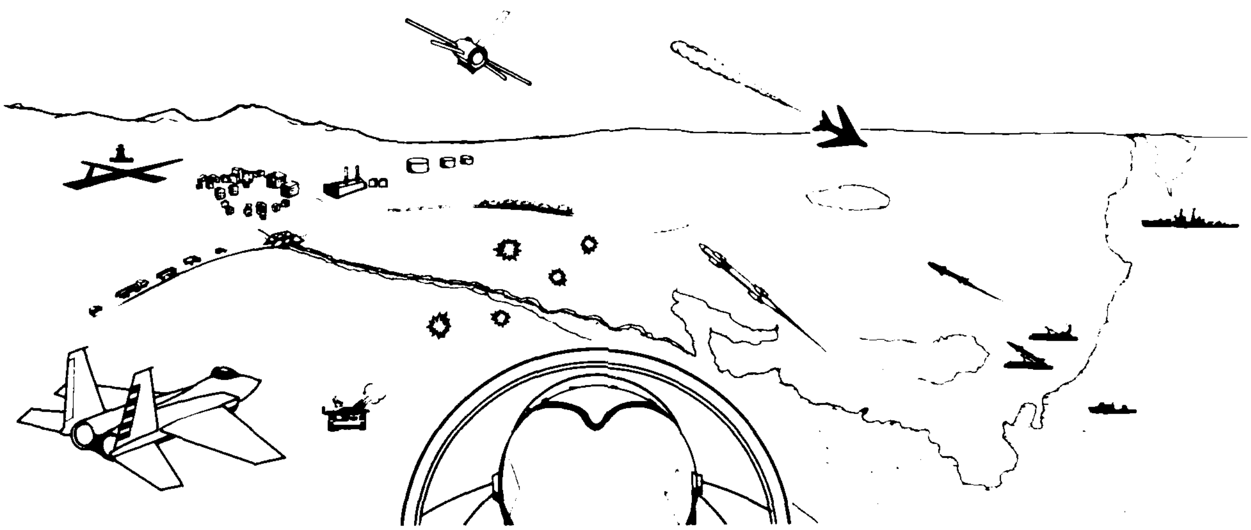

Figure 8 - Tactical Target Range

terrain. Also, near the southern edge of the corridor, a large number of tactical targets and threats have been placed near Washington, N.C. (Figure 8). These include fixed features such as an airport, bridges, factories, and SA-2 sites, as well as tactical features such as tanks, trucks, ZSU-23/4 antiaircraft guns, and SA-6 units (Figure 9). A railroad train and a patrol boat on a nearby river inlet will be dynamic targets.

Possible exercises for evaluation include a low-level mission from Seymour-Johnson AFB to an intercept point near the practice range and various attacks on practice bombing and strafing targets. Alternately, the mission could proceed northward into the generic hills to a recognizable turnpoint, then southeasterly into the corridor where a road/railroad intersection could be the intercept point for an attack on one of the hard targets - airport, bridge, or factory. This attack could then be followed by targets of opportunity in that same area. Both of these scenarios could include a return to base navigation task.

AIR-TO-AIR GAMING AREA

The area around the corridor will be made up of generic terrain approximately 300-by-300 nm. This means that a small number of terrain blocks will be used over and over to provide ground information (primarily for the air-to-air missions). These terrain blocks will closely match the corridor terrain, and the pilot will not recognize any difference except that he no longer has map correlation. The eastern coastline will be included to provide a course navigation and orientation cue. In actual simulator application the entire gaming area would probably have real world correlation. For the evaluation, however, the time constraints limit the amount of real world modeling.

The air-to-air targets include both friendly and enemy aircraft. The F-15 is considered a formation lead ship and is modeled in high detail (Figure 10). This detail includes formation lights, markings, movable wheels, and speed brake. Also, a transparent canopy and selectable afterburner are depicted. The

Figure 9 - Enemy Ground Missile Sites

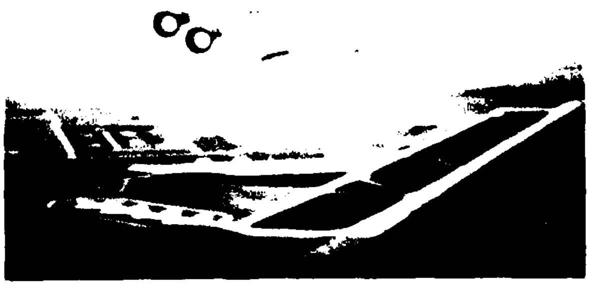

Figure 10 - F-15 Lead Aircraft Model

other aircraft are part of the various air-to-air missions and are modeled at a lower level of detail more atuned to the normal viewing range. These aircraft will also have selectable afterburners and wing positions where appropriate (Figure 11).

Seymour-Johnson AFB is included in the data base to support takeoff and landing maneuvers. Each mission could start and end at the airbase, but for the evaluation it may be preferable to reset to the beginning of a specific exercise. The airbase model (Figure 12) will provide sufficient ground cues for slow-speed taxi and other ground maneuvers. Also, the system's normal range of weather effects may be invoked for instrument takeoffs and landings. Alternately, visual departures and entries may be made using the surrounding geographic features as landmarks.

SPECIAL EFFECTS

A large part of the data base effort for the LFOV demonstration has been the creation of special effects. These generally include scenario components which cannot be handled with normal polygon modeling techniques. Air-to-air missiles, bomb explosions, tracers, and antiaircraft flak are a few examples of available special effects. These effects usually add significantly to the visual system and/or host processing load. The degree of fidelity with which they are simulated will depend on a trade-off among system capacity, training effectiveness, and pilot acceptance. For example, when an aircraft is hit with an AIM 7 (Figure 13), does the trainee need to see only an explosion (Figure 14) or the burning aircraft's downward spiral and explosion on the ground? The trade offs made for the purpose of the LFOV evaluation were also affected by the short time involved. Different choices may be made in an actual application of the system.

Most of the special effects use the CT5A's animation capabilities. This allows very realistic images of dynamic situations such as a SAM launch (Figure 15) or bomb explosion. This technique

Figure 11 - Lower Level Detail Aircraft Model

Figure 12 - Seymour-Johnson AFB Model

Figure 13 - AIM-7

Figure 14 - AIM-7 Hit Explosion

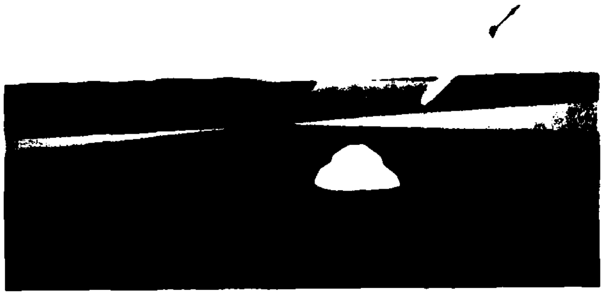

Figure 15 - SAM Launch

has the added benefit of unloading the host computer. Only the hit indication and a position are sent from the host ballistic program. The visual then selects the appropriate animation sequence, moves it to the given position, and starts the sequence. The animation sequence may cycle until deselected from the host or it may cycle only once, requiring no further host input.

Another necessary visual effect for a fighter simulator is the sun. No visual display device will provide the brightness associated with the sun, but the gradual occultation as an aircraft passes in front of it can be simulated (Figure 9/1). In actual training application, the sun's interference with infrared missiles should be included in actual training application.

Figure 16 - Aircraft in the Sun

As noted above, several more and/or different data base decisions might be required in an actual training application of the system. It could be more mission/aircraft oriented for example. Also, the inclusion of infrared sensors in the aircraft, a requirement for radar correlation, and possible detached eyepoint for TV guided weapons would affect the data base as well as the image generator.

METHOD OF EVALUATION

A visual system integrated with the F-15 FS will be evaluated to determine the training capability of such a system for initial and operational training of air superiority, air-to-surface combat, and transition tasks. A listing of the tasks to be evaluated is contained in Reference 2. The tasks have been arranged into 14 separate missions designed to evaluate air superiority and air-to-surface transition training tasks. Three groups of evaluation pilots, totaling 48, will be used in the evaluation. These pilots are F-15, F-16, and A-10 instructor pilots from operational and training units. The evaluation design is shown in Table 2.

The pilot groups are broken up as follows:

F-15 Group. Twenty-four F-15 pilots will serve as evaluation pilots and fly transition and air superiority missions. Twelve F-15 pilots will be from the RTU environment; and the other 12 evaluation pilots will be from the operational training environment.

F-16 Group. Fourteen F-16 pilots will serve as evaluation pilots and fly transition and air to surface missions to evaluate the application of an LFOV system to train specific F-16 training tasks. Half of the F-16 evaluation pilots will be from the RTU environment; and the other half will be from the operational training environment.

A-10 Group. Ten A-10 instructor pilots will serve as evaluation pilots and fly transition and air-to-surface missions to evaluate the application of an LFOV system to train specific training tasks. Half of the A-10 evaluation pilots will be from RTU environments; and the other half will be from the operational training environment.

Prior to the start of the evaluation, team members will receive training on the system, practice the evaluation tasks, and make dry runs of the evaluation procedures. Subsequent training of new evaluation team members will be through on-the-job training.

TABLE 2 - GENERAL STRUCTURE OF F-15 LFOV EVALUATION

Table 2. F-15 LFOV Evaluation Design.

Mission Type	Pilots Required					
	24 F-15		14 F-16		10 A-10	
	12 RTU	12 Operational	7 RTU	7 Operational	5 RTU	5 Operational
Transition	X	X	X	X	X	X
Air Superiority	X	X				
Air-to-Surface			X	X	X	X

At the beginning of each week, evaluation pilots will report to the FS site. These pilots will be responsible for rating the training capabilities of the LFOV system and providing written comments to expand upon the ratings. During the initial in-briefing, all evaluation pilots will be asked to complete a F-15 LFOV background questionnaire. Evaluation pilots will be briefed by the project manager on the purpose and format of the evaluation, the data collection form questionnaire, the training capability rating scale, factors that should be considered in the evaluation of tasks, and the specific mission. Briefings on subsequent missions will be oriented toward that specific mission.

After the in-brief has been completed, evaluation pilots will go to the F-15 FS. The evaluation pilot will sit in the simulator cockpit and will receive a cockpit/visual system familiarization briefing by the console pilot. For the F-15 evaluation pilots, the briefing will be relatively short, concentrating upon the areas of subsystem differences, operation, and areas of the simulation that need to be addressed for the evaluation. The cockpit briefing for the F-16 and A-10 pilots will be in more detail to familiarize them with the operation of the F-15 weapon system. All evaluation pilots will use a kneeboard and attach copies of the mission profile and rating scale to it. All other mission profiles and briefing guides are on file in the project case file. When the cockpit briefing is completed and all questions have been answered, the console pilot will leave the evaluation pilot in the cockpit and return to the instructor operator station. A simulator technician will assist the console pilot in console operation and data collection as required.

Console pilots will be F-15 pilots who have served for one week as evaluation pilots. The duties of the console pilot will be to manage each mission from the console and to maintain a log book. The console pilot will copy the task ratings and comments given by the evaluation pilot, will debrief the evaluation pilot at the end of each mission, and will insure that questions are clearly and completely answered.

The first mission for all evaluation pilots will be for the purpose of familiarization and warm-up practice. This familiarization mission will only be used on the first day of the evaluation week. During the familiarization mission, communication procedures will be practiced and the evaluation pilot will familiarize himself with the FS operation. When the console pilot is satisfied that the evaluation pilot is familiar with the FS, the evaluation will begin.

The console pilot will set the simulator to a preselected set of flight conditions or initialize the simulator for the task to be flown. Initial conditions for the initial task of each mission will be preprogrammed to preclude accidental insertion of erroneous conditions. Initial conditions for subsequent evaluation tasks of a mission will be manually set in by the console technician.

During each mission, the evaluation pilot will perform each maneuver/task once in order to evaluate the training capability of the LFOV. Upon completion of each task, the evaluation pilot will be asked to provide a rating of training capability using the rating scale. Evaluation pilots will rate the training capability of the LFOV system in their area of expertise, i.e., RTU or operational training environment. Comments on these ratings will be made as appropriate. If necessary, and at the request of the evaluation pilot, the task may be reflown in order to rate and comment upon the task. The console pilot will transcribe the ratings and comments concerning factors that impacted the training capability rating (e.g., field of view limitation impacts, brightness, visual system integration with the F-15 FS, resolution, etc.).

The console pilot will initialize the FS for the next evaluation task, and the evaluation pilot will fly the next task. This method will be followed for all tasks to be evaluated during the mission.

When the last task in each mission is completed, the console pilot will freeze the simulator and obtain the ratings and comments for the last task. The evaluation pilot will then egress from the cockpit and will proceed to a debriefing area accompanied by the console pilot.

Another evaluation pilot and another console pilot will be brought to the FS area by the program manager. The new evaluation pilot will sit in the cockpit. The new console pilot will brief the new evaluation pilot on the cockpit and the simulator operation. The familiarization part of the mission will then begin for the new evaluation pilot.

In the meantime, the evaluation pilot who has completed a mission will be given the data collection form with his task ratings and comments for review, revision, and expansion. Any comments not put on the data collection forms will be recorded in the console pilot's log. This general method will be followed for each evaluation pilot for all missions.

The overall training effectiveness of the visual system for each training phase will be appraised by the aggregate of the results of all subobjectives listed under each objective. The measures for each individual subobjective are stated with those objectives. Failure of one or more subobjectives to meet the criterion will not necessarily cause the operational effectiveness of the F-15 visual system for that training phase to be judged unacceptable. Levels of performance below the criterion and the operational impact of each such deficiency will be identified. Based on the aggregate results of all objectives, a judgment will be made by the evaluation team as to the usefulness of LFOV visual systems for F-15, F-16, and A-10 aircrew training devices.

CONCLUSION

A preliminary analysis would indicate that even though the full aircraft FOV is not made available to the pilot, a LFOV visual system for a FS can still be a very cost effective training device. The addition of the LFOV visual system to the F-15 FS should increase the FS's capability to train individual air-to-air tasks such as basic fighter maneuvers (BFM) or complex tactical scenarios involving a large number of active targets, seven of which may be moving in the visual scene at any one time. High resolution computer generated graphic models of several different aircraft types should enhance threat recognition training and allow visual identification prior to weapons employment. Pilots may practice transition from weapon system displays to visual acquisition of both air and ground threats. Tasks such as night, weather, or low altitude air combat maneuvers should be more safely trained in a FS with a LFOV than in an aircraft. Maneuvers may be flown against preprogrammed adversary motion paths or against an instructor flown adversary aircraft. Programmable SAM and AAA threats, capable of launching and firing, let the pilot practice evasive maneuvers. Realism of weapons use is enhanced by visual cues such as smoke trails and explosions. Pilots should be able to maintain orientation with adversary aircraft outside the visual field-of-view by a way of light spot projector.

In addition to air-to-air tasks, most air-to-ground tasks can also be trained. Realistic terrain and ground target modeling allows low altitude navigation both to and from the target area. Training for both conventional and tactical ranges is possible. Weapons effectiveness can be evaluated by special visual effects, such as bomb explosion and bullet impact animations. Basic aircraft flight training is enhanced as well. Visual cues associated with the traffic pattern can be effectively integrated into the instruction process. Various weather and lighting conditions may be created for realistic instrument training, and formation flight with both similar and dissimilar aircraft may be practiced.

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IMAGE GENERATOR ARCHITECTURES AND FEATURES

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ABSTRACT

In order to meet user requirements, tradeoffs are made in the implementation of the four functions (scene management, prioritization, geometric processing, and video processing) that comprise a digital image generation system of the sort used for flight training. This paper discusses how different approaches to image generator architecture affect the features apparent to the user. Among the architectural variations discussed are programmable versus pipelined geometric processing, and four variations of video processor (scanline, reverse-priority-ordered frame buffering, priority-ordered frame buffering, and distance buffering). The architectures are compared with respect to system cost, overload sensitivity, and the implementation of anti-aliasing, texture, and translucency features, among others. Understanding the tradeoffs involved will help designers and users better meet the requirements of a training task.

SPECIFICATION AND DESIGN OF IMAGE GENERATORS

Visual image generators are used to synthesize scenes which respond in real time to, typically, control inputs of a pilot in a flight simulator. The image generators discussed in this paper use digital electronics to generate signals to drive a raster display, usually a cathode ray tube or a light valve projector. Because the displayed scene must respond interactively to the control inputs, new images must be generated 30 to 60 times per second. This requirement, together with the required resolution and scene detail of the images, leads to the development of image generators which are large, complex electronic systems.

The functions performed by the image generator in making a scene may be grouped into four categories: scene management, prioritization, geometric processing, and video processing. The scene management function is the process of collecting the mathematical descriptions of the objects to be used in the scene, a process which usually starts by data retrieval from a disc storage device. Prioritization is the determination of which objects may occlude other objects in the generated image; roughly speaking, higher priority objects are closer to the eyepoint than lower priority objects. Geometric processing is the conversion of the mathematical descriptions of the three-dimensional data base objects into two-dimensional descriptions associated with the coordinates of the display. Video processing comprises all of the remaining steps needed to define the image at each picture element of the display, including the geometric subdivision of faces into pixels, detailed occlusion, and the generation of video signals for the display.

There is no single conventional architecture for implementing the four categories of functions, although there are a limited number of approaches presently in use. The situation with respect to image generator architectures may be contrasted with that of computers, for example, in which nearly all of the systems produced are refinements of one basic architecture. Having no conventional architecture for image generation systems is a situation with implications for both the user and the designer.

Ideally, the user would not need to know how system functions are implemented. Instead, the user might prefer to just know the features of the system, i.e., what the system does, not how it does it. Unfortunately, performance limits in present image generators are too great to permit a simple specification like "images shall be indistinguishable from the real world", and every attempt to write a specific detailed specification runs the risk of using terms or concepts which are inapplicable to the architecture and set of features of a particular design. For example, specifying the capability of a system to produce edges will run into problems in systems designed with limits on a polygon basis, or which make use of texture or curved surfaces.

From the designer's viewpoint, the situation would be simplified if there were simple common measures of performance. In the real situation, there are innumerable tradeoffs among architectures and features. The "correct" tradeoffs depend upon the intended application. Every product designer must be aware of the requirements of the intended user of his product, but the complexity of the product and the subtlety of the tradeoffs make this task especially difficult in the case of image generators.

This paper discusses some of the fundamental tradeoffs involved in designing an image generator to provide certain features to meet the user's needs. To limit the scope of the discussion, only the top level of image generator design is discussed, and then for only a restricted number of the most popular variations. The features discussed are limited to a few of the most architecturally interesting, but include both image related features, such as capabilities for textured and translucent objects in the scenes, and application related features, such as system cost and overload conditions.

SCENE MANAGEMENT AND PRIORITIZATION

System Functions

Scene management and prioritization functions are often performed concurrently in a general purpose computer, but the functions are distinct. The image generation for simulation begins with an eyepoint position and direction of view provided by another computer in the simulator system. The first step in making the image is to select the objects that might be in view from that viewpoint, and this selection process is the basic scene management function. Scene management is performed continually as the viewpoint changes, and the differences between successive viewpoints are usually so slight that the computation requirements and data bandwidths are within the capacity of conventional minicomputers. Similarly, the priority relations among objects which determine occlusion also change slowly in many applications, so it is convenient to run the prioritization algorithms in the general purpose computer as well.

The prioritization function is distinct from occlusion. Two objects have a priority relationship if one may potentially occlude the other, i.e., if every line of sight from a given viewpoint will strike the high priority object before the lower priority object whenever the two happen to overlap in the view. Occlusion is the precise determination of which parts of each object are visible given the priority relationship. If the objects interpenetrate or mutually overlap no priority relationship of the sort described will exist. Consequently, image generators which depend upon priority algorithms to establish priority relationships must use data bases meeting special conditions. These conditions usually end up requiring that all objects be subdivided into convex pieces.

Systems using priority algorithms usually have an architecture which feeds the results of the priority algorithm into the video processing (Fig. 1). The video processor takes the two-dimensional descriptions of the objects, as produced by the geometric processor, and uses the priority order to determine on a picture element (or finer) basis which portions of the objects should be displayed.

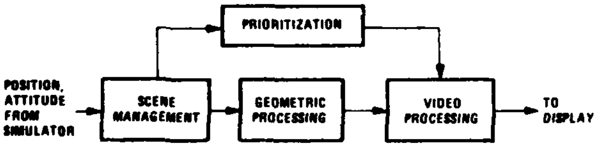

Figure 1. Conventional organization of image generator functions.

An alternative, however, is to have the prioritization performed in the video processor along with occlusion (Fig. 2). Conceptually, this approach is straightforward; for each picture element the video processor must decide which face is closer to the viewpoint and then perform occlusion accordingly. The distance sorting approach removes the restrictions on the types of objects in the data base that are imposed by priority algorithms, and it does away with the priority algorithm execution. Despite the conceptual simplicity and flexibility of distance sorting, the cost of the high speed hardware required to do operations on each picture element, and problems with picture quality and translucency effects, limit the application of the technique.

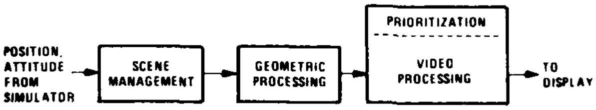

Figure 2. Prioritization performed with video processing in a distance buffered architecture.

If a priority algorithm approach is selected, there are circumstances when the processing speeds of conventional minicomputers may be inadequate. Ordinarily, objects change priority slowly as the viewpoint moves in the data base. Moving objects in the data base complicate the situation because they must be prioritized not only with respect to each other, but with respect to the fixed objects. In addition to running the priority algorithm more frequently, the real time software may have to build mathematical planes to separate moving objects from fixed objects. Separating planes, or other mathematical structures used by the priority algorithm, are ordinarily built off-line for the fixed data base. Altogether, increased processing requirements may require a more powerful computer or special purpose hardware to execute the algorithms.

Scene management functions may also tax the capacity of minicomputers. Ordinarily, the viewpoint changes relatively slowly, as determined by the motions of the vehicle being simulated. Consequently, lists of data potentially in view can be updated rather slowly. If the vehicle can turn rapidly or rotate, it is usually not a serious problem to expand the potentially viewed area to include a wider margin. Even expanding to the whole sphere of view may only require a few times as much data as the actual displayed portion. However, new developments in display technology make it possible to concentrate the scene detail in an "area-of-interest" where the person under training is looking. The ultimate in area-of-interest displays is an eye-tracked system, where scene detail is concentrated in the high resolution portion of human vision. This approach avoids wasting image generation capacity on portions of the scene only peripherally in view, but it also means that scene management must be performed at rates compatible with the very high slew rates of the eye. As with prioritization, this implies either a more powerful computer or specialized hardware, or both.

GEOMETRIC PROCESSING

In order to show objects which appear perspectively correct from any viewpoint, processing must start with a data base representation which gives a three-dimensional model of the object to be depected. Most conventionally, the representation uses vertices in rectangular (x,y,z) coordinates to build polygonal faces and polyhedral objects, but the surfaces could be described by equations of curved surfaces or by more general recursive functions. However represented in the data base, geometric processing is performed to transform the objects into two-dimensional representations in the coordinate system of the display screen. The steps in this processing typically include translation and rotation, illumination, perspective division, clipping (to the screen boundaries), and computation of parameters needed for later shading and texturing of the surfaces.

There are two basic approaches to geometric processor design: special purpose pipelined hardware or general purpose programmable hardware. Until very recently, the only feasible method of achieving the required throughput was to build pipelined hardware specifically for the task, perhaps with some microprogrammable processes embedded in the design. The pipelined approach achieves very high throughput, but the design is complex and expensive to modify. A more general computer approach is now just becoming feasible with parallel processing and the use of high performance VLSI computing elements. Because the development of general purpose computing elements is supported by a broad market and the image generator market is comparatively small, the economics of the programmable approach will probably become more favorable with respect to custom pipeline designs as time goes on. In addition, there is the inevitable trend to more complex geometric processing algorithms to support a greater variety of image features. This means more programming rather than more custom hardware when the programmable approach is adopted.

The geometric processing problem is ideally suited to parallel processing because the image is built of hundreds or thousands of independent objects. Nonetheless, the computational requirements are formidable, requiring roughly 20 million floating point operations per second and perhaps 50 million bytes per second of input and output. Considering just the arithmetic operations, about 150 of the most advanced microprocessor arithmetic units would have to be kept busy to perform the calculations. Spreading the load evenly among so many processors poses many problems, but the approach is near the borderline of feasibility for devices as expensive as image generators.

Whether programmed or done in special hardware, there are distinct possibilities of merging scene management and prioritization functions into the geometric processing hardware structure, and one of the design tradeoffs in doing so is the flexibility of making changes versus the efficiency of processing. (This is evident within the software realm itself, as well. The trend is definitely away from writing scene management software in assembly language and towards coding in high level languages. The loss in execution efficiency is now more than compensated by increased flexibility and maintainability.)

Near the video processing end of the geometric processing, the principal design tradeoff is in regard to system bandwidth versus load management ability. Image generators often drive more than one display, so it is natural to dedicate hardware to each display to provide parallelism in the computations. However, whenever hardware is dedicated to a display, the system will have some susceptibility to overload in one channel while there is spare capacity in another, an obvious inefficiency. At some point in the system, the bandwidth of generated data becomes too great to permit interchange among processors, but the exact point is a design decision. One logical point to make the division is after geometric processing, but the split could be made earlier, in the middle of geometric processing. The point in the system after clipping to window boundaries is another logical point for the split. In general, systems dividing the data streams earlier will avoid design problems of high data bandwidths within the machine, but at the expense of less efficiency and greater overload susceptibility.

VIDEO PROCESSING

A general purpose computing approach may be considered for geometric processing, but video processing, with requirements hundreds of times greater, is safely in the domain of special purpose hardware for the foreseeable future. High processing and data bandwidth requirements are inherent in the generation of 30 million pixels per second per channel, the result of subdividing the displayed faces into picture elements. Each picture element is described by three color components which in turn are affected by smooth shading, atmospheric haze fading, translucency (which will show the colors of underlying pixels), anti-aliasing (which "smooths" edges), and a variety of other effects.

Scanline Architectures

One of the original approaches to dealing with so much processing was to perform the operations a scanline at a time in synchronism with the raster display of the scanlines. This approach is now well documented and has been used by most of the image generator manufacturing companies. [1]

In order to generate the data for a given line of the display, the objects (or the edges of polygonal faces forming the objects) must first be sorted to find those intersected by the line. The beginning and end of each face on the line is then determined, and occlusion performed using the previously computed prioritization. The visible pieces of polygons are then converted to picture elements and displayed.

It might seem that the sorting process would be a principal drawback to the technique, but it actually is not. The sort is implemented in hardware that supports many simultaneous comparisons, so that the N log N growth of sorting times associated with the sequential sorting of random arrays does not apply. In fact, the principal disadvantage is that the entire processing operation is synchronous by line, and hence the processing overload condition will be driven by the single most complex scanline in the scene. Consequently, a scene which is sparse overall may nonetheless overload the system because time spent on a complex line cannot be made up later on empty lines.

Buffering two or more scanlines alleviates the problem by allowing the generator to run less strictly in synchronism with the display. Once it becomes economically feasible to buffer a whole screen, a family of "frame buffered" architectures becomes possible that offers other advantages in addition to the elimination of scanline overload.

Reverse-Priority-Ordered Writing

Rather than fill scanlines one at a time from the top of the screen, a frame buffer allows construction of the picture in a number of different orders, unrelated to scanline position. The most conceptually simple is the so-called "painter's algorithm" in which faces are converted to pixels and written into the buffer in reverse-priority-order, i.e. the lowest priority faces are written first and then overwritten by higher priority faces to accomplish occlusion. For example, the sky would be written first, followed by the ground plane, distant objects, and finally close objects.

Note that to accomplish occlusion by this method it is necessary to generate every pixel of every face, regardless of whether or not any portion of a particular face is visible on the screen. Thus if there are a million pixels in the display, several times that number of pixels may have to be generated, depending upon the amount of occlusion in the scene. Consequently, although the generation of the pixels is straightforward, a great deal of fast hardware will be required, and the system may be subject to overload under a non-intuitive condition of total pixel area written.

Priority-Ordered Writing

The overload due to total writing can be partially cured by changing to the less straightforward scheme of writing the highest priority objects first. In this method a mask must be built to keep track of the portions of the screen written during the course of processing. By reference to the mask, which could actually be built hierarchically with blocks of bits corresponding to the pixels of the display, succeeding faces can be checked for occlusion and portions skipped over as appropriate. System complexity is increased in that additional logic is required for the masking and skipping, but the efficiency is also increased. The processing of shading, fading, texturing, and the like is avoided on occluded pixels in favor of the simpler masking and skipping operations. If the skipping and mask updating can be accomplished much faster than the processing of displayed pixels, then the system will be very robust with regard to overloads.

Distance Buffering

Both priority-ordered and reverse-priority-ordered writing depend upon a separate prioritization process to support the video processing. Prioritization can be performed concurrently with video processing by expanding the dept of the frame buffer to hold the distance to the picture element in addition to its color components. The objects may then be computed in any order and the distances to new picture elements compared to those previously written. At the end of processing, the surfaces closest to the viewpoint at each pixel will be represented in the buffer.

For computational convenience, the existance to a plane parallel to the screen plane may be used instead of the true viewing distance, and the reciprocal of the distance can be used in memory rather than the direct function. Systems are called "Z-buffered" rather than distance buffered when the distance to a plane is used.

Z-buffering has the great advantage of solving the priority problem, but it has several other drawbacks. Like reverse-priority ordered writing, every picture element must be computed, even the ones ultimately occluded. The frame buffer must be enlarged to store the distance function, a disadvantage that diminishes as memory becomes cheaper. But the most serious disadvantages lie in the difficulties with anti-aliasing and translucency implementations, which are discussed in the next section.

IMAGE GENERATOR FEATURES

The features of a system are the elements of its specification. These elements include overload properties and other applications related characteristics, and the image quality and types of visual effects that can be produced. There are dozens of visual effects that can be itemized in an image generator specification, ranging from color properties to the generation of landing light illumination effects. For present purposes it is sufficient to discuss a few of the important features that have an architectural impact upon the system.

Image Content

Anti-aliasing. Aliasing problems originate from attempting to determine the display of an entire pixel based upon a single sample point within the pixel, or from too few sample points within the pixel. The symptoms of aliasing in an image are stairstepped edges, thin lines broken into dotted lines, and discrete rather than continuous motion as objects undergo transitions from scanline to scanline when the scene changes.

Solutions to the aliasing problem involve either the sampling of many points within the pixel and possibly adjacent pixels, and then combining the points in a weighted average to obtain the picture element color and intensity, or treating the image analytically with a similar combination of weighted areas in the picture element.

Translucency. There are translucent objects, particularly smoke and clouds, that enhance some generated scenes. However, the principal use of translucency is to facilitate the change in the level of detail of object models. To save capacity, simple models can be used for objects in the distance and then replaced with more detailed models as they become closer. A translucency capability allows a smooth transition among the models, thereby permitting later transitions without the distraction of a sudden replacement.

Texture. Texture is a modulation of the surface of a generated object using a hardware generated or stored pattern. The intensity of the surface is usually varied pseudorandomly to give a greater sense of depth and apparent motion in the image. Surface parameters such as color and translucency can be modulated in addition to intensity to provide a great range of effects. An interesting special case of texture is the reproduction of digitized photographs, perhaps including translucent regions, to add realism to the generated scene (Fig. 3.)

Figure 3. An image with translucency and texture effects.

Smooth Shading. Image generators designed to work with polygons can provide an illusion of smoothly curved surfaces by shading the objects as if they were curved. The smooth variation of intensity used for smooth shading can be extended to smooth variation of color or translucency in the same manner in which texture was extended for these parameters.

Curved Surfaces. Curved surfaces may be approximated by polygons, but special hardware can also be provided to generate the surfaces from a few parameters. Because polygon processing is so straightforward, especially in video processing, it is debatable whether less hardware is needed to directly generate complex curved surfaces rather than generating them by polygons, but curved surfaces clearly provide for a more compact data base representation of objects that are inherently curved.

System Features

The remarks regarding the variety of visual effects also apply to the profusion of other system features. Three of the most important are discussed here.

Overload Resistance. All systems have finite processing capacity, but all of the elements of the system should be well balanced so there are no critical bottlenecks. The capacity of the system should be as large as possible within the cost constraints, and there should be graceful overload and recovery characteristics.

Modular Construction. Presently, there is no choice but to make image generators large and to some degree complex, but many of the problems of large systems can be minimized if the architecture is highly regular. The "modularity" of a system may be quantified as the ratio of the number of circuit cards in the system to the number of types of cards in the system. High modularity is desirable because it helps production economy, simplifies training of maintenance personnel, and minimizes the spare parts requirements. The greater the modularity number, the greater the benefits.

Another reason for desiring a highly regular architecture is that it eases the transition to increased use of large and very large scale integration. The development of custom integrated circuits is more easily amortized if they are used repeatedly within the system.

Configurability. Designing an image generator from scratch is too lengthy and expensive a process to be undertaken for every new application. Consequently, it is desirable to design systems which are adaptable in terms of capacity and features so as to fit as wide a range of applications as possible. This also provides a growth path for the user should his requirements change.

Making a system reconfigurable by capacity is generally more consistent with high modularity than making it reconfigurable by feature. Nonetheless, features which involve substantial amounts of hardware, such as curved surface generation, are candidates for design as options.

ARCHITECTURE CONFLICTS WITH FEATURES

Obstacles

Some architectures lend themselves better to the implementation of certain features than do others. Rarely are the obstacles theoretically insurmountable, but practical system cost and complexity may be unacceptable unless a clever innovation is found to resolve the potential incompatibility. The resolution of the problem may take the form of a restriction of the system capability, the use of an approximate rather than exact method, or, ultimately, the exclusion of the feature in favor of others more compatible with the architecture and more important in the intended application.

Scanline Architectures

The major problem of scanline architectures is the intersection overload problem previously discussed. There are other, more minor, problems related to the maintenance of a stack of scanstripe segments and the resolution of overlaps and translucent objects in the stack. The algorithms for resolving all of the occlusion analytically on a subpixel basis lead to complex hardware.

Nonetheless, a very general technique for "modularizing" a video processor architecture applies. If work is to be shared among processors, it is better to share it by alternating among pixels or scanlines than to subdivide the screen into regions. The loading is much more likely to be even if the load is shared as suggested. In the scanline architecture, it is better to have, for example, one processor do the odd scanlines and the other the even scanlines (in a field) than to have one do the right half and the other the left half of the screen. If the screen is dedicated by halves, an overload may occur if the scene complexity, perhaps the airport in a flight simulation, happens to fall predominately in one half.

The reverse-priority-ordered writing problem of having to write every pixel, whether occluded or not, is partially offset by the relative simplicity of the approach. General translucency is implemented straightforwardly by mixing a portion of the underlying color and intensity with the new object. Anti-aliasing can be performed by accounting for the fraction of the area in the picture element being covered, and mixing according to the fraction; the anti-aliasing can be done over a larger convolution base with a weighted function if required.

The most difficult problem with this method arises from occlusion not being performed on a subpixel basis. Consider a mountain made of green poloygonal faces silhouetted against a bright sky. The sky would be written first into the buffer, then one green poloygon, and then a matching adjacent polygon. The two polygons should meet on an internal edge so as to occlude the sky completely below the top of the silhouette. However, when the first of the mountain polygons is written, the fractional pixels on all the edges will be blended with the background color, the sky. The adjacent green polygon will then be blended with edge pixels having a sky-colored component already included in those pixels. The net effect is that a thin line of sky will appear along the internal edges of the mountains.

One approach to curing the problem is to tag internal edges when they are first written into the buffer so that the first internal edges will completely overwrite the edge pixels rather than blend. However, there are cases of vertices and thin edges where there is more than one internal edge in the pixel. In addition, the internal edges of translucent objects must pick up the background color, so there are more special cases. Overall, the tagging schemes are at best complicated.

Priority-Ordered Writing

To perform priority-ordered writing with anti-aliasing, occlusion must be performed on a subpixel basis. One way of keeping track of the subpixels is to keep a "bed of nails", a bit map with each bit corresponding to a subarea of the pixel. If the bit is set it means that the corresponding nail has been covered; initially all the bits are set to zero. Only one set of color components need be maintained for the whole pixel, with additions made as the nails are filled in. This solves the internal edge problem for opaque faces.

Translucent faces now cause a potential problem, however, because we must decide what to do with the nails when a translucent face is written. If we set the nails for a translucent face, the nails will not be available for the correct occlusion of underlying opaque faces that will be written later. If we don't set the nails for translucent faces, then the internal edges of transparent faces (which might be almost 100% opaque) will not be anti-aliased correctly. In any case, a separate translucency factor will have to be stored, adding to the nails and color components already needed for each pixel.

The algorithm to treat the problem of top down translucency is somewhat more tractable than the problem of internal edges in reverse-priority-ordered writing. The bed of nails is a basic mechanism for detecting internal edges in any combination without having precomputed tags. Nonetheless, there seems to be no perfect solution under all combinations of multiple overlays of translucency and internal edges.

Note that the presence of translucent objects also diminishes the overload resistance of priority-ordered writing. If all objects were opaque, only pixels intersected by visible edges of surfaces would receive more than one contribution requiring a write cycle. A total of one plus the intersected fraction times that screen size would have to be generated to make a frame. The fraction of edge pixels is small (less than 0.3) so the total amount of processing (assuming skip over is negligible) is quite predictable. Translucency adds a potentially large and variable amount of writing to the processing, considering a cloud or smoke puff covering the whole screen. Some restriction must be placed upon the amount of translucency in the scene to protect the system from such overloads.

Distance Sorting

Z-buffered architectures have difficulties with anti-aliasing and translucency implementations. To correctly occlude and suppress aliasing in the image, operations must be performed on a subpixel basis. Since the distance sorting is performed on discrete sample points, the straightforward approach would be to adopt sorting on a subpixel basis. To accomplish this, the distance and color components of each subpixel must be stored. The expense of generating and storing the information for more than one or two subpixels seems prohibitive with present technology, so it seems that Z buffered systems must be relegated to applications where image quality is not important, or where the required resolution is low. A possible approach to improving the image quality is to store the Z data analytically for small blocks of the screen, but this would require sophisticated processing algorithms.

Translucency presents the problem of storing a number of overlaying faces that cannot be resolved until the entire scene is built. Building the stack of data at each pixel is prohibitively expensive, so translucency cannot be handled within the normal structure of the system. Rather than abandon the feature entirely, it is possible to separately prioritize the translucent objects and add them after the rest of the scene has been built. It is easiest to add the translucent objects in reverse-priority-order, with the additional step of checking distance for occlusion of the objects by previously written opaque faces. The translucent faces will have the same internal edge problems as ordinary reverse-priority architectures.

CONFLICTS AMONG FEATURES

Textured Translucent Surfaces

Any operation which must be performed on each picture element will require additional pipelined hardware, and it will therefore tend to be expensive to implement. This is true for operations such as smooth shading, smooth coloring, and haze fading, but texture is especially expensive because the computations are more complex. To save texture hardware it would be desirable to only put texture on visible pixels. For example, a Z buffered system could save a pointer to the texture mapping plane equation for each sample point which could be used along with the stored Z data to compute the texture modulation just prior to display. There would be some defect in the anti-aliasing of edge pixels, but no worse than the regular Z buffered images. Similar schemes can be worked out with other architectures.

The addition of translucency complicates matters. With the possibility of overlapping textured translucent faces, texture must be generated prior to the frame buffer input and the expense must be borne. To allow use of texture generation upon output in a system with translucency, restrictions must be placed upon the use of texture. One possibility is to prohibit the use of texture on translucent surfaces and to store an attenuation factor for the texture modulation on the underlying surface. Another approach is to only allow translucency for model switching and to keep the outlines of the objects similar so that a texture may be applied using the Z value from either model; no texture is allowed on models that may be switched completely out.

Prioritization of Curved Surfaces

There are several problems in integrating curved surfaces into the cited architectures. General curved surfaces have concave features that are difficult to prioritize by methods other than Z buffering. A restriction to convex pieces solves this problem, at a significant loss in generality.

If a large curved surface, such as a terrain representation, must be subdivided for any reason, there will be a problem in matching the edges of the curved patches when the patches must change to different levels of detail. This can be avoided by restricting level of detail changes to small curved features added on top of underlying surfaces. However, this will limit switching effectiveness and also generally require the computation of the intersection of the two curved surfaces, a much more complicated requirement than bounding the surfaces by planes.

SUMMARY AND CONCLUSIONS

This paper has discussed two geometric processing architectures and four video processing architectures in the context of a half dozen or so image generator features. Each architecture has strong and weak points as summarized in Table 1.

Architecture	Strengths	Weaknesses
Pipelined Geometric Processor	Throughput	Inflexibility, complexity
Parallel Programmable Geometric Processor	Flexibility, modularity	Throughput
Scanline Video Processor	Requires little memory	Scanline overload, priority-overload
Reverse-Priority Video Processor	Easy translucency	Internal edge occlusion
Priority-Ordered Video Processor	Overload resistance	Translucency implementation, large memory required
Distance Sorting Video Processor	Easy prioritization	Aliasing, translucency implementation

Table 1. Image generator architecture characteristics.

For any particular application, the strengths and weaknesses must be weighed. For example, if data base flexibility is important but image quality is not important, the distance sorting architecture is suggested. On the other hand, every architecture has weaknesses. The designer does well to identify the weaknesses as early as possible, and to do the best possible to minimize them through innovative design or appropriate operational restrictions. Users should find out what the weaknesses are and assess those weaknesses in the light of the application requirements.

For high performance flight simulation, the author's opinion is that within the next two or three years, reduced costs of processors and memories will make a parallel programmable geometric processor with a priority ordered video processor the architecture of choice. This conclusion is based upon the belief that overload resistance and image quality are extremely important in this application. The disadvantages of translucency appear tractable with clever design, and in any case translucency is a feature with specialized application where some limitations can be accepted.

More generally, an important theme of this paper is that image generator design must deal with a set of features that must work together. Features new to the art such as photographic texture or curved surfaces must be combined with all the other features required to make a system that meets a given set of requirements. Users should therefore approach innovative features with some skepticism; the tradeoffs must be understood to find out if they meet the user's requirements.

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PILOT ORIENTED PERFORMANCE MEASUREMENT

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ABSTRACT

Flight simulators provide a complete quantitative record of a pilot's flying performance. Evaluating this record is complicated by the volume of data and by its fine detail, dozens of flight parameters, sampled many times per second. Automated performance measurement systems (APMS) reduce the volume of data to an amount which is manageable and understandable. The usual APMS is aircraft state oriented. The APMS keys on aircraft state (e.g., X-Y position, bank angle) to define intervals over which performance data are integrated. This APMS is relatively insensitive to pilots' intentions and so may average performances which had differing objectives, based only on their having occurred at the same point during the task sequence. An alternative APMS has been developed which is pilot oriented. This APMS defines measurement intervals based on control inputs. Control inputs are identified by discrete changes in flight path. These intervals are psychologically relevant in that they begin with a goal-directed control input and end with a countervailing input. By relating performance in the pilot defined intervals to state defined intervals, it is possible to quantify performance on given flight segments (e.g., a level turn), and to specify factors which lead to a given level of performance.

INTRODUCTION

As man-machine systems have become more complex and costly, the need for effective measurement of operator performance has increased dramatically. Performance measurement systems (PMS) are needed which will permit assessment not only of total man-machine system performance but also of performance factors contributing to total performance. To accomplish this sort of assessment measures are needed which permit the decomposition of performance into perceptual, information processing and physical control performance components.

The need to decompose overall performance into its components is particularly apparent when there is an interactive effect of task difficulty factors on overall performance. For example Rinalducci (1) examined the performance of pilots in maintaining level flight in an F-16 simulator. Rinalducci used two measures of performance, mean altitude above ground level (AGL) and RMS deviation from 200 ft AGL. Both measures were sensitive to the effects of visual cue and airspeed manipulations as well as to difference between straight and turning flight. In addition both measures were sensitive to interactions between these variables. One variable, visual cues, is clearly a perceptual/informational factor. Neither the other two variables nor the interactions are amenable to intuitive labeling. Since the performance measures do not permit analysis of component processes, it can be shown that these factors affect performance, but not how they do so.

Attempts to study component control processes have followed two lines. One approach is to use a discrete stimulus such as a cross-wind gust (2) to elicit a control input. Because the input was elicited, it is possible to obtain timing information, which shows the contribution of perceptual, subject and control task factors to input latency and effectiveness. This approach provides information not only about how well an operator controls the vehicle but also about the effectiveness of the operator's response. The limitation of the approach is that it can only be applied when inputs which are made in response to a discrete environmental change. The ad lib control inputs which operators make frequently in unperturbed, steady-state operation are not amenable to this approach.

An approach which has been used to study ad lib control inputs is simply to measure the rate of control inputs. An input rate measure which has been used in the study of driving is steering reversal rate (SRR), the rate at which the steering wheel is reversed through a small finite arc. Greenshields (3) has found SRR to increase with traffic density. McLean and Hoffman (4) have found SRR to be affected by lane width, speed and preview. Hicks and Wierwille (5) found control task difficulty to affect SRR.

Although SRR is sensitive to the effect of task variables on ad lib control performance, it has drawbacks. MacDonald and Hoffman (in 6) found addition of a secondary task to affect SRR differently in simulated and actual driving. More importantly, SRR is often uncorrelated with overall steering performance (6).

Control reversal rate has also been employed in flight control research. As in driving, control reversal rate is sensitive to changes in the difficulty of the flying task, but the sources of this sensitivity are obscure. Blomberg, Pepler and Speyer (7) used elevator position reversal rate (EPRR) to measure control performance in the A-300 aircraft. Blomberg et al found introduction of an electronic flight information system (EFIS) to increase EPRR. Other measures of flying performance showed the EFIS to improve pilot performance. Introduction of an autopilot, which reduced the difficulty of the control task by controlling horizontal position, caused EPRR to decrease. As in driving control reversal rate is sensitive to flying task difficulty, but the factors underlying this sensitivity are not clear.

For measures of ad lib control inputs to be useful, indices of input effectiveness, such as are available for elicited control inputs, are needed. A PMS is presented here, which employs measures of effectiveness of ad lib inputs. Two assumptions underlie this PMS: (1) the conditions which prevail when the input is made serve to elicit the input and (2) the qualitative effect of the input reflects the operator's intention in making it. That is, if an input causes the vehicle to change direction of travel, then the operator's intention was to change direction. While this assumption may not apply to the totally naive operator, it is reasonable for one having even minimal skill.

Measures based on the above assumptions are used to decompose control performance into a perceptual task component and a physical control task component. Following description of the PMS, data are presented to show effects of perceptual and control task difficulty variables on the performance measures. These data were gathered in a flight simulator visual system evaluation, the results of which are presented elsewhere (8). The intent here is simply to describe the functioning of the PMS.

THE MEASUREMENT SYSTEM

Because the intent of the PMS is to provide measures of performance which are sensitive to the pilot's intentions moment by moment, both overall and component performance measures need be defined specifically with reference to the flying task considered. The PMS presented below is used to evaluate performance in maintaining level flight at a specified altitude.

Four performance measures are presented (see Table 1). Two measures relate to overall control performance: Target Altitude (TA) is the mean of the local altitude minima and maxima; Altitude Range (AR) is the mean difference between local maxima and minima. These measures give the altitude the pilot is attempting to maintain and the degree to which the aircraft varies about that altitude. Target Altitude and AR are analogous to conventional measures of mean altitude and standard deviation. Two measures, Smoothness (S) and Critical Error Rate (CER) are used to decompose performance into its components. These measures are based on attributes of individual control inputs.

Control inputs of interest are those made through the aircraft stick. Unlike previous approaches, which have defined inputs in terms of control manipulandum displacement, the present PMS defines inputs in terms of their effect on the velocity vector. This approach has the advantage that it employs a functional criterion for defining an input, rather than an arbitrary one.

Table 1
Performance measures for level flight

OVERALL PERFORMANCE MEASURES	
Target Altitude (TA):	Mean of local altitude minima and maxima.
Altitude Range (AR):	Mean difference between local altitude maxima and minima.
COMPONENT PERFORMANCE MEASURES	
Smoothness (S):	Proportion of critical control inputs.
Critical Error Rate (CER):	Ratio of lag distance to lag time for critical control inputs.

A control input is designated by a change in sign of the vertical acceleration. If the vertical acceleration is positive (increasing rate of climb), a control input is said to have been made when the vertical acceleration becomes negative (decreasing rate of climb). This definition is analogous to that used for SRR. This functional criterion makes the PMS highly sensitive, since control inputs are identified according to a criterion which adapts to all task relevant factors.

Once we have determined that a control input has been made, it is necessary to determine the degree of effectiveness of the input. Since control inputs are made to affect velocity, they can only fall into one of two categories: (1) those after which velocity changes sign (direction of travel changes) and (2) those after which velocity does not change sign (direction of travel remains the same). With regard to error control, these two classes of control input effectiveness have psychological and task relevance because in the former case the input causes a decrease in error, while in the latter error continues to increase.

In the PMS critical inputs are those which reverse the direction of travel and so decrease error, and non-critical inputs are those which do not alter the direction of travel. Efficient control might be expected to involve a relatively large proportion of critical inputs. A greater proportion of non-critical inputs might result in less efficient control since many inputs do not result in error reduction.

In the PMS Smoothness (S) is defined as the proportion of control inputs which are critical inputs. Smoothness has a value of 1.0 when all inputs are critical inputs made for the direct purpose of velocity control. If, on the other hand, no inputs were made for the purpose of altering the direction of travel, that is, none were critical, then S would have a value of 0.0. A higher value of S represents more efficient control.

As the distinction between critical and non-critical inputs provides a finer grain analysis of control behavior than simple input rate, so a still finer grain analysis can be obtained by examining the effectiveness of critical inputs. Since critical inputs are made to reverse the direction of travel, their effectiveness can be determined by measuring the rate at which error accumulates following the input. An effective input is one which results in a low rate of error accumulation. In the PMS this measure is given by Critial Error Rate (CER), the ratio of the lag distance to the lag time from the critical input to altitude minimum/maximum.

The two measures, S and CER, permit the decomposition of control performance into behavioral components. For this decomposition to be useful, two things are necessary: (1) the component measures need be tied to psychologically relevant processes and (2) the contribution of the performance components to overall performance must be determined. The following analysis of control performance in a flight simulator addresses these issues through examination of flying performance in straight and turning flight under varying conditions of environmental visual cue quality.

FLYING PERFORMANCE EVALUATION

In the flying performance evaluation we shall examine the effect of two task difficulty factors on our measures of performance. Different types of task difficulty factors will be shown to affect performance components differently. The interaction of the components in overall performance will also be shown. Finally we shall show how overall performance reflects the strategy adopted by the pilot to cope with decrements in component performance.

One of the task difficulty factors addressed is the quality of out-of-the-cockpit visual cues provided the pilot. De Maio and Brooks (9) and De Maio et al (8) have used the slope (b̲) of an altitude estimation function to evaluate the altitude cueing effectiveness of simulator visual environments. Flying performance is examined in five environments, whose cueing effectiveness ranges from b̲=.2 to b̲=.8.

The second task difficulty factor is determined by the physics of flight. When an airplane is in wings level flight, the force of gravity is counterbalanced directly by the lift vector. When the aircraft is banked, a cosine component enters the lift equation. This cosine component increases the difficulty of the control task in proportion to the size of the bank angle up to 90°.

We will begin the performance analysis by looking at overall performance as measured by TA (see Fig 1). In both straight and turning flight TA increases substantially in those environments providing poor altitude cueing (b̲≤ .5). Turning also causes an increase in TA in all visual environments, but this effect is not as great as that of visual cue quality.

Target Altitude measures the altitude the pilot attempts to hold. In order to see why pilots raise TA with increased task difficulty, we examine another overall performance measure, AR (see Fig 2). Since AR measure how precisely the pilot controls altitude, it drives TA in that the TA must be, at the least, high enough to preclude collision with the ground on minimum altitude excursions.

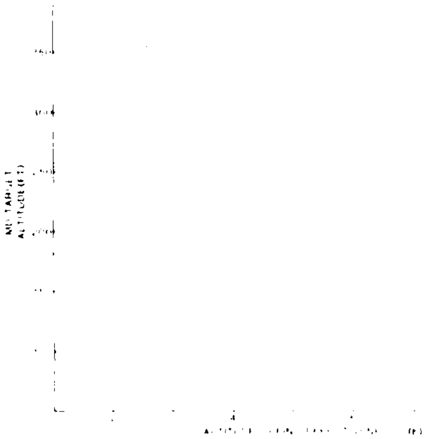

Figure 1. Target altitude for straight and turning flight

As was true with TA, AR is sensitive to both perceptual and motor control task difficulty factors. The pattern of the effects, however, differ substantially for the two variables. Altitude Range is greater in turns than in straight flight at all levels of altitude cueing. At low levels of altitude cueing this difference is very large, roughly 200 ft.

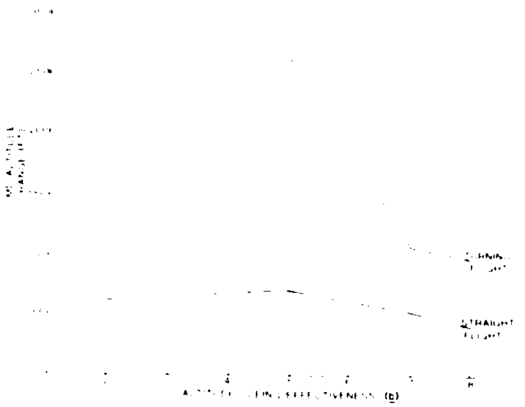

Figure 2. Altitude range for straight and turning flight

In straight flight AR increases only slightly (@ 30 ft) due to cue quality variation, and yet TA increases substantially. At the same time a much larger difference in AR due to turning under good cue conditions leads to little change in TA. In fact the function relating TA to visual cue quality in both straight and turning flight is much more like the AR function for turns than it is like that for straight flight. This similarity leads to the conclusion that control precision performance (i.e., AR) in turns is the determinant of TA in both turning and straight flight. Since turns must be executed, the pilot chooses a straight flight TA which permits maneuvering comfortably.

COMPONENT PERFORMANCE ANALYSIS

The above analysis of AR permits us to determine that task difficulty affects control precision. The analysis of TA shows how pilots might determine an appropriate altitude based on their ability to control altitude. What remains to be shown is how the perceptual and control task factors act individually and in concert to affect control precision. This analysis is accomplished by examining the performance components, S and CER.

Smoothness is a measure of control input efficiency, the proportion of inputs that are critical inputs (that is, effective in the sense of altering the aircraft's direction of travel). Examination of Fig 3 shows that S is highly sensitive to altitude cue quality but insensitive to control task difficulty (bank). Changing the quality of visual information available to the pilot affects the proportion of critical and non-critical inputs of the control inputs made. When cue quality is high, most inputs are made to change the direction of travel. On the other hand, when cue quality is low, a relatively small proportion of inputs is made for this reason.

It is reasonable to suppose that non-critical inputs, also, have a purpose. Since the proportion of these inputs increases when altitude cues are poor, these inputs may serve to give the pilot information needed for aircraft control. When altitude cues are good, only a small number of non-critical inputs is needed to provide flight control information, and the majority of inputs is made to effect flight control. When visual cues are poor, more non-critical inputs are needed, and so S declines.

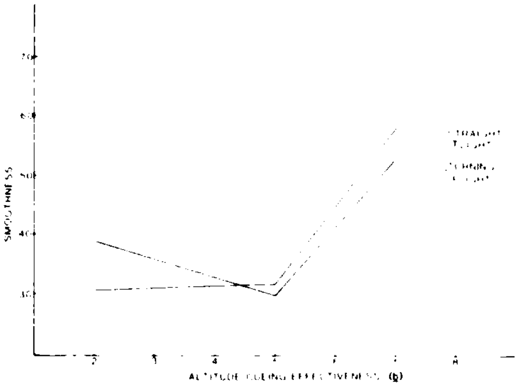

Figure 3. MD smoothness for straight and turning flight

The second component performance variable, CER, measures the effectiveness of individual critical control inputs; that is, how quickly error accumulates following an error reducing input. Since CER measures the responsiveness of the man-machine system, we might expect it to be differentially sensitive to control task difficulty factors. Examination of Figure 4 shows this sensitivity. Critical Error Rate increases from about 15 ft/sec in straight flight to about 34 ft/sec in turning flight. Yet CER does not vary systematically with altitude cue quality.

We have now identified two components of control performance: S, or input efficiency, and CER, or input effectiveness. These performance components show the differential sensitivity to task difficulty factors that permits us to determine how increases in difficulty affect the control process. Increased perceptual task difficulty leads to a decrease in S as more inputs are made to provide the pilot information and fewer for the express purpose of flight control. Increased control task difficulty leads to an increase in CER. When the control task is more difficult, inputs are less effective.

Conceptually the effects of variation in control efficiency (S) or input effectiveness (CER) can readily be related to overall control performance (AR). When inputs are less effective due to increased control task difficulty, the aircraft responds more slowly and AR increases. When input efficiency decreases, due to increased perceptual task difficulty, directional changes occur less frequently and again Altitude Range increases.

In order to demonstrate a quantitative relation between control efficiency and effectiveness and overall performance, a third variable must be introduced, that is, Effective Input Duration. Effective Input Duration (EID) is the time between inputs for non-critical inputs and the time between input and local maximum (minimum) for critical inputs. The difference in definition for critical and non-critical EID arises because the directional change following a critical input acts psychologically as an input. Effective Input Duration is about the same for critical and non-critical inputs, although the inter-input interval is about twice as long for critical inputs as for non-critical inputs.

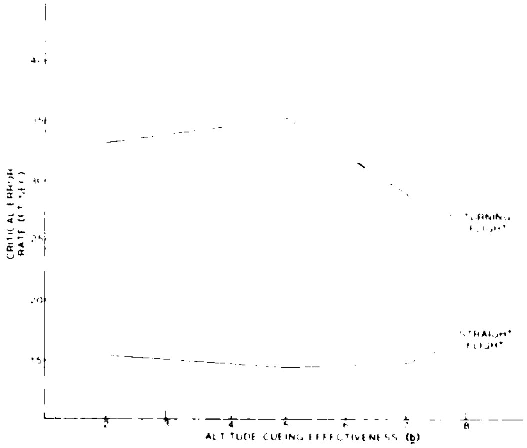

Figure 4. MD critical error rate for straight and turning flight

Effective Input Duration is not a particularly useful performance measure itself because, like the input rate measures discussed above (SRR, EPRR), it exhibits sensitivity to a variety of task factors affecting performance of both operator and aircraft. Yet the difference between EID and inter-input interval may be useful in explaining some of the conflicting input rate data in the literature. Since input rate is half as great for critical inputs as for non-critical, factors which affect S will affect input rate even if EID is not changed. Effective Input Duration too affects input rate when S may be unchanged. Depending on the magnitude and direction of these two effects, input rate may increase or decrease in response to the ensemble of task difficulty factors.

Altitude Range may be predicted from S, CER and EID using the function:

$$AR = 2*D*((S*C)+(1-S)*2C) \quad (1)$$

Where:

AR = Altitude Range, S = Smoothness
C = Critical Error Rate and
D = Effective Input Duration.

Equation 1 says the average excursion above or below the Target Altitude is determined by rate at which error accumulates for a particular type of input multiplied by the proportion of such inputs and by the effective input duration. The error accumulation rate for non-critical inputs is twice that for critical inputs since deceleration to zero does not occur. Using the median values for S, CER, and EID (see Table 2), Equation 1 predicts an AR of about 267 ft in turning flight with poor altitude cues ($\underline{b} \leq .5$). The obtained AR was 260 ft. In wings level flight with good altitude cueing, predicted AR is 55 ft while actual AR is 49 ft.

DISCUSSION

Two performance measures have been developed which permit the decomposition of flight control performance into component processes. These component processes are differentially sensitive to factors affecting the difficulty of the flying task. Smoothness, the proportion of critical inputs, reflects the efficienty of control. Increasing the difficulty of the perceptual component of the flight control task leads to a decrease in S. Critical Error Rate measures the effectiveness of critical control inputs. This measure is sensitive to the difficulty of the physical control task itself.

Table 2
Effective input duration (Sec)

Cueing Effectiveness	Straignt	Turning
Low (b .5)	1.7	2.0
High (b .7)	1.3	1.4

In order to relate performance on these two difficulty specific components to overall control performance, a third performance component, sensitive to general task difficulty, is included. EID measures the amount of time the pilot "holds" an input. At higher levels of the task difficulty, EID increases. The precision of control, AR, is a multiplicative function of S, CER and EID.

The precision of control is a function of component control processes beyond the conscious, voluntary control of the pilot. The only voluntary control option open to the pilot is to select a TA which is a compromise based on both task requirements and limitations to control precision. The pilot adjusts this TA to permit accomplishment of the flying task within the constraints of perceptual and psychomotor limitations.

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NEW CONCEPTS IN AIRCREW TRAINING
USING COMPUTER GENERATED IMAGERY - A STUDY REPORT

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ABSTRACT

The results of a study of the use of computer generated imagery in non-traditional training techniques are reported. These techniques complement and extend the role of a simulator from that of aircraft replicator to that of a training device. The study had three primary objectives: 1) exploit the flexibility of CGI to generate new concepts in aircrew training methods; 2) develop and demonstrate examples of these concepts; and 3) perform exploratory testing of the examples to assess their effectiveness and pilot acceptance.

For future study, the concept of using the simulator as a specific visual task trainer is discussed.

INTRODUCTION

Aircraft simulators have been designed and used primarily as substitutes for actual aircraft. Computer generated imagery (CGI) provides the flexibility to enhance training in ways that cannot be done in an aircraft. The thrust of this research was to conceive and demonstrate new training approaches that take advantage of the flexibility of CGI. Two broad categories of techniques were available to us:

(1) simulation of tasks untrainable in aircraft during peacetime but required during combat, and

(2) application of teaching/learning methods unavailable in aircraft.

The first category was not emphasized, since many of these special effects are available in present simulation visual systems. The second category is exemplified by techniques such as allowing the student to view an engagement from various viewpoints (his own, the threats, overview, etc.) or making visible something that the pilot must visualize but cannot see in the real world, such as the radar antenna pattern of an opposing aircraft during air-to-air combat.

The work has been performed in a series of three one-year stages. During the first stage, literature was searched and experts consulted in the process of generating concepts for aircrew training. During the second period, real time examples of several of the training concepts were implemented on a VITAL IV computer generated image system at McDonnell Douglas Electronics Co. (MDEC). During the last stage, additional examples were implemented, improvements were made to the previously created examples, and exploratory testing was performed both at MDEC and at the Air National Guard facility at Davis Monthan Air Base in Tucson, Arizona. In this study report the earlier work will be briefly reviewed and the work performed during the final period will be described in detail.

CONCEPT GENERATION

The initial stages of research called for the generation of new concepts in aircrew training using computer generated images combined with a flight simulator. The emphasis was in complex combat skill training as opposed to more routine tasks such as takeoff and landing. This was initiated by consulting with experts in the fields of human factors, training psychology, visual perception, combat flight, simulation, visual systems design and flight instruction. In addition, a limited literature search was conducted.

Table 1. Key Complex Combat Skills to be Trained

Factors Affecting Probability of Kill (P_K)

A. Energy Management
  1. own
  2. threat energy state

B. Offensive Weapons Systems
  1. switchology
  2. knowledge of best system selection

C. Assessment of Threat (Current)
  1. status assessment
  2. knowledge of what to do about it.

Factors Affecting Probability of Survival (P_S)

A. Energy Management
  1. own
  2. threat (know energy state of threat)

B. Defensive Systems Management
  1. display threats
  2. respond to threats

C. Assessment of Threats
  1. status/number
  2. knowledge of appropriate action.

Maximizing $P_K \times P_S$

Low Level Flight

APPARATUS

Some of the concepts resulting from this effort were demonstrated on VITAL IV computer generated image systems at the McDonnell Douglas Electronics Co. in St. Charles, Missouri and on the A-7D aircraft simulator at Davis Monthan Air National Guard Base in Tucson, Arizona. However, ideas generated could be demonstrated on any computer generated image system. This is an essential point.

MDEC's VITAL IV system consists of a general purpose minicomputer, special purpose high speed computational hardware, and a calligraphic color display with collimating optics. This display would normally be mounted outside the window of an aircraft simulator cockpit to display a representation of the "real world" to the pilot. The simulator position and attitude information is supplied to the visual system, which correspondingly updates the visual scene thirty times per second. The scenes have in the past been made specifically to simulate the real world flight environment, including special effects such as variable weather conditions, surface-to-air missiles, air-to-air missiles, anti-aircraft artillery, tracer bullets, and so forth. Two such systems were utilized for this project. Basic studies in flight cue perception were performed on a laboratory system at MDEC. The remainder of the studies were performed on a three window system on the A-7D operational aircraft simulator at Davis Monthan.

SAMPLE IMPLEMENTATION

This section briefly describes the sample concepts implemented during the second stage of research.

Visible Sensor Cone

A generic teaching aid researched was to make visible something the pilot must visualize but cannot see in the real world. As an example of this technique, we created a CGI scene of a MIG threat aircraft with a visible "lethal cone" extending from its nose. The objective was to teach the student how this normally invisible cone looks in three dimensions from the various positions attained during an engagement, and to allow him to develop techniques for avoiding it. (See Figure 1)

Visible Air Track of Own and/or Threat Aircraft

In a large number of situations it is useful for the pilot to be able to view his or another aircraft's flight path either during or immediately after a maneuver. To accomplish this we implemented a set of contrails formed by inserting lightpoints along the flight path into the environment in real time during a simulator flight. The advantage with this implementation is that the pilot may view the aircraft flight path immediately for positive feedback. (See Figure 2)

Multiple Viewpoint Selection

One of the key training needs frequently expressed by the instructor pilots as being difficult to teach is referred to as "situation awareness. In order to decrease this teaching difficults multiple viewpoints in conjunction with the visible air tracks previously discussed were used.

By viewing an aircraft's flight path from the multiple viewpoints after a particular aircraft maneuver is completed, provides the needed information concerning "situation awareness" to both the instructors and students. The viewpoints most frequently selected were:

overview,
profile view,
view from ground, such as a surface to air missile site,
or target aircraft's view. (see Figures 3 and 4)

Immediate Bomb Scoring

This technique displays Hit/Miss score, aircraft release parameters, and impact parameters in the visual display for quicker feedback, which is known to produce better learning. The parameters displayed were:

clock angles,
miss distance,
angle of attack,
"g" load,
release altitude,
minimum altitude,
heading in degrees,
pitch in degrees,
roll in degrees. (See Figure 5)

Instructor Positionable Cursor

Cursors have long been a valuable tool in computer-aided design applications. They would be equally valuable as part of the computer generated scene in aircraft simulation visual systems. Thus, we implemented an instructor positionable cursor controllable from the console joystick. (See Figure 6)

Cursor at Selectable Depression Angles from the Horizon

This cursor is one which remains a fixed, selectable number of degrees below or above the horizon. This could be set, for instance, to 3 degrees depression and it would represent a desired glideslope angle for landing. Any object appearing centered in the cursor is known to be located along a 3 degree slope from the aircraft. If the cursor were set at a larger angle, it could be used to represent a desired dive angle for air-to-ground attack. Use of this type of cursor can help a student learn the correct sight picture for dive bombing or strafing. It can also be a great aid in learning to visually judge and correct glideslope for landing. (See Figure 7)

Velocity Vector Cursor

This cursor is a visual indication to the pilot of the extended flight path of the aircraft. It was found to be useful for conveying information about aircraft attitude and aircraft angle of attack. As with the other cursors the luminance intensity was adjustable, such that as students became more proficient the cursor's intensity was progressively reduced to extinction. This assures that ultimately the student's response is evoked only by the real world cues. (See Figure 8)

Visible Air

A scene composed of 16,000 lightpoints uniformly spaced to form a cube. Referred to as "visible air" this visual cue demonstrates important visual aspects of flight. For instance, by flying through this scene a student can quickly learn the basics of how the motion of objects around the aircraft conveys information about the aircraft's position, motion and aimpoint.

Energy Maneuverability Diagram

In air combat it is critically important for a pilot to know not only his own aircraft's limitations (performance envelope) but also those of his potential adversaries. A useful tool in this process is the energy/maneuverability diagram. This is normally a diagram of turn rate versus air speed. We designed a new type of energy/maneuverability diagram containing altitude in addition to the standard information. The diagram consists of three parts: Axes systems, aircraft flight envelopes, and aircraft energy state indicators. The axes consists of a vertical altitude axis and two horizontal velocity axes, one of ownship, the other for the threat aircraft. Each velocity axis is positioned, along the altitude axis at the aircraft's current altitude. The altitude axis is fixed. The flight envelopes show the maximum turn rate and the maximum sustainable turn rate at full throttle as a function of airspeed and altitude for each aircraft. At low speeds - those below the speed at which the highest turn rate can be achieved - the maximum turn rate is limited by the lift line, that is to say, turning faster will result in the aircraft having too little lift to stay airborne. At speeds above the speed of maximum possible turn rate, the maximum turn rate is limited by the structural limits of the aircraft or the pilot. The sustainable turn rate divides the envelope into two parts: an energy loss region above it, and an energy gain region below. An aircraft in its energy gain region and at full throttle will increase speed or altitude; an aircraft in its loss region will descend or slow down. The flight envelope is formed from nine velocity-turn rate points whose exact values depend on the aircraft type and the current altitude (see Figures 10, 11 and 12).

Typical values were used for our demonstrations; they do not represent any real aircraft. Each aircraft's current speed and turn rate is indicated on its diagram by its current state marker. The threat aircraft's state is represented by a dot, while ownship's state is represented by an "X". A trail of dots is attached to ownship's state marker to show its recent history. An "equivalent speed" marker for the threat aircraft is presented on ownship's diagram showing the threat's current turn rate and the speed it would have at ownship's altitude if it kept its total energy (kinetic plus potential) constant. Finally, there is a relative energy gain indicator which points toward the side of the aircraft that is gaining energy relative to the other aircraft. The tangent of the deflection of this indicator from vertical is proportional to the relative rate of energy gain.

EXPLORATORY TESTING

After implementing the above described special effects and training aids, we began exploratory testing to determine whether the concepts, when put into practice, indeed showed signs of having the utility we expected. Since a broad range of aids and techniques for using those concepts needed to be examined, we opted to examine each in a relatively cursory fashion rather than examine a few in great depths. What follows is a description of one of the experiments performed and its results.

Non-Real World Visual Training Cue

The intent of this experiment was to ascertain the degree of influence the non-real world visual training cues, velocity vector cursor, horizon depression cursor, and visual airspace have on simulated flight performance.

Subjects

The suject pool comprised 20 pilots, grouped into experienced and novice test and control groups. The average flight hours per subject, in each group, are:

Control		Hours/Subject
Experienced	3	2041
Inexperienced	4	61
Total	7	910
Test		
Experienced	4	2800
Inexperienced	9	74
Total	13	913

Procedure

The experimental procedure was divided into three segments: pretraining, control, and training. The pretraining segment was performed by both control and test subjects, control segment by control subjects only, and training segment by test subjects only.

During the pretraining segment, control and test subjects were instructed in how to use a joystick driver for aircraft control. They were instructed to fly the simulated aircraft through approaches and landings using 3 degrees as a glideslope angle. The subjects were informed of their downrange distance and that each approach would have a different altitude and crossrange distance. Then a practice period of fifteen minutes was flown in which approaches were made under day and night visual conditions.

During the control segment, control subjects were allowed an additional flight practice period. This period was equal in length to the training period given test subjects during the training segment. The only difference was that the control subjects received no feedback or instruction concerning their flight performances.

During the training segment, test subjects were shown the visual airspace, horizon depression cursor, and velocity vector cursor. They were instructed concerning the operation and usage of the cursors. The test subjects performed a flight training period of 15 minutes during which the cursors were active and the subjects were given additional instruction in the correct cursor operation.

Crossrange, downrange, and altitude data was gathered during the final two approaches, one day and one night. This was done after each segment and once again upon conclusion of the experiment. The final data (post training) was gathered in order to evaluate learning retention in test subjects after the training segment. The data was later converted to crossrange versus downrange and altitude versus downrange graphic representations of the aircraft's flight path.

Exploratory Testing Results

After evaluating the control subjects' flight paths it was observed that their performances were little influenced by the practice flight sessions. The final approaches from pretraining and control sessions typically mimicked each other, demonstrating an inability to learn from the additional practice flight time. These results indicated that the control subjects, both experienced and inexperienced, were unable or unwilling to either recognize, diagnose, or modify their flight deficiencies.

Evaluation of the test subjects' pretraining and training flight paths showed surprising similarities for both experienced and inexperienced groups. Both groups' pretraining flight paths deviated greatly from the correct approach. The most common error was in glideslope judgement. Either the pilots flew directly to the runway or they attempted to achieve an appropriate glideslope angle, but were unable to judge that angle correctly. The two groups also performed similarly during the training flight approaches. Comparison of pretraining and training flight paths revealed that the test subjects were very successful at using and understanding the visual cursors. The most pronounced improvements were in glideslope angle estimation, error detection and error correction.

The post-training approaches were flown in order to determine whether the abilities acquired during training were retained. Results indicate that only the inexperienced pilots whose flight time was above that of novices retained the skills gained through training. There are several possible explanations of why the experienced pilots did not retain the skills they gained during training. The most reasonable of these is that the visual training session of 15 minutes was insufficient to alter ingrained habits - good or bad - acquired through extensive training and experience. We haven't sufficient data to conclude how experienced pilots could best be trained in order to retain the skills gained through training, but the results strongly support the need for early visual training.

Exploratory Testing Conclusion

The objectives of this study were to generate new concepts in aircrew training methods that take advantage of the flexibility of computer generated imagery, to demonstrate examples, and to perform exploratory testing of these examples. The purpose of the exploratory testing was to provide a baseline of information from which detailed training experiments could be designed for future evaluation. All of these goals were met. In general, we found pilot reactions to the demonstrated examples to be quite favorable. The key to this, we believe, is the fact that the philosophy under which these concepts were generated was compatible with operational instructor pilots' and students' views. The philosophy was that it can be worthwhile to forego pictorial realism in favor of operational realism. Additionally, the approach to simulator utilization was as a training tool, not as an aircraft replicator. It was recognized that, when viewed as an aircraft replicator, the simulator will always be found wanting; however, when viewed as a training tool, its potential has only just begun to be explored.

FUTURE IMPLEMENTATIONS

This section briefly describes continuing concept investigation of visual intelligence.

Angular Judgement Training

Literature commonly used for flight instruction contain large sections on how to teach flight motor skills but offer very little on how to interpret visual intelligence. Typical pilot training courses offer a smattering of visual cue interpretations, but do not offer systematic visual judgement training. It is apparent that the ability to make precise judgements of angular displacement and movement is a significant factor in the overall task of flying an airplane, however, the matter of teaching these flying skills is seldom directly addressed.

Angular Judgement Example

The task of judging a defined angle in piloting an aircraft is forever present. The pilot is expected to hold a given pitch angle, turn to a heading, intercept a glide path, etc., in his performance, however direct training to visually recognize these defined angles has been haphazard to say the least. There's an old saying that, "A good landing requires a good approach" and conversely "a poor approach means a poor landing", and basically these are correct.

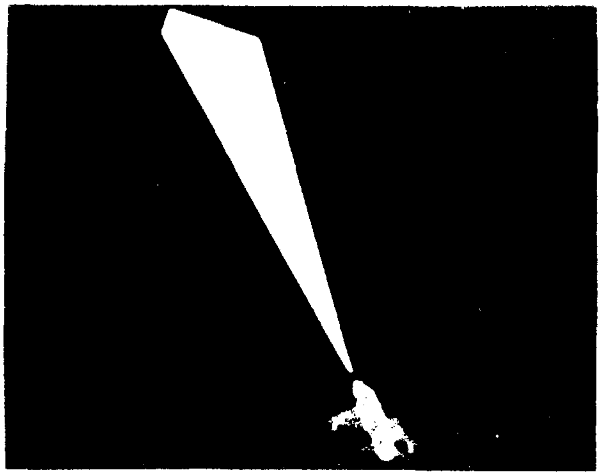


FIGURE 1. VISUAL SENSOR CONE

FIGURE 2. VISUAL AIR TRACK

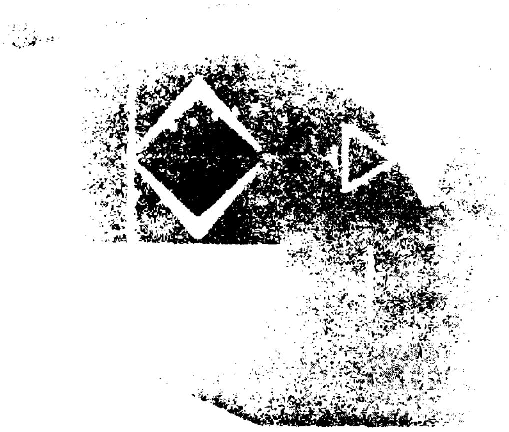


FIGURE 3. MULTIPLE VIEWPOINT – OVERVIEW

FIGURE 4. MULTIPLE VIEWPOINT FORWARD VIEW

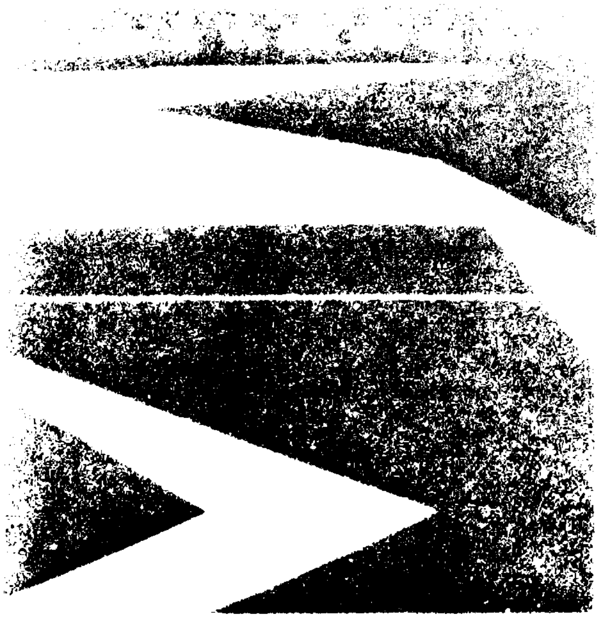


FIGURE 5. IMMEDIATE BOMB SCORING

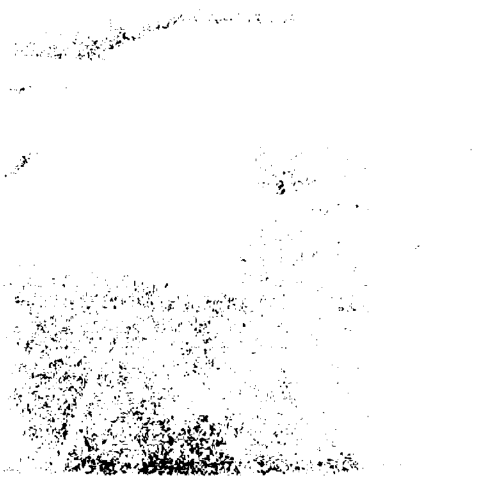


FIGURE 6. INSTRUCTOR POSITIONABLE CURSOR

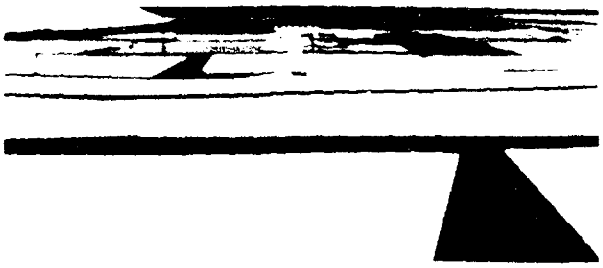


FIGURE 7. SELECTABLE DEPRESSION CURSOR

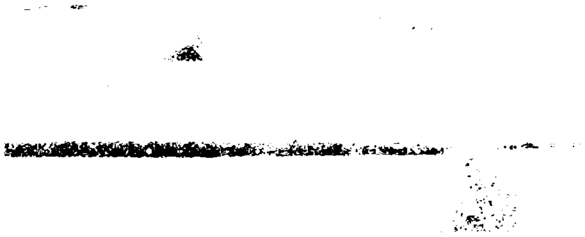


FIGURE 8 VELOCITY VECTOR CURSOR

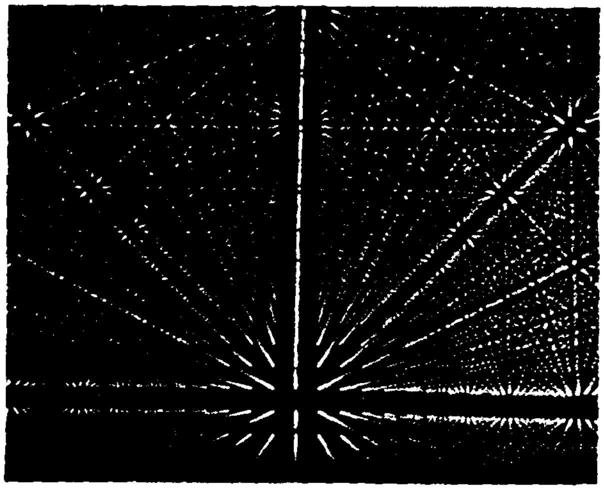


FIGURE 9. VISIBLE AIRSPACE

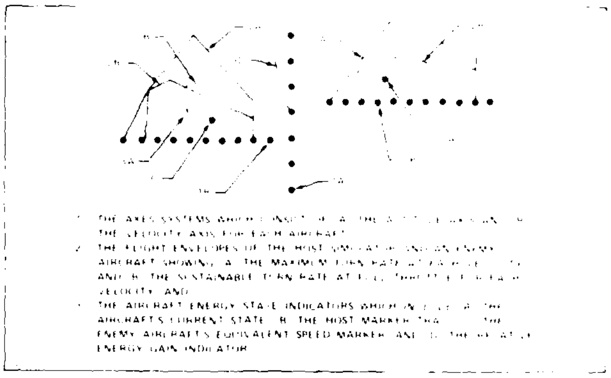
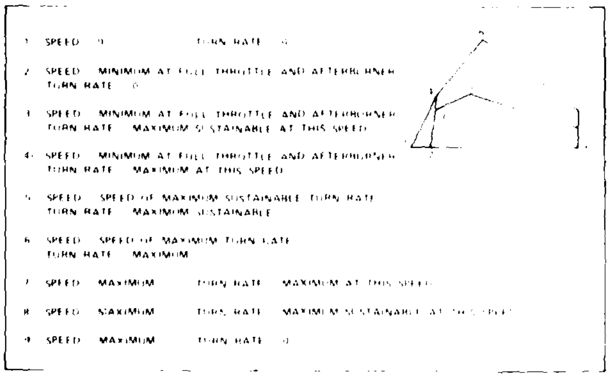


FIGURE 10. ENERGY MANEUVERABILITY DIAGRAM COMPONENTS



1 SPEED 0 TURN RATE 0

2 SPEED MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE 0

3 SPEED MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE MAXIMUM SUSTAINABLE AT THIS SPEED

4 SPEED MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE MAXIMUM AT THIS SPEED

5 SPEED SPEED OF MAXIMUM SUSTAINABLE TURN RATE
TURN RATE MAXIMUM SUSTAINABLE

6 SPEED SPEED OF MAXIMUM TURN RATE
TURN RATE MAXIMUM

7 SPEED MAXIMUM TURN RATE MAXIMUM AT THIS SPEED

8 SPEED MAXIMUM TURN RATE MAXIMUM SUSTAINABLE AT THIS SPEED

9 SPEED MAXIMUM TURN RATE 0

FIGURE 11. ENERGY MANEUVERABILITY DIAGRAM DEFINED

FIGURE 12 ENERGY MANEUVERABILITY DIAGRAM

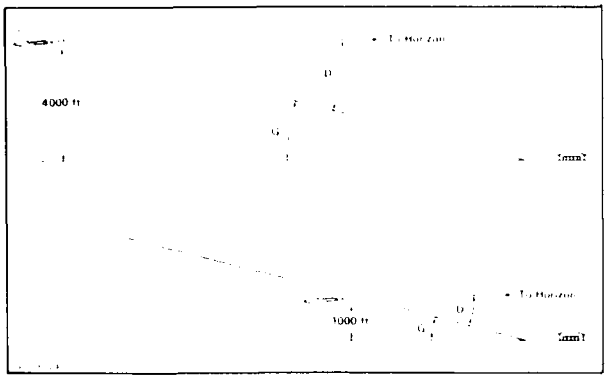


FIGURE 13. DEPRESSION ANGLE TO TOUCHDOWN

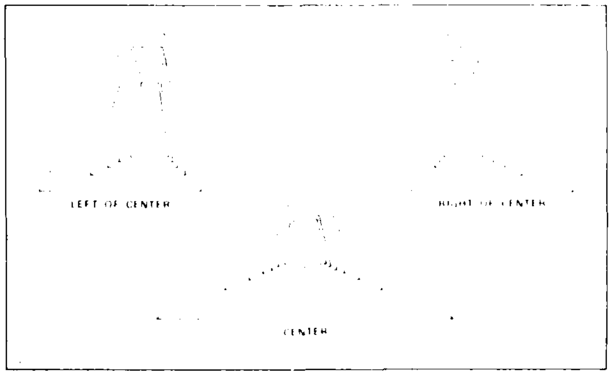


FIGURE 14. RUNWAY WIDENING EXAMPLE

The approach is defined as a course with a given flight path lined up with the centerline of the runway and intersecting the runway near the desired touchdown point at an acceptable glideslope angle. The heading of the aircraft will line up with the centerline of the runway, unless complicated by crosswind and present minimal problem in the judgement of the heading angle at this time.

The visual evaluation of the glideslope remains complicated under all conditions. Although a pilot may not be conciously aware of the visual cues of angular change he uses them to evaluate progress of the approach.

Two of the visual angular evaluations required for accurate glideangle judgements are as follows:

1. Depression angle of the touchdown point from the horizon or apparent horizon. The importance of this evaluating cannot be overstated because it is an angle that remains constant through the approach, is not affected by surrounding elements. (See Figure 13)

2. Constant widening of the runway shape, as a function of decreasing distance between the aircraft and runway, is used to assess the correctness of the approach. To be used effectively, it has to be combined with vertical lengthening of the runway image, as well as with the decreasing vertical distance between the horizon and the top of the runway image. (See Figure 14)

The flight path and its associated angles, angular changes and dimensional relationships provide valuable visual cues that are difficult to demonstrate in the ever-changing natural environment. Training aids such as computer generated images could be used to present dynamic movement to improve angular recognition. The computer generated image for the illustration given would require simple scene elements such as a horizon and a runway shape. The scene elements needed, however, to promote recognition of meaningful movement in the periphery would require only single lightpoints. The simple combination of scene element and movement is endless when combined with the task of improving pilot skills.

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ON-LINE TASK ANALYSES IN MAINTENANCE SIMULATION

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ABSTRACT

The Air Force Human Resources Laboratory is currently sponsoring a project to investigate the costs and benefits of interactive, computer-based simulation in support of avionics maintenance training, utilizing a video disc picture data base to represent the actual equipment. The focus is on simulations which support the development of genuine troubleshooting expertise--the competence to go beyond prescribed procedures. A unique aspect of this project is the use of on-line task analyses. An on-line task analysis is defined as a computer-resident data base representing the set of goals and actions employed in accomplishing a task. Goals are divided into subgoals or actions, serving to decompose the troubleshooting problem into simpler problems. Actions involve direct manipulation of equipment. On-line task analyses may be useful in the development and delivery of quality, cost-effective maintenance simulations. Four benefits of on-line task analyses and a methodology for the development of these analyses are presented. The associated potential training effectiveness gains and cost savings are currently being tested empirically.

INTRODUCTION

A major advantage of maintenance simulators over the use of actual equipment for training is that, as a training device, simulators can be designed to support the instructional process, whereas actual equipment is designed only to perform a specific function. However, the evidence to date shows no training effectiveness advantage of maintenance simulators over acutal equipment trainers.(1,2) With an inherent training advantage, why do maintenance simulators not produce superior training outcomes?

Simulators incorporating computer-assisted instructional technology with courseware designed specifically to train maintenance skills have the potential to realize an instructional advantage for maintenance simulators. Such maintenance training systems are quite new and the results of empirical evaluations of these systems are not yet available.(3,4,5) This paper describes how the Interactive Graphics Simulator (IGS) project sponsored by the Air Force Human Resources Laboratory seeks to achieve an instructional effectiveness advantage over traditional actual equipment training.

The focus is on simulations which support the acquisition of genuine troubleshooting expertise defined as the competence to go beyond prescribed procedures in fault isolation tasks. The approach is to model the task as well as the equipment. Simulator lessons are designed so that no equipment action may be performed until the trainee has explicitly [illegible] the cognitive problem solving steps which [illegible] making that equipment action.

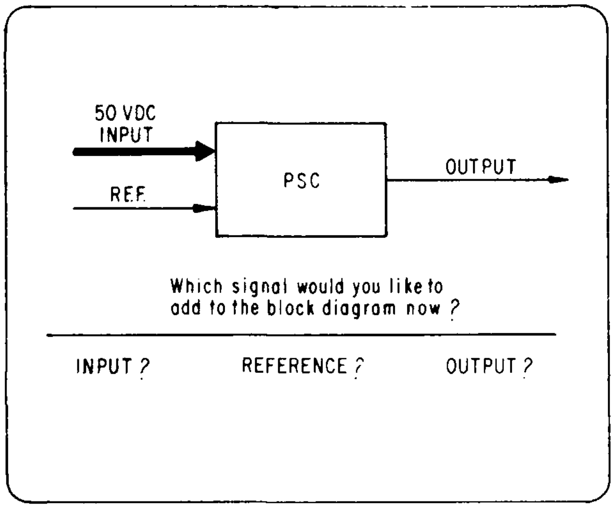
The ability to simulate the detailed human problem solving approach used in troubleshooting a specific piece of complex equipment (as well as in simulating the equipment itself) may result in increased training effectiveness. When troubleshooting, no purposeful equipment action is ever performed without an objective in mind backed up by reasoning. While the empirical evaluation of the IGS approach has just begun, a method for creating task-centered maintenance simulations has been developed. It is the purpose of this paper to explain this method.

INTERACTING WITH A TASK-CENTERED SIMULATION

Before going into the details of how task-centered maintenance simulations can be developed, it will be helpful to the reader to understand the simulation from the perspective of a trainee. The trainee sits before a keyboard and two video displays. One display represents the equipment. User interaction with this display is done through use of a touch panel. A second display represents the cognitive or problem solving component of the task. User interaction with this display is done through use of the keyboard.

The equipment display is a standard color video monitor on which a picture data base of the equipment relevant to the task is displayed. The monitor is equipped with a touch panel and, in a fashion that has become almost standard in microform and video disc simulations of equipment, the student accesses controls, readouts, test points, and components by indicating with a touch of a finger on the video monitor face that portion of the picture to display in greater detail. For example, if a voltmeter range is to be set from 100 to 10, one begins by touching the voltmeter drawer on a rack of equipment pictured on the monitor. The rack picture is replaced with a picture of the voltmeter drawer. Next, the range control is touched and the voltmeter picture is replaced with a picture of the range control, currently positioned at 100. At this point, the "10" on the range scale is touched and the range control picture with the range control set to 10 is displayed. Now, the user might touch an area on the monitor screen labeled "done" to indicate that this equipment action is complete.

The task display is a medium or high resolution graphics display on which text, diagrams, decision alternatives and feedback messages are presented. For example, suppose the trainee is developing a block diagram of the signal path involved in a troubleshooting problem. Figure 1 depicts one step in this process. Here, the trainee is focused on the inputs and outputs for one particular functional block, the PSC. The trainee has already identified that the input should be 50 VDC, and has two more signals to identify. The text display shows a graphic representing the PSC and its two inputs and one output. The signals already identified (in this case, the 50 VDC input) are labeled and highlighted. A text prompt beneath the graphic asks, "Which signal would you like to add to the block diagram now?" At the bottom of the text display are the decision alternatives to be used in answering this question. The correct response is either "reference" or "output." Feedback messages are associated with each incorrect response. In this example, if the trainee had chosen "input," the feedback message, "You have already identified this signal, pick another!" would have been displayed.



Which signal would you like to add to the block diagram now ?

INPUT ? REFERENCE ? OUTPUT ?

Figure 1. Typical task display. Depicted is an intermediate step in the development of a block diagram. Here the trainee has already identified that the INPUT should be 50 VDC and has two more signals to identify.

Interaction on the task display continues until an equipment action is required, say for example, "Set up voltmeter." At this time, control is passed to the equipment display. When the voltmeter is correctly set up, control is again returned to the task display. In this way, a simulation proceeds from an initial task display in which the problem scenario is set, through a series of task displays leading to the first equipment action, through the equipment action simulated on the equipment display, and back to the next task display. This process continues, alternating between the task and equipment displays, until the problem is solved. The simulation is task-centered in the sense that planning and problem solving activity controls access to equipment manipulation.

ON-LINE TASK ANALYSIS

In the preceding example, the [illegible] questioned how a quality task [illegible] might be developed. Quality [illegible] impacted by (a) the accuracy [illegible] decision alternatives, (b) the consistency of problem solving approach from simulation to simulation as reflected in the decision alternatives, (c) the cost incurred in developing comprehensive sets of decision alternatives for an entire set of simulations, and (d) the ability to chain together equipment actions which should be performed as a single integrated equipment action given sufficient trainee expertise. The IGS project incorporates the development and use of on-line task analysis in order to address these concerns.

On-Line Task Analysis

An on-line task analysis is defined as a computer-resident data base representing the set of goals and actions employed in accomplishing a task. It is a problem reduction tree.[6] It represents a problem solving strategy known as hierarchical decomposition or planning by abstraction, wherein the troubleshooting problem is divided into simpler and simpler subproblems.

One way to arrive at this type of task analysis is to ask continually the question, "In order to get the job done, what must I do?" If three things must be done; A, B, and C, one repeats the question with each of these. "In order to do A, what must I do?" The process is repeated until the answer to "What must I do?" belongs to the assumed repertoire of the trainee, and is in a sense elemental. For example, changing the range on a voltmeter from 100 to 10 would be considered elemental.

The nature of the relationship between the task and the equipment is neatly represented by the on-line task analysis itself. The on-line task analysis has the form of a tree. The root node of the tree represents the task. From it emanate several branches to nodes representing the major subcomponents of the task. From each subcomponent emanate branches to nodes representing their decomposition, and so on, until the task is decomposed into elemental equipment actions. Therefore, all equipment actions are terminal nodes in the tree.

The target task of the IGS project is the operation and maintenance of an F-111 avionics test stand.[7,8] Figure 2 provides an abbreviated listing of the task analysis for this job. The full analysis tree is up to 16 levels deep and contains between 1,000 and 2,000 nodes at present.

Benefits of On-Line Task Analysis

On-line task analysis can be useful in the development and delivery of quality maintenance simulations. Four benefits of on-line task analysis are presented here. We remind the reader that the associated potential training effectiveness gains and cost savings are currently being tested empirically. After this discussion of how to use on-line task analysis in the development and delivery of simulations, a method for developing the task analysis itself is presented.

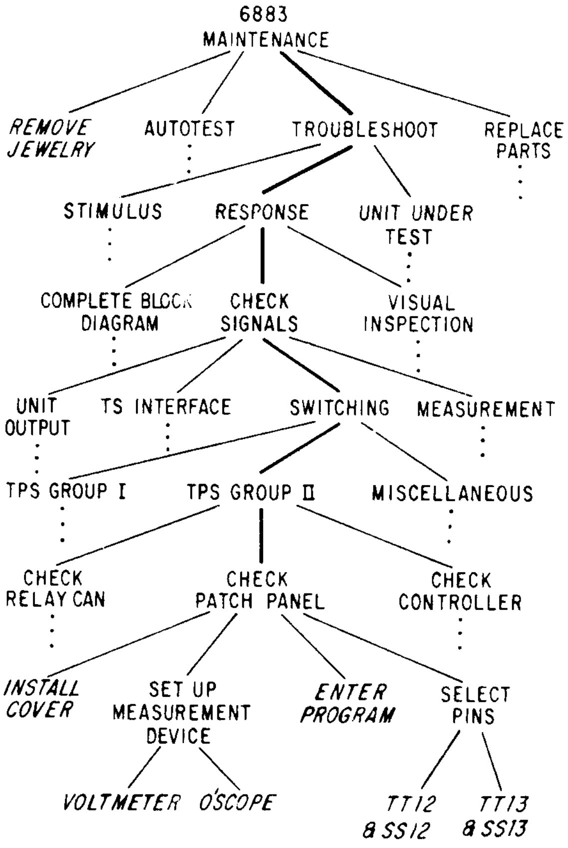
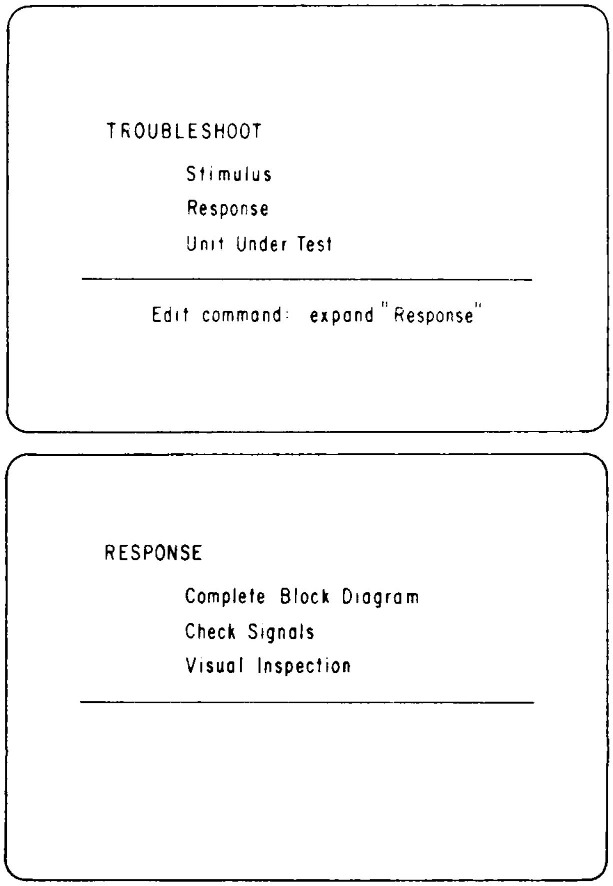


Figure 2. Task analysis tree for 6883 maintenance. Only one line of decisions/actions is represented; all others have been pruned, as indicated by the ellipses. Task elements listed in *italics* are terminal nodes and entail equipment manipulation.

Benefit 1: The focus of the simulation is shifted from the equipment to the task. A commitment to the use of on-line task analysis makes equipment simulation subordinate to the task. This graphically depicted by the fact that all equipment actions are terminal nodes in the task analysis tree. Given this approach, the role of the simulator is clearly defined as a training device, serving training objectives, and not merely an alternate form of the actual equipment.

The simulation of equipment is a vital aspect of this approach to maintenance simulation; eventually, there must be some way to practice equipment actions. The equipment may be simulated by a video disc, a 2-dimensional flat panel simulator, or a 3-dimensional high fidelity mock-up. The advantages of each form of equipment simulation apply only to the equipment simulation component of a task-centered maintenance simulation.

Benefit 2: Computer-based simulation courseware is developed by simply flagging a path through the task analysis tree for each fault. This process is supported by an authoring editor. The editor displays a parent node with the names of immediate subordinate nodes underneath (see Figure 3). A subject matter expert (SME) moves down the task hierarchy by expanding nodes.



TROUBLESHOOT

Stimulus

Response

Unit Under Test

Edit command: expand "Response"

RESPONSE

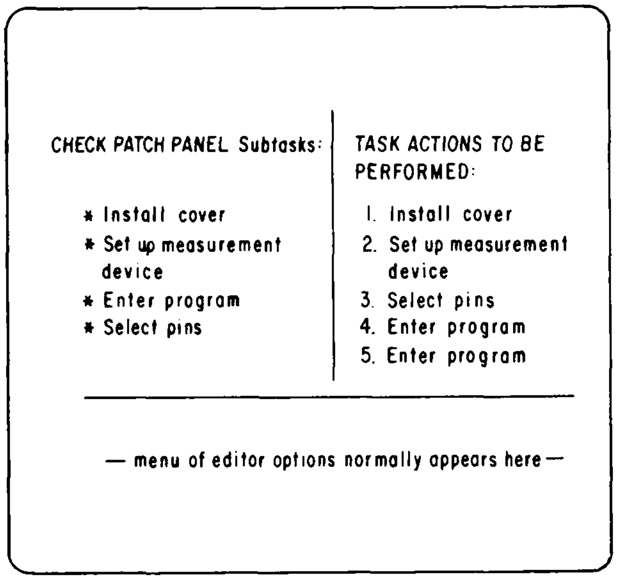
Complete Block Diagram

Check Signals

Visual Inspection

Figure 3. Using the authoring editor to move through the task tree. In this figure, the node, "Response" is expanded, corresponding to moving down one level in the task tree depicted in Figure 2.

A simulation is built as follows. Beginning with the top node, the SME selects which subordinate nodes must be performed at this level of detail. The list of subnodes is the same list of decision alternatives presented to the student during simulation run time. Subnodes may be assigned in order (e.g., "You must first do A, then B, and then C."), or they may be combined in various logical combinations (e.g., "You must first do either A or C, then you must do , and then you must do A again."). Associated with each assigned node is the task or equipment display that will be presented to the trainee when that decision alternative is pending. Recall that a task display contains text and graphics summarizing the current state of the problem and a menu of decision alternatives. Figure 1 depicted a typical task display. The trainee responds by typing in the text of the decision alternative chosen. Feedback messages are created by the SME, one for each decision alternative for each assigned subnode. Figure 4 illustrates the use of the simulation development editor.



CHECK PATCH PANEL Subtasks:	TASK ACTIONS TO BE PERFORMED:
* Install cover	1. Install cover
* Set up measurement device	2. Set up measurement device
* Enter program	3. Select pins
* Select pins	4. Enter program
	5. Enter program

— menu of editor options normally appears here —

Figure 4. Simulation courseware development editor. This display corresponds to the task structure depicted in Figure 2. Suppose "Check Patch Panel" was the method selected for checking the switching signals of TPS Group II relays (refer to Figure 2). When the "Check Patch Panel" node is expanded, the above display appears with the task components listed on the left and a blank screen on the right. The SME, using editor commands normally listed at the bottom of the screen, assigns the task components required to perform the patch panel check for this problem. The result is the list of task components shown on the right-hand side of the screen. At this point, if the SME entered a "2," this would cause the "Set Up Measurement Device" node to be expanded and the process of simulation courseware development would continue. Task displays are created by entering a command to "create task display" and the number (from 1 to 5 in this example) of the task action to associate with the display. Feedback messages are similarly constructed. The menu the trainee sees at the bottom of a task display is retrieved automatically from the task analysis tree and consists of all items listed on the left-hand half of the editor screen.

After the subnodes of a given node have been assigned and associated with graphics, text, and feedback messages, the SME expands the problem. If, for example, in Figure 4, the first assigned subnode of "check patch panel" is "1. install cover," the author will ask the authoring system to "expand 1." This will cause the subnodes of "install cover" to be listed, and the SME will select which of these subnodes must be accomplished in what logical order to complete successfully this subtask. Task displays and feedback messages are created for each of these assignments. The process is repeated, over and over again until terminal nodes are reached.

Terminal nodes are predominantly equipment actions. The equipment actions are defined in whatever fashion is suitable to the method chosen for representing the equipment. In the IGS project, the equipment is represented by video disc images on the equipment display. In this case, an equipment action is defined as a sequence of video disc images and touch inputs corresponding to the equipment action to be performed. The example at the beginning of this paper, setting the voltmeter range to 10, would require that a sequence of video disc images and touch areas be set up corresponding to the following sequence: select the voltmeter from the rack of equipment, select the range control from the pictured face of the voltmeter, touch the area labeled "10," and press "done."

Simulation development time under this approach can be extremely rapid. An SME can flag the solution path for a given fault in a matter of hours. It may take only 20 to 40 additional hours to complete the simulation by building the task displays and equipment sequences associated with each node assigned to the solution path. Such a simulation may take the student an hour, perhaps 2 hours, to complete. These figures are meant to convey only a qualitative feel for how this authoring approach facilitates the simulation development effort. Precise quantitative data on the cost of simulation development will be in the IGS final report.

In summary, the availability of an on-line task analysis provides a ready means of developing simulations. The decision alternatives for each step are provided by the task analysis. The SME simply assigns steps appropriate to solving the fault at hand and associates task or equipment display information with each.

Benefit 3: This approach promotes consistency in problem solving approach at the same time it allows for flexibility in simulation design. Since all simulations are developed from the same task analysis tree, they present a consistent problem solving approach. That is, any menu (list of decision alternatives) displayed in one simulation will be exactly the same in all other simulations which need to display that menu. The menus are not entered by the SME in the task display. They are provided by the task analysis tree. Only the correct choices are provided by the SME. This consistency in approach from simulation to simulation assures that the set of simulations is coherent and should help reinforce learning.

This approach to authoring also supports a wide degree of latitude in constructing a simulation problem. In particular, it supports the development of part tasks and the development of alternative troubleshooting approaches. An example will illustrate one way in which part tasks can be developed. Suppose decision alternatives at some point in the simulation include complete block diagram, visual inspection, and check signals. It may be the SME's wish at this time to focus on the check signals component of the task, and glaze over completing the block diagram and visual inspection.

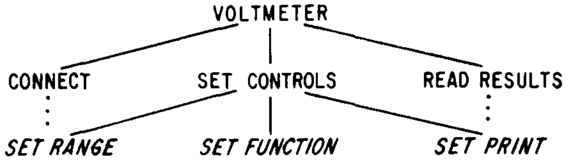
In order to accomplish this, the SME can assign all three subnodes, in sequence. But the SME will not fill out in detail the paths for "compete block diagram" and "visual inspection." Instead, a summary scene for each of these two component tasks will be created summarizing what the trainee would have accomplished had these subtasks been completed. Only for the check signals subtask will the SME trace out the entire path. The scenario for trainees would go as follows. "What would you like to do next--complete block diagram, visual inspection, or check signals?" Trainees select, correctly, "complete block diagram." In response to this, the trainees see a task display showing a completed block diagram and stating, "Here is your completed block diagram, press NEXT to continue." Again the trainees see the following decision alternatives: complete block diagram, visual inspection, or check signals. This time they choose "visual inspection" and again receive a summary of what this task would have yielded at its completion and are returned again to the following choice: complete block diagram, visual inspection, or check signals. Now, when trainees pick "check signals," they do not get a summary, but instead, get a task display with the decision alternatives appropriate to performing the next step in the decomposition of the check signals task. In sum, through judicious use of summary scenes, a designer can tailor a simulation as needed.

The authoring approach also supports the development of alternative troubleshooting strategies. For example, suppose any of three functional areas, X, Y, or Z, might be explored next. Further suppose the fault lies in region X. The author can assign these areas as follows: "X, Y, and Z may be performed in any order; Y and Z are optional, X is required." As a second example, suppose either of two methods for checking a certain signal is acceptable. Suppose that one method is the favorite of one SME and that the other is the favorite of another. If both methods are to be followed through in detail, one can assign them as follows, "Do either Method A or Method B." The task analysis subtrees for both Method A and Method B follow beneath the node for each. If development resources do not permit building paths for both methods, and it is still perceived to be important to give the trainee the option of selecting either method, a summary scene can be associated with, say, the choice of Method B, stating, "Yes, you could use Method B. This is a perfectly legitimate approach. However, today we would prefer you to try Method A."

<u>Benefit 4: Interaction with the student at each simulation step can be adapted</u>. As trainees master a task, it becomes appropriate to support the chaining of commonly co-occurring equipment actions. For example, consider the task of setting up a voltmeter to make a certain measurement. Perhaps the voltmeter has 10 controls, and 4 of these need to be set to make this measurement. Assume that the task of setting up a voltmeter is not in the repertoire of the trainee early in the training regimen but that this task certainly should be later on. It is appropriate, then, that the task of setting up the voltmeter be represented explicitly in the on-line task analysis. That is, each control is treated as a separate equipment action, and each control to be set must be selected explictly on the task display before it can be set on the equipment display. This is very helpful for trainees who have not yet mastered the task of setting up the voltmeter.

Eventually, as a consequence of practice, this task becomes familiar and it is no longer appropriate to force trainees to plan separately for and then make each control setting. It is appropriate to allow the trainee to select the goal "set up the voltmeter" and then go directly to the equipment display and perform, in an integrated fashion, each of the control settings needed. In other words, the detail or graininess of the simulation should adapt to the trainee's level of competence. This can be achieved through use of the on-line task analysis.

In this example, each time the trainee sets a voltmeter control, the performance on that task is recorded. If the task is performed correctly a given number of times, then simulation run-time control of that equipment action is passed to the next higher level in the on-line task analysis. So, if the four controls that need to be set have all been performed correctly as separate tasks, the next time the task "set up voltmeter" is encountered, all equipment displays under this node can be run as a single, integrated equipment display without intervening task displays. To summarize, in the beginning, the task of setting up the voltmeter was four separate task decisions each followed by an equipment action. As soon as mastery of these component processes was demonstrated, the task of setting up the voltmeter became one single task decision followed by one single equipment action. Figure 5 summarizes this process.



Training Sequence Before	*Training Sequence After*
1. Enter "Set up voltmeter"	1. Enter "Set up voltmeter"
2. Enter "Set range control"	2. Set range to 10
3. Set range to 10	3. Set function to KOHMS
4. Enter "Set function control"	4. Set print to TRACK
5. Set function to KOHMS	
6. Enter "Set print control"	
7. Set print to TRACK	

Figure 5. <u>Chaining equipment manipulations</u>. As a consequence of demonstrated proficiency in setting voltmeter controls (left-hand training sequence), the system automatically adapts and subsequently permits the separate equipment manipulations to be chained together as one integrated equipment action (right-hand training sequence).

To generalize, this approach is used throughout the on-line task analysis tree. Each trainee has a student model consisting of the on-line task analysis annotated with a record of his or her performance at each node. As the trainee gains experience in a given node, it undergoes a state transition from one state to another. For task display nodes, the state transition series is as follows: recognition, recall, performance, summary. Recognition means that the menu is displayed; decision alternatives are explicit. Recall means that the menu is not displayed; decision alternatives must be retrieved from memory. Performance means that all subordinate task display nodes are ignored and only the subordinate terminal nodes (the equipment actions) are run. Finally, summary means that no further action need be performed by the trainee; the results of the actions which would have been required are summarized.

Applying this scheme to the voltmeter example results in the following scenario. At first the student must recognize from a list of controls the correct ones to set, select each control in turn, and perform the associated equipment action on the equipment display. As each control's node enters the recall state, each control must still be selected verbally, its name must be recalled from memory, and the associated equipment action taken. As each control's node enters the performance state, simulation run-time control of the equipment actions is taken over by their superordinate node, the voltmeter node, and the student no longer needs to separate the individual equipment actions--they are performed as one, integrated whole. Finally, when the voltmeter node is in the summary state, when the student selects "set up the voltmeter" he or she would receive the message, "The voltmeter has been set up properly to measure the signal at hand."

The effect of this student modeling is to focus trainee attention on unmastered portions of the task, potentially promoting training effectiveness and reducing the time needed to complete a set of simulations. This is done on a completely individualized basis. Figure 6 gives a concise means of visualizing the effect of the adaptive quality of this approach.

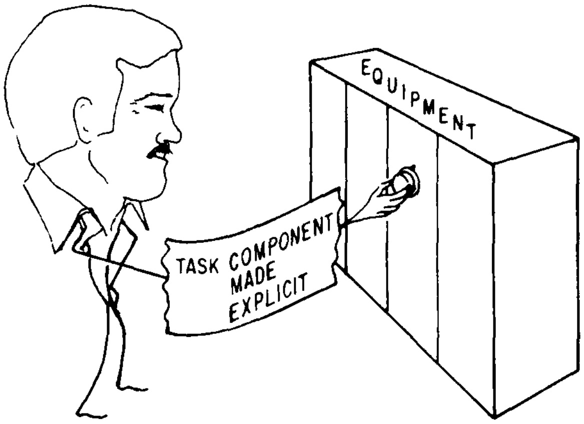
Development of the On-Line Task Analysis

Everything stated above presupposes the existence of an on-line task analysis. The approach to the development of on-line task analyses used in the IGS project is (1) to build a skeleton of the task analysis through traditional front-end analysis, employing the technique of hierarchical problem decomposition, and (2) to refine and fill out the details of the on-line task analysis as a consequence of trying to use it.

Suppose we have entered into the authoring editor the skeleton analysis of the job. Then we try to create a simulation using what we have on-line so far. The top node gives us our first set of alternatives. Presumably, these are useful in assigning the first few decisions that need to be made. Each of these is expanded in the manner described in the section on building simulations. Eventually a node will be expanded which does not contain all of the decision alternatives needed.

For example, suppose we expand a node and get the familiar decision alternatives "complete block diagram" and "check signals." Suppose the simulation at hand requires that at this point a visual inspection be performed after completing the block diagram and before checking signals. Using the editor, this new subcomponent is added to the list of subcomponents for this node. Now that "visual inspection" is available as a decision alternative, it is used.

PRIOR TO DEMONSTRATION OF COMPETENCE



AFTER DEMONSTRATION OF COMPETENCE

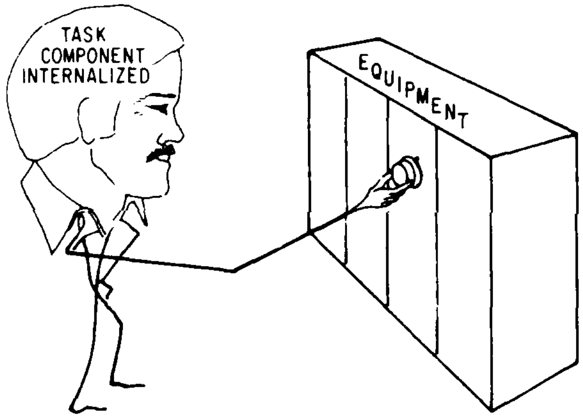


Figure 6. Adaptive simulation. Prior to demonstration of competence on a task component, the adaptive model requires the trainee to verbalize explicitly task planning and decisions before making the associated equipment manipulations. After competence has been demonstrated, the planning and decision structure has been internalized by the trainee, who may now interact with the equipment directly.

The three subnodes at this point in the task are assigned as follows: complete block diagram, visual inspection, and check signals. Of course, when the visual inspection node is expanded, there is nothing there. The strategy is, at this time, to complete a skeleton task analysis for this subtask. The skeleton is then used to complete the expansion of the visual inspection node for the simulation at hand, adding detail to the on-line task analysis as needed.

An on-line task analysis grows and becomes refined as a consequence of developing simulations. Since the menus that trainees see at the bottom of each task display are read at simulation run-time from the on-line task analysis, all changes to the on-line task analysis affect all simulations previously developed. Each new decision alternative will appear automatically on the appropriate task display.

This approach to developing an on-line task analysis for use in simulation has the major advantage of ensuring that the task analysis is always relevant to the simulations to be developed. One need not develop a complete task analysis from scratch. The strategy is to let the demands of the simulations cause the on-line task analysis to grow. To the extent that the set of faults simulated is complete and representative of the job, the task analysis will be also.

CONCLUSIONS

Evidence to date shows no training effectiveness advantage for maintenance simulators. This evidence does not include empirical studies of a new variety of maintenance simulation, simulators actively incorporating computer-assisted instruction technology with courseware designed specifically to train maintenance skills. The Interactive Graphics Simulator project (IGS) of the United States Air Force Human Resources Laboratory is an example of this new class of maintenance simulators. The cost benefits and training effectiveness of the IGS approach to maintenance simulation are currently being evaluated in the training classroom.

The IGS approach may successfully produce a training effectiveness advantage over traditional instructional approaches involving actual equipment because it forces the trainee to interact with the equipment in the context of his or her job. That is, with the IGS approach, the focus of the simulation is shifted from the equipment to the task. A second feature of the IGS approach that may translate into a training effectiveness advantage is the ability to adapt the simulation presentation to evidence of student mastery. The structure of simulations is altered dynamically in a way that focuses student attention on unmastered tasks and away from mastered tasks. The consistency of a problem solving approach may also result in instructional benefits.

As well as potential instructional benefits, the IGS approach also provides instructional design assistance to the subject-matter-expert. Simulations are easily created by flagging a path through an on-line task analysis, a computer-resident data base representing the set of goals and actions employed in accomplishing a task. The on-line task analysis is robust enough to support the development of part-task simulations and alternative troubleshooting approaches.

A final important contribution of the IGS approach to the field of maintenance simulation is its methodology for the development of on-line task analyses. The basis of this methodology is to extract a global representation of a task or job as a consequence or side effect of developing simulations of instances of the job. That is, as individual simulations are built, a composite representation is accumulated. This methodology may also provide important inroads to the development of the knowledge base component of expert systems.

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A COMPARISON OF SIMULATOR PROCUREMENT/PROGRAM PRACTICES: MILITARY VS. COMMERCIAL

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ABSTRACT

The costs of complex military flight simulators have been steadily rising, causing all concerned to carefully evaluate procurement and life-cycle costs of these devices. In making these evaluations, the issue is often raised that commercial airline simulators of comparable quality can be procured for less money and with shorter schedules. This paper provides a comparison of military and commercial procurement methods, concentrating on the major differences between them. It analyzes the key discriminators between military and commercial contract requirements which collectively cause simulator procurement and program practices to be so different, and costs to vary so widely, when the resultant flight simulators procured by both methods are highly regarded for their training capabilities. Recognizing that some of the military requirements are unique and necessary, this paper takes the position that military simulator procurement can utilize some of the methods employed in commercial procurements to reduce life-cycle costs.

INTRODUCTION

Simulation equipment procurement practices vary greatly between military and commercial customers. As a result of these different practices, the cost of procuring military training equipment is significantly higher than the cost of procuring commercial training equipment. The question addressed by this paper is: are there training equipment requirements which can be satisfied at lower cost by the application of some or all of the commercial procurement practices?

Both commercial and military simulators today are highly regarded for their positive transfer of training, as a result of efforts by the FAA and military and commercial users to reduce or eliminate the limitations found in earlier devices. The desired increases in fidelity have been achieved in part by the increased use of actual flight test data in the simulator design. The overall quality of commercial simulators today is such that the FAA now allows virtually all training and crew certification to be accomplished in simulators meeting FAA standards. The extensive use of simulators has dramatically reduced commercial airline training in actual aircraft, similar to the reductions found in many military training programs.

This paper focuses on the acquisition aspects of both military and commercial simulator programs, and explains how operational considerations influence procurement requirements, practices, and costs. Simulator maintenance support concepts are discussed and analyzed to show how they affect the requirements of the contract. The elements of the contract, in turn, are related to the complexity of the program, which basically determines the program schedule.

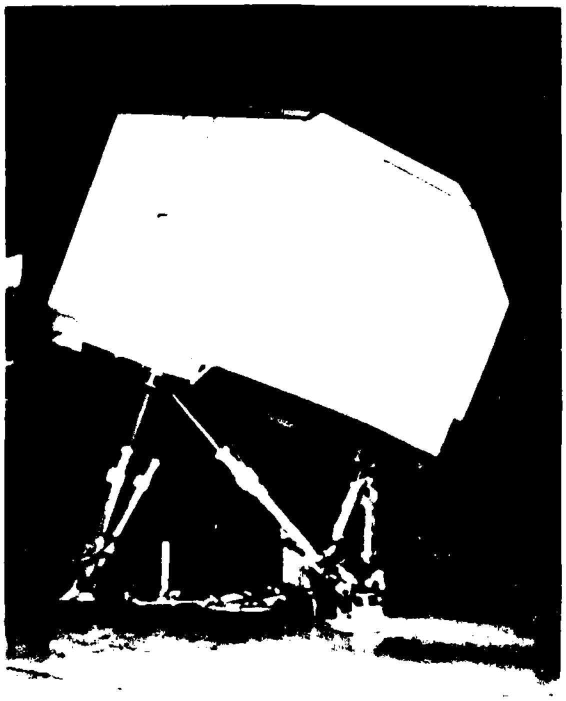
There are alternate ways of obtaining training other than procurement of either military or commercial simulators. For example, a complete training system could be procured comprising simulator, part task devices, and instructional systems as is done for the training of KC-10 flight crews in conjunction with American Airlines Training Corp. Although this and other possibilities exist, this paper addresses only the direct procurement of simulators with concentration placed on the differences in procurement practices.

A typical military simulator program is compared with a typical commercial simulator program, with attention provided to the obviously different contractual requirements and program practices. These differences are then evaluated for potential application of the commercial practices to military procurements, with the final section of the paper offering recommendations for future consideration.

Not all military training needs can be satisfied by the application of commercial practices. For example, security considerations, nature of aircraft, mission, and geographical location may dictate all of the current supporting documentation and logistically driven simulator characteristics. However, certain training applications could utilize simulators which are procured using some or all of the commercial practices resulting in appropriate cost benefits.

IDENTIFICATION OF KEY DISCRIMINATORS BETWEEN MILITARY AND COMMERCIAL PROGRAMS

Both military and commercial simulators are highly complex training systems which can be configured to meet individual customer needs. Table 1 shows some of the typical simulator features which have been included on Link simulators. As can be seen from the table, except for features required for tactical training, commercial simulators require the same capabilities as those found on military simulators. Moreover, the completeness and fidelity of commercial simulation in the operational flight areas often provides the same level of training effectiveness currently provided by military simulators. It must be remembered, however, that military training needs are understood and accepted, and the proposed use of commercial simulators or commercial procurement practices should not be construed as a redefinition of those requirements.



(A) Flight Compartment

Table 1 TYPICAL SIMULATOR FEATURES

	PRESENT IN MILITARY SIMULATOR	PRESENT IN COMMERCIAL SIMULATORS
Exact Replica of Cockpit	x	x
High-Fidelity Flight Simulation	x	x
6-Degree-of-Freedom Motion System	x	x
Digital Computers	x	x
Visual System	x	x
Navigation Equipment (including INS, Omega, etc.)	x	x
On-Board Computers	x	x
High-Fidelity Sound Simulation	x	x
Fault Isolation Diagnostic System	x	x
Weather Radar	x	x
Weather Simulation (Pressure, wind, Temp, Thunderstorms)	x	x
Training Systems Features		
Initial Positions	x	x
Initial Conditions	x	x
Snapshot and Recall	x	x
Record Playback	x	x
Demonstrations	x	x
Procedure Monitoring	x	x
Parameter Print/Plot	x	x
Remote Instructor Control Unit	x	x
Hardcopy of IOS Displays	x	x
MAP Displays	x	x
Lesson Plans (Manual and Auto)	x	x
Malfunctions (Hundreds - both manual and automatic insertion)	x	x
Parameter Freeze	x	x
Extensive Auto-Test Guide Driver	x	x
Fire Detection/Suppression	x	x
Sate [illegible] Operator Stations	x	x
G-Se [illegible]	x	N/A
Digit [illegible] ar Landmass Simulation	x	N/A
Tactical Avionics	x	N/A
Tactical Environment	x	N/A

This paper compares a military simulator program with a commercial simulator program and discusses the various aspects of the programs where significant variation is evident. The two programs selected represent typical military and commercial program requirements. They are the U.S. Air Force C-130 simulator program and the American Airlines 767 simulator program. The C-130 program included the development of four pilot-production units and two cockpit procedure trainers, and the production of six follow-on units. The comparison with the 767 program is based on the initial pilot-production unit, which simulated the C-130E aircraft. Figure 1 depicts the 767 simulator; the C-130E simulator is shown in Figure 2. The C-130E simulator

(B) Instructor Station

(C) Trainee Station

Figure 1. 767 SIMULATOR (A, B, C)

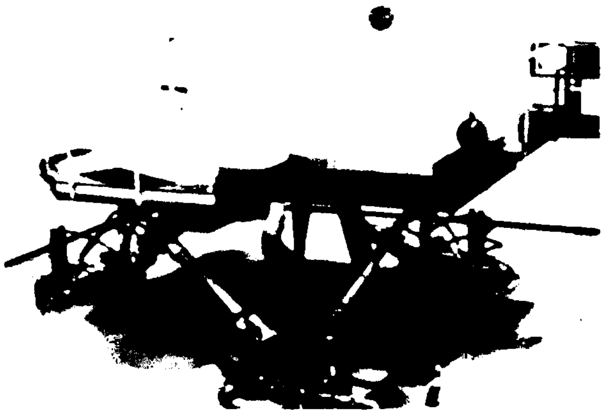
included a full replica of the pilot, copilot, flight engineer and navigator stations as well as a satellite navigator's station. The C-130E was developed many years prior to the simulator award and the design basis aircraft itself was several years old at contract award. The American Airlines 767 simulator was developed in parallel with the aircraft development/testing and, as a simulator of a transport aircraft, it offers many similarities to the C-130 simulator. The initial configuration of the 767 required simulation of the pilot, copilot, and flight engineer and the extensive simulation of modern on-board computers and computer driven avionics and displays. The 767 was one of the first transport aircraft to use CRT displays for primary instrumentation and caution and warning.

Because of its parallel development with the aircraft, the task of keeping the simulator configuration current with the aircraft required extensive engineering change activity. The many small changes were grouped together as "block" changes and in addition, two major configuration changes were accomplished. The aircraft (and simulator) were initially changed from a three-crew configuration to a design allowing operation by either three or two crew members. Subsequently, the configuration was changed for operation by only two crew members.

Costs

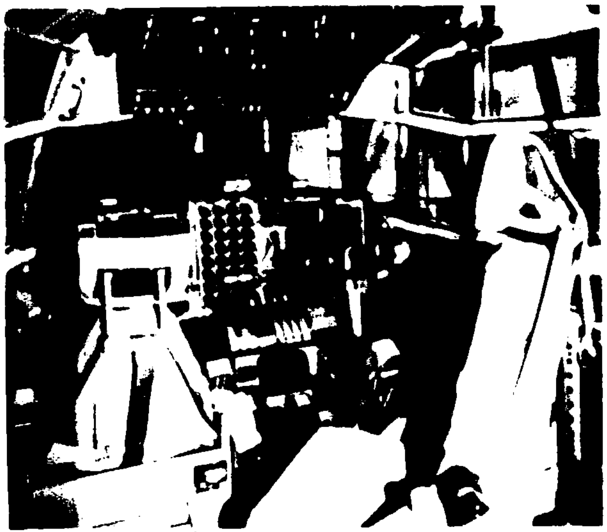
One of the most notable differences between military and commercial simulators is that of acquisition costs. The comparison of sell prices of the two devices is somewhat distorted by the differences in the procurement practices. For example, contract clauses involving share ratios, ceilings, customer-furnished data and aircraft parts, etc. require detailed analysis in order to make meaningful comparisons. Suffice it to say that when comparisons are made, the costs associated with the development, test and acceptance of the comparison programs showed that the cost of the C-130E simulator, less DRLMS, was approximately 1.7 times the cost associated with the AAL 767 program. Similarly, the costs of spares and test equipment purchased on the C-130E program were significantly higher than those on the 767 program.

Another valuable comparison of costs is provided by an analysis of the engineering hour content of the devices. The C-130E simulator, excluding the DRLMS, required approximately 450,000 engineering hours. The AAL 767 required approximately 130,000 engineering hours. These engineering hours include all engineering, program office, and ILS hours required for design/test of the basic simulator and associated data items. This large differential cannot be supported by the differing complexities of the devices (since they are known to be similar). The following sections provide insight as to why this significant difference exists.



(A) Flight Compartment

(B) Instructor Station



(C) Trainee Station

Figure 2. C-130E SIMULATOR (A, B, C)

Program Requirements

Military program requirements are specified in more detail and are more encompassing than commercial program requirements. A commercial simulator is usually selected as the most "attractive" device for the offered price, and as a result, the specification is typically written by the contractor and subsequently negotiated with the customer if additions or changes are required. A typical commercial specification is therefore far less detailed than a military specification. A commercial contract is typically 50 to 60 pages in length, including payment schedules, and all pertinent clauses. These two documents represent the total procurement package documenting the agreements.

In contrast, military procurements involve the detailed specification(s) of the specific training device, referenced specifications, a contract, a Statement of Work, a contract data requirements list, referenced data item descriptions and various other proposal and source evaluation documentation. Once requirements are levied and agreed to, it becomes necessary to ensure that the requirements will be met. Military program management approaches by both the customer and the contractor become very complex compared to those on commercial programs, largely due to the number of specified requirements and their related activities.

The C-130E PPU contract required the delivery of a simulator plus 95 data items. These data items ranged from relatively small documents such as the facility requirements report (136 pages) to the acceptance test procedures (ATP) which included some 6,000 pages. A typical commercial simulator program requires approximately 20 data items, each with much less complexity/detail. The ATP, for example is typically 2,000 to 2,500 pages in length.

The impact of data items on a military program is often misunderstood. In many cases, the costs allocated to an individual item do not reflect the true cost of producing the item, since some or all of these costs are often included in the program level-of-effort loading. Figure 3 depicts the data submittal process and provides insight into the many steps required on each data item submittal. To complicate matters, typically 20% to 35% of all Government specified data items require initial submission within 120 days after contract award. The proper management of a contract during the start-up phase is critical. Yet the magnitude of the data-item-related efforts requires considerable attention, thus distracting attention from the simulator. In contrast, the efforts of both the commercial contractor and customer in the first 120 days of the contract are almost exclusively dedicated to the development of the training device.

The requirements listed in the various procurement documents add to the complexity of the program and deliverable product without necessarily affecting the complexity/utility of the training device. For example, military simulators typically require reliability and maintainability plans to be submitted and approved. In addition, exhaustive reports are required which analyze and allocate the reliability and maintainability factors to the piece-part level to "ensure" end product performance will be satisfactory. Subsequently, the simulator must be tested to prove that the device meets the stated requirements, with the obvious objective that the simulator will perform and be maintainable so that the stated availability objectives can be met. With these objectives attained, presumably, the simulator will support the needed training requirements. Certainly the generation, review, submittal, revisions and correspondence associated with these plans, let alone their implementation, require significant effort.

The commercial approach regularly meets the same availability objectives in a much less complicated manner. The contractor is expected to design to good commercial standards and is held accountable for the design/production of simulation equipment which meets the availability requirements (usually 98% to 99%). The contractor, concerned about his reputation as well as the contractual requirement, is motivated to produce a quality product, which usually meets or exceeds the requirement. On the rare occasion when the availability criterion is not initially met, corrective action is taken until the problem is resolved. In the commercial case, the reliability and maintainability requirement is implemented by simply specifying the requirement in the contract and allowing the contractor flexibility in meeting it.

The military approach to reliability and maintainability is more costly and schedule consuming, in exchange for assurance that the requirements will be met. A question does exist as to whether or not the added costs are justified when one considers that no substantive value to the training device is added by these requirements.

In military procurements, there are other requirements which are similar in purpose to the reliability and maintainability requirements discussed above, whose effectiveness can be reviewed. Some of these requirements are intended to provide on-going status and assurances of program performance. The added costs of these check-functions have been justified as being essential to ensure product integrity. A discussion of the necessity of these requirements will be addressed in the next section.

Many requirements levied in military programs are indeed necessary under current practice, although they are not required in commercial programs. These requirements are often driven by the maintenance support concepts. For example, if organic support is used, then the skill level and turnover rate of the maintenance technicians must be considered. This could result in the need for addition of requirements, such as the technician training courses, or in changing the level of the requirements. It would increase the detail of software documentation, built-in test equipment, and maintenance publications. In addition, use of the military technicians also requires use of the applicable logistic system. This, in turn, calls for data and practices which are compatible with the user's logistic organization (e.g., the level and complexity

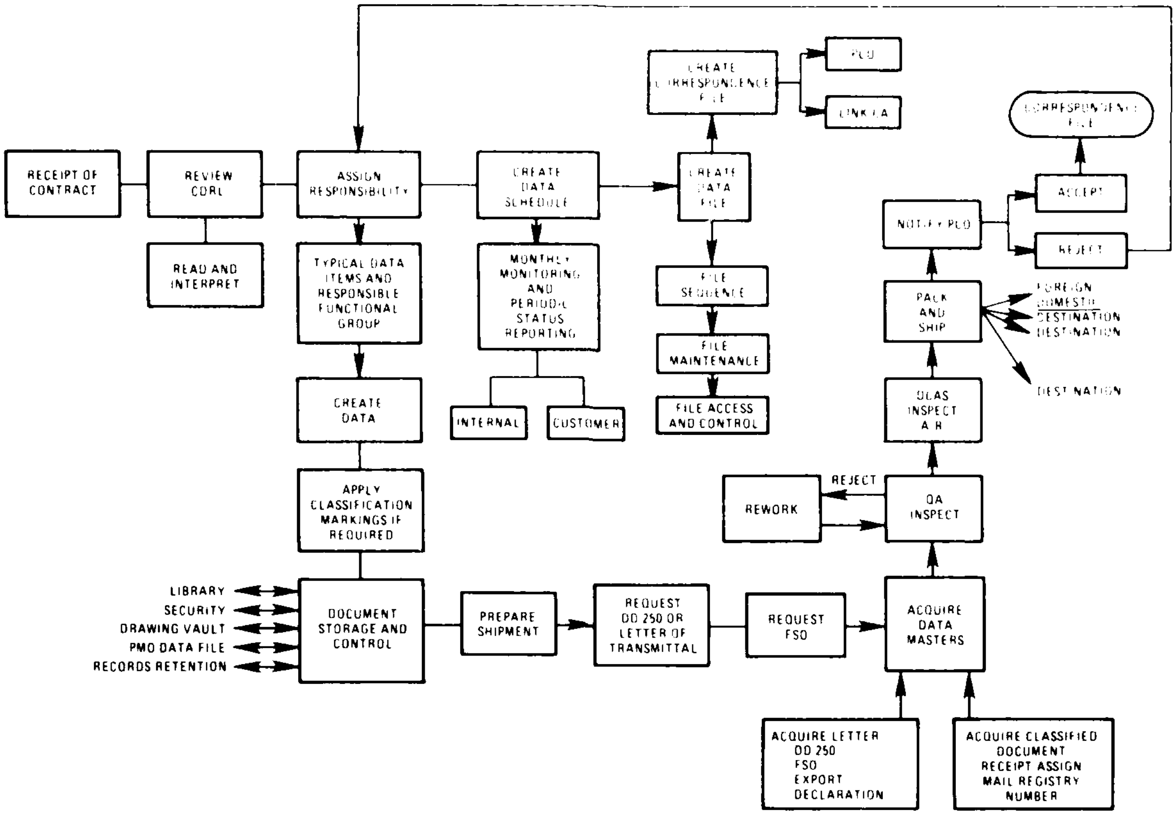


Figure 3. DATA SUBMITTAL PROCESS

of the provisioning documentation and support equipment). These attendant requirements influence the cost of the simulator program both directly and indirectly.

To illustrate this point, consider the requirement for the use of "approved parts" which, where feasible, means the use of MIL-spec parts. It is necessary to limit the number of unique part numbers in the Government inventory, and MIL-spec parts form the backbone of this inventory. The use of MIL-spec parts in the simulator, however, greatly impacts its cost and schedule.

The first obvious requirement is the effort associated with early identification of the required parts, the contractor's screening of the requirements (to search for the part numbers consistent with previous submittals/approvals), processing of requests/rejections, and creation and maintenance of the approved parts selection list. Several departments need to coordinate these activities, and, accordingly, program and functional management of these tasks is required. In addition to these efforts, the cost to procure the selected MIL-spec parts will be more expensive than the equivalent commercial part. As will be discussed later, the schedule is also impacted by the use of these parts and their associated efforts.

The true cost impact of the use of MIL-spec parts is very difficult, if not impossible, to analyze. Certainly, the component cost differential between the MIL-spec parts and the equivalent commercial parts can be argued to be insignificant when considering their commonality with existing inventory. However, the cost of these parts is overshadowed by the costs of performing the other aspects of the parts control program. These latter costs cannot be easily estimated because the program complexity is increased, which results in increased schedule, as well as added management and expediting tasks. Commercial programs while not requiring a formal parts control program as part of the contract, rely on good business practice to achieve the same result. The industry has consistently demonstrated that devices sold as long as 20 years ago are supportable in a cost effective manner.

Aircraft Parts and Data

Another key discriminator between military and commercial simulator programs is the method of procuring aircraft data and parts. The typical military program requires the contractor to be fully responsible for the procurement of parts and data. These items are normally on the critical path and therefore represent a major risk to the contractor. If the simulator is being developed for a prototype aircraft, these parts are usually long-lead items because the aircraft production line is normally the aircraft manufacturer's first priority -- i.e., the production of parts for the simulator has lower priority and is not included in the production plan. Similarly, the generation of data required to support the simulator design has lower priority than aircraft design, redesign, certification testing, and other tasks which require the same people. In some instances when the contractor has full parts and data responsibility, the Government is unwilling to intercede and assist in obtaining parts and data. While this approach appears to relieve the Government of the risks associated with late parts and data delivery, it does impact the program and thus, in many cases, the simulator schedule and cost.

In contrast, commercial airlines typically take more interest in assuring that parts and data are available for the simulator manufacturer. In many instances, the customer provides the parts and data as customer-furnished equipment. In doing so, the customer can control, or at least more positively influence, the availability of these items. In some cases, the airline management prefers to avoid any risks associated with the parts and data availability, resulting in another approach: although the responsibility resides with the simulator manufacturer, the customer takes the initiative to influence the delivery dates and priority for parts and data. In some cases, this includes pre-ordering or reserving sets of parts and data in anticipation of a simulator contract award, which ensures timely availability of these for the simulator manufacturer. In other instances, the customer exerts influence on the aircraft manufacturer through coordination efforts. The key in either of these approaches is that the customer (whether military or commercial) has a much greater influence with the aircraft manufacturer than does the simulator manufacturer.

Methods of Concurrent Change

The design of simulators to reflect the concurrent change activity of the parallel aircraft development is an important facet of a successful simulator program. The commercial simulator programs are very effective, resulting in commercial simulators being delivered which match the configuration of the design-basis aircraft. The system employed permits an early review of aircraft changes and, where applicable, incorporation of the changes (in blocks) in parallel with the ongoing program activities. This is made possible by the advance authorizations (based on contractor cost estimates) provided by the airlines to proceed with changes which are subsequently negotiated. Even major aircraft changes can be incorporated in this fashion. As stated earlier, American Airlines, for example, converted their aircraft from a three-crew configuration to a two-crew/ three-crew alternate configuration and subsequently to a two-crew configuration. The second simulator conversion was accomplished after testing had already begun, but by proper planning, parts expediting, and customer assistance, the simulator started customer acceptance testing reflecting the latest configuration. The net impact of these major modifications on the program schedule was only six months! These changes required new data and many new aircraft parts, including aircraft structures and panels, and yet the simulator was available to support the critical training needs.

The military procurement system cannot operate in this manner. A principal reason is that changes of any significance cannot be started prior to approval of the Engineering Change Proposals (ECP's). Since ECP's are rather time consuming to produce (1 to 3 months), and then require time for Government review, delays before incorporation are generally much longer than in the commercial application. Consequently, in many cases, the only practical way a contractor can accommodate a major change is by incorporating ECP's at the end of a program because the in-process change activity associated with military procurement is much more complex than that of the commercial simulator.

Support Concepts

The simulator support concept may be the single most important element in the procurement of the simulator. Therefore it is important to review and contrast the various concepts on military and commercial programs.

The military support concepts vary widely among the various services and in many instances, within a service. The C-130 program, for example, uses organic maintenance, with a total of 64 (41 Air Force and 23 Civil Service) personnel required at the Little Rock AFB site to support four simulators and two Cockpit Procedures Trainers (CPT's). A contractor support alternate which was proposed to the Government would have utilized 29 personnel to provide the necessary maintenance (20 hours per day, 7 days a week) and engineering support.

One of the most successful contractor simulator maintenance programs is the Army Synthetic Flight Training System (SFTS). That program has evolved over the last eight years, and provides for:

1) Total contractor maintenance support.
2) Total contractor spares management and control.
3) Training of contractor maintenance personnel to satisfy expanding requirements.
4) Clear lines of contractor management responsibility and authority.
5) Reasonable requirements for maintenance and logistic reporting.
6) Army "owned" documentation, spares, etc., which permits recompetition if required.

The cost effectiveness of this support program is now a matter of record. The availability achieved has been 98% compared to a requirement of 90%.

In the commercial sector, airlines typically maintain their simulators with a much smaller team of experienced personnel. American Airlines utilizes its own maintenance personnel supplemented by one Link field service person for a six month to one year period to augment the staff on new simulators being installed. American Airlines utilizes 43 maintenance personnel dedicated to the support of 13 simulators and four CPT's to support training (20 hours per day, 7 days per week).

NASA-Ames recently procured a 727 flight simulator and other miscellaneous equipment to conduct research on new flight management techniques compared to conventional aircraft. NASA's concept called for the purchase of commercial equipment and commercial documentation to support not only the maintenance, but significant change activity by contractor personnel. This approach permitted the procurement of the hardware and software at a fraction of what would have otherwise been required.

Program Management Approaches

The program management approaches utilized on military simulator programs are far more complex than those employed on commercial programs. Upon the C-130E contract award, a large contractor program management team (13 members) became essential. The many requirements not only had to be managed internally, but also reviewed with the customer and addressed in the meeting minutes, data items, and correspondence. The C-130E program had a long series of Engineering Design Reviews (EDR's) and Program Management Reviews (PMR's) with large numbers of Government personnel in attendance.

Although many of these meetings were conducted in two or three days, some lasted one week or longer. The Preliminary Design Review required nearly two weeks and the first of the four increments of the Critical Design Review lasted three weeks. These meetings generated many action items (191 requests for action were generated in the C-130E PDR) which again resulted in more program management attention. Many of the action items subsequently resulted in correspondence. It is estimated that during the C-130E program, approximately 1,150 letters were written by the Government, and a similar volume of correspondence was generated in response, by Link. Many of these letters included long attachments answering previous inquiries or commentary. The efforts associated with this high degree of customer involvement are inevitably reflected in the cost of the simulator.

Commercial simulator programs also rely on a contractor program management team. However, the team is much smaller, usually consisting of a program manager, a program engineer, plus clerical and administrative support. A small team can accomplish the program management function because the commercial program is less complex, has fewer requirements supporting the simulators, and has minimal customer involvement in the design and management aspects of the program. For instance, PDR's, CDR's, and EDR's are typically not held on commercial programs. Approximately eight customer meetings with four or fewer attendees are held. Far less customer correspondence is required. Very few actions usually remain at the conclusion of a meeting since many decisions are made during the meeting. The commercial simulator programs have been employing this program management technique successfully for more than two decades indicating that formal PDR's, CDR's, and EDR's are not essential management tools.

Acceptance Testing

Another significant discriminator in program management approaches centers upon the acceptance process. The military approach is characterized by large Acceptance Test Procedures (ATP) and a significant period of the schedule dedicated to acceptance. The acceptance is also supported by a large cadre of test team members.

The C-130E schedule allocated four months for the in-plant customer acceptance testing (termed qualification testing), with an additional one and one-half months required for a configuration audit, reliability testing, and maintainability testing. The total in-plant customer acceptance test period (including the audit and R&M testing) actually required 10 months. Approximately 20 Government personnel were involved with the C-130E acceptance testing at any one time. The ATP was approximately 6,000 pages long. The ATP length was required because each specification requirement needed to be specifically addressed, and each procedure was written so it could be understood by entry-level technicians unfamiliar with the simulator. With a long test schedule, it was difficult to maintain acceptance crew consistency. As a result of personnel changes, many subjective areas were retested, causing further schedule extensions.

A commercial simulator acceptance process minimizes the amount of subjective testing by using a dedicated crew/acceptance team (usually four or fewer) and automated test guides which are based on actual aircraft performance. This approach makes the process more efficient and objective, while maintaining comprehensiveness. Also, commercial ATP's are typically much shorter. The AAL 767 Test Guide was approximately 2,100 pages. In addition, the FAA requires a Test Guide to verify that the requirements of the Advisory Circular are met. The total 767 Interim Phase II FAA Test Guide was 322 pages in length. The emphasis is always on proper simulator operation, rather than exactness of the ATP format. Additional efficiencies have been achieved by accepting the contractor's running of the ATP, coupled with spot checking by the customer. In the AAL 767 program, AAL completed approximately 40% of the test guide over a four-week period. The balance of the acceptance period concentrated on fine tuning the simulator for crew subjectivity and on obtaining Interim Phase II approval. This customer cooperation and willingness to concentrate on obtaining results in the most efficient manner is a prime example of how both organizations benefited without sacrificing the objective. In this case, the objective was to get a qualified simulator in training on schedule. This resulted in the timely training of 42 crews (during a six month in-plant training period) and an approximate savings by AAL of $2 million.

The incorporation of comprehensive warranty and update provisions in the contract facilitate the acceptance testing of commercial simulators. The willingness of a commercial customer to make more rapid decisions on the acceptability of a simulator is based on the security that missed defects will be corrected. First, the commercial contract includes an expanded warranty program under which defects will be corrected for a specified period, typically two years. Second, commercial contracts in many instances often contain update requirements, under which a specified number of man-months of engineering support are available to correct any subsequently discovered problems. Thus, testing and retesting the simulator in an attempt to find every possible defect is not considered necessary.

Schedule

Another significant discriminator between military and commercial simulator procurements is the schedule. Typically, in both cases, simulator schedules are critical. Further, from an investment viewpoint, a shorter schedule means lower acquisition costs, and earlier training cost savings. The contractor is as anxious as the customer to reduce schedules, since his costs would be reduced, making him more competitive. However, military schedules are typically much longer than commercial schedules. Table 2 compares the original 767 simulator schedule with the original C-130E schedule. The program schedule accomplishments shown reflect the various changes during the course of the programs. The significant comparison is that despite the two major aircraft configuration changes and other concurrent change activity, the 767 simulator required only an additional 7-1/2 months to the completion of in-plant acceptance beyond the original schedule. The salient element in this comparison is that the C-130E required 12 months longer than the 767 to complete in-plant customer acceptance.

Table 2 SCHEDULE COMPARISONS
(Months After Award)

	ORIGINAL C-130E	FINAL C-130E	ORIGINAL 767	FINAL 767	TYPICAL NEW 767*
Start of Hardware Software Integration	18	21	17-1/2	25	14-1/2
Start of In-Plant Customer Acceptance	23	33	22	29-1/2	19
Completion of In-Plant Customer Acceptance	28-1/2	43	23-1/2	31	20-1/2

*This column shows the anticipated schedule for a new 767 simulator which would be designed to reflect a new customer's configuration, training features, etc.

Since schedules are critical to both customer and contractor, why are military schedules often longer than commercial schedules for simulators of comparable complexity? The answer to this question is very complex. A key factor is the availability of the aircraft and simulated equipment data. This in turn is followed by the availability of aircraft parts and avionics. As discussed above, customer awareness and involvement in the data and parts procurement has a significant impact on simulator schedules. The relative involvement in data and parts acquisition appears to be a contributor to the longer military program schedules.

Long-lead Government-screened MIL-spec parts in many instances become critical schedule path items. For example, MIL-spec connectors often require a one-year or longer lead time, whereas commercial connectors are readily available. In many instances, lead times change and schedule impacts cannot be determined until after the parts selection and approval process has been completed. Attempts to substitute at that point in the program may relieve but usually do not eliminate schedule impacts.

The program management approaches previously discussed also have a direct bearing on the length of a program schedule. The conduct of the program directly influences the activities associated with the design and production of the simulator. The comparison of the ATP length previously cited is directly translated into program schedule requirements. Further, the degree of customer involvement in the design review and approval process also has the potential to severely retard the schedule.

The complexity of the simulator program, as measured by the various data items, meetings, correspondence, etc., has a major effect on the simulator program and thus its schedule.

Summary

Although we have discussed the discriminators individually, in actual practice they are all blended together and all interact simultaneously. The combination of all of these elements results in a whole which is greater than the sum of its parts in terms of program complexity. Therefore, overall effectiveness in the acquisition of complex devices such as simulators, appears to be greatly enhanced by the reduction in the number and complexity of the requirements and processes.

EVALUATION OF COMMERCIAL PRACTICES WHICH HAVE POTENTIAL APPLICATION TO MILITARY REQUIREMENTS

In certain situations, many of the approaches utilized in commercial procurements could be selectively applied to procure simulators for the military. As discussed previously, many of the current requirements included in the military contracts are mandated by the maintenance support concept. The various discriminators between the two programs could be put into two categories:

1) Those applicable only if support concepts are changed to accommodate these practices and

2) Those applicable independent of the support concept.

Prior to categorizing and discussing the various key discriminators, a brief review of the impact of the support concept selection is in order.

Support Concept

The election of an organic support system requires the Government to draw upon many organizations which are geared to the support of expensive, critical items of equipment and the missions that this equipment is designed to accomplish. These organizations are essential to ensure that the readiness of the United States defense is maintained. Flight simulators, however, are heavily taxed by this system and in many instances, without practical justification. The criticality of a simulator malfunction, and the criticality of instant repair of the simulator is far less important than the support of an attack aircraft in a wartime environment. Moreover, there are fewer simulators than aircraft in the Government inventory. Yet, when the two devices draw upon the same support organizations, many of the same requirements are imposed on each procurement program. The reliance upon organic maintenance personnel and existing supply systems forces the Government into an inefficient maintenance concept for some of its equipment. The magnitude of the cost impact of these basic policies depends upon the size of the program and the extent to which the particular service is willing to modify its requirements.

The direct cost of maintenance is only one element in the costs associated with the choice of the maintenance concept. In order to maximize savings associated with the various choices, selection of the maintenance concept must take place prior to issuance of an RFP because overall program complexity is affected dramatically by this decision. Contractors usually find it very difficult to price various alternatives or indeed, to separate the impact of individual requirements so as to arrive at costs that are allocated correctly. The cost savings possible with contractor support can in many instances be demonstrated without regard to other attendant program economies as was recorded in a GAO report:

> "In the mid-70's, the Air Training Command published the results of a contract vs. in-house cost comparison study in support of T5 and T45 (Undergraduate Navigator Training System and Simulator for Electronic Warfare Training System) navigational and tactical simulators used in its undergraduate training program. Prior to the study, the simulators were maintained by 56 in-house personnel. As part of the study, ATC solicited bids for contract maintenance support. The proposal by the low bidder, who was ultimately awarded the contract, showed a requirement for only 26 maintenance personnel; less than 50% of the in-house staff used by ATC to maintain the simulators. It should be noted that personnel costs represented approximately 90% of total support costs for in-house maintenance."[1]

The Navy has also recognized this fact, having recently disestablished the Training Device Technician field. The support of the Navy's existing inventory of aviation training devices is being procured competitively from private industry by NTEC not only to take advantage of cost savings, but perhaps even more importantly, to relieve critical shortages of technical skills. In this case, the contractor will be permitted to exercise the Government supply system, with primary responsibility for providing spares residing with the U.S. Navy. The contractor will be allowed to procure spares if the U.S. Navy system cannot provide the required spares in a timely manner. Existing available support equipment will be turned over to the contractor who will be responsible for any replacements or additional equipment. Documentation must be kept current, and contractors must meet Navy reporting needs in order that support contracts may be reopened for competition in the future.

The use of organic maintenance to support highly sophisticated training equipment often leads to a series of inefficiencies. Owing to relatively high turnover rates, ongoing maintenance training is required. The replacement technicians typically lack technical knowledge and as a result, training courses must be very detailed. Thus, maintenance technicians require longer and more expensive courses than are needed for contractor personnel. Further, the relatively low experience level among available on-site maintenance personnel limits the type of maintenance which can be performed on-site. This in turn requires a different spares philosophy, the use of depot repair and more extensive test equipment. The higher skill level of contractor personnel allows better use of available personnel and permits cross-training so that individuals can maintain multiple areas of the trainer. An important factor resulting in higher contractor support efficiency is that non-productive personnel can be eliminated from the site, allowing a better motivated team.

Discriminators Dependent on the Support Concept

There are certainly situations where organic maintenance should be continued. However, potential savings in the use of contractor maintenance should be considered in selecting the support concept on new simulator programs. In addition to the cost savings associated with the maintenance, the following major program requirements should be considered for elimination.

Materials, Parts, Processes. The use of MIL-spec parts, parts screening, controlled manufacturing standards and other associated requirements is currently made necessary by the logistics system supporting the maintenance function. Their impact on program cost and schedule (discussed in the previous section) is considerable, and accordingly these requirements should be considered as possibly expendable. The Government now permits the use of certain commercially available off-the-shelf equipment in all procurements. As an example, commercially available computers and CRT display systems are not only permitted, but required to be supplied as part of the simulation equipment. This assures the Government of the latest technology with lowest cost and good support. Yet this selection requires the very compromises that are being advocated here -- that is, the use of commercial components, commercial standards in design and manufacturing, and most important the willingness to accept standardization and reduced involvement in the design process. Another example is the use of commercially available and demonstratable visual systems. Here again, the Government is willing to waive MIL-spec requirements in exchange for the benefits of the reduced cost and schedule.

The substitution of a contractor parts control program (without Government involvement) would remove many data items and other obstacles to the performance of the program. The use of commercial approaches to design and manufacture opens the door to existing design and its attendant benefits. Considering that the training equipment is ground-based, and that some of the

[1] GAO report, Special Programs, Audits Division, Project 8AE-140, March 26, 1979

main portions of the simulator are permitted to be unaltered commercial items, does it make sense to require MIL-spec parts and processes for those pieces designed and built by the simulator manufacturer?

Logistics Data. Approximately 30 data items were required on the C-130E program to support the purchase and dispositioning of the spares and support equipment necessary for organic maintenance. This is in addition to the significant investment required for the purchase of the items. Substantial numbers of Government personnel were involved in the process of evaluating and procuring the spares as well as statusing and handling them. The cost to the Government of applying the logistics concepts to the C-130 simulator program may very well have exceeded the cost of the design, production, test, and installation of the device.

In contrast, the spare parts for commercial simulators are identified using existing engineering bill of material listings without the specific provisioning documents being generated for current DOD programs. Similarly, satisfactory support analyses are performed on commercial contracts without the costly documentation (e.g., Logistics Support Analysis Record) required in an organic program. Thus, if there is no need to use the Government supply system, significant savings can result by eliminating many costly requirements.

Design Documentation. The level of design documentation is directly attributable to the support concept. The software documentation required by current military programs typically can exceed 350,000 pages in length! The documentation is geared to entry-level maintenance technicians who are unfamiliar with the equipment, so that the documents become in effect training manuals. Further, the level of documentation is required to support any subsequent change activity by a maintenance team with little experience. Consequently, the detail required is extensive. In contrast, commercial documentation provides an understanding of the system simulated and the approaches utilized in obtaining the desired simulation. The advent of higher-order languages such as Fortran has eased the documentation requirements, since capable programmers can understand the software by reviewing the coding statements and appropriate commentary. The commercial customers routinely maintain and perform minor updates without difficulty utilizing the commercial level of documentation. The cost of the military documentation and its disruptive impact on the development programs is overwhelming. A considerable cost savings could be realized if this requirement were relaxed. The use of a contractor support system would permit this to happen.

Similarly, the level of detail required in the drawing packages is far greater in military contracts. The formats of the drawings are more restrictive and, in addition, lower levels of drawings are required to be submitted. Presumably this is to permit flexibility in second-source selection (which rarely happens in simulators) and provide assurance that spare parts could be manufactured by the Government if necessary. The Government must pay for the drawings and in addition, maintain (control, file, etc.) them in its system. Commercial customers require only the drawings necessary for maintenance in the commercial format and find their requirements satisfied at much lower costs.

Configuration Control. A favorite topic of discussion in today's procurement arena is configuration control. Most simulator manufacturers have demonstrated hardware configuration control systems which meet both military and commercial requirements and adequately ensure that replacement parts can be procured so that they are form, fit, and function interchangeable. Software configuration control, which includes both the instruction/data code and documentation, is a subject of current concern because the Government wants assurance that the final product not only results in the proper simulator performance, but also is exactly documented so that it can be understood and/or changed as required. The controls imposed by the Government therefore are very rigorous and in some ways constraining.

A problem arises in the simulation business because software is constantly being changed during the design, test, and customer acceptance periods. The need for software configuration control is a well-founded and accepted requirement. On commercial simulator programs, systems are employed which provide insight into the exact revision level, date last changed, check-sum, etc., of software modules in a very efficient manner, without automatically tying the software documentation into the control system. Most of the risk of out-of-date documentation disappears because the documentation is less complex and/or detailed. The risk is then minimized by documentation updates upon completion and acceptance of the software rather than in a concurrent mode.

The efforts associated with very rigorous software configuration control systems are very costly and adversely affect productivity. Since commercial simulators are routinely designed, delivered, and maintained without this rigor, and without significant problems, serious consideration should be given to the use of contractor maintenance and an attendant relaxation of the software configuration control requirements.

Manuals. The relatively low experience level of the available on-site maintenance personnel, coupled with their high turnover rate, causes the imposition of a requirement to write technical orders to accommodate that skill level. Little or no pre-existing knowledge can be assumed. In addition, military technical publication standards regarding format, artwork, and materials result in significantly more expensive manuals which contain essentially the same data as those procured according to standard commercial practices. Thus, if contractor maintenance is employed, considerable savings can be realized by the reduction in requirements associated with the generation, verification, and validation of manuals.

Spares/Support Equipment. The cost of spares and support equipment on a military program far outweighs the equivalent requirements on a commercial program. Because of the remove-and-replace maintenance philosophy employed, repair of the Equipment Replacement Units (ERU's) must be done at the depot level. In commercial applications, contractor personnel normally perform the majority of ERU repair on site. As can be demonstrated using any support cost model, a depot repair philosophy results in a significantly higher spares procurement at the ERU level. This repair philosophy, in turn, necessitates the purchase of sophisticated test equipment to fault-isolate failed units and to verify their repair. Where on-site repair is possible, the simulator itself in most cases can be used for this purpose during the maintenance period.

Because the military requires that its existing supply systems be employed to support the simulators it procures, simulator-unique equipment is entered into the national stock numbering system at a cost of approximately $5,000 per part number over the life of the trainer. In addition, the base supply system adds another $500 annually per part number per site. The AFLC Logistics Support Cost Model indicates that inventory management is second only to spares as the leading support cost driver. Similarly, support equipment procurement and management is cumbersome when utilizing the logistics systems.

The commercial simulators are adequately supported with far fewer spares and support equipment and with less involvement from depot or equivalent. As noted earlier, American Airlines in support of its 767 simulator invested significantly less than the amount invested by the Government for the C-130E. In many cases, even with less investment, the avoidance of the depot system translates into fewer delays and downtime and thus better equipment availability. Thus, the concept of a dedicated complement of spares and support equipment, which is feasible with contractor support, offers the opportunity for significant cost savings without degradation of simulator availability.

Discriminators Independent of Support Concept

Many current military procurement practices could be brought into alignment with commercial practices as a method of cost reduction even while maintaining the organic support concept. The following paragraphs discuss the items which, if adopted, could either stand alone or represent additional savings to those dependent upon the use of contractor support.

Customer Involvement. The military procurements require a high degree of customer involvement in all aspects of the conduct of the program. This involvement complicates the management function and in many cases adds to technical complexity during the design process. It affects the performance of the contract and is one of the most significant factors attributing to the difficulty in maintaining schedule. This involvement is apparent in the need for the submission of data items like the Configuration Management Plan, Detailed Human Engineering Plan, Personnel Subsystem Test and Evaluation Plan, Hazard Analysis Report, Transportability Report, Reliability/Maintainability Demonstration Plan, System Safety Program Plan, System Test Plan, Technical Manual Plan, and the Integrated Support Plan. In addition, many design reviews and status meetings are required with relatively large numbers of attendees. The commercial approach of minimal involvement after selection of a competent manufacturer permits the contractor to concentrate on designing and building the simulator. This topic has been discussed in workshops with contractor and Government personnel and the word "micro-management" has been coined to express the current approach. One possible solution worthy of consideration is an extension of what the Government currently does in the proposal evaluation period.

Major U.S. Air Force procurements managed by Aeronautical Systems Division (ASD) require examination of the contractor's capabilities via an MM/PCR (Manufacturing Management/Production Capability Review) before contract award. If this were extended, either on a per-contract basis or on a periodic basis, to certify the contractor's capability and procedures in many of the above areas, each contract would be relieved of the redundant submittals, revisions, and discussions associated with each item. This would give the Government assurances (perhaps along with DCAS monitoring) that the processes being employed by the company are sound, without injecting undue interference. Similarly, a lesser involvement in the design review process would in effect eliminate many instances of specifying "how" a certain requirement is to be met. Going a step further, adoption of the commercial practice of much higher-level status reporting would eliminate the need of many additional reports and/or meetings which compound the program complexity and disrupt program operations.

Certainly, the military procurement agencies as they exist today could not accept these suggestions without considerable change in the way the Government does business. The expanded use of firm pricing in conjunction with bonuses or penalties as is done on some commercial contracts, would alleviate many of the Government's misgivings. This pricing philosophy would more firmly place the burden of performance on the contractor, but would only be successful if the contractor is given the freedom to manage the program without undue interference. Another possible change would require reorganizing the procurement team in such a way that decisions could be made by key individuals rather than by committee. This would considerably reduce the cost of the Government's procurement team and also streamline the program from the contractor's viewpoint.

The quality of the product is not necessarily improved by the current high level of attention and scrutiny exercised by the Government. Commercial simulators produced under less rigorous conditions of customer supervision are highly acceptable training devices and deliver excellent transfer of training capability. Therefore, the commercial method of managing the procurement should be closely analyzed for applicability to the military procurement programs.

Acceptance Approach. The approach used by the military in accepting a simulator is far more demanding than that employed by the commercial customers. The acceptance approach differences center on the size of the ATP, the method of evaluating subjective areas and the size and continuity of the test team. The size of the typical military ATP and the method employed in subjectively evaluating the simulator reflect on the Government's desire to accept the training device only after it is "perfect," minimizing the risk that a requirement was missed or a defect was left undiscovered. To achieve this aim, a large acceptance team is deployed, which not only identifies valid problems, but frequently injects disruption and in some cases confusion to the acceptance process. Lessons learned from the commercial practices suggest that the test team be reduced to as few members as possible. Additionally, the use of warranty and updates to correct problems found after acceptance could alleviate the anxieties and risk associated with the Government's "single- shot" approach currently practiced at acceptance.

Another problem associated with customer acceptance of flight simulators is the "tailoring" that is required to make the simulator subjectively fly like the aircraft or operate like the equipment. Many times, the requested changes are not supported by aircraft data or training need. Because of the nature of these requested changes, contractors usually object to the continuation of extensive testing/ changing in these areas.

The commercial approach is to ascertain that the test guides are met to the customer's satisfaction. Then a specified period is allocated to the subjective tailoring process. In some instances this period is exceeded, but relatively speaking, the program proceeds as planned and scheduled while accommodating the crew inputs. In this case, crew experience and consistency are paramount, as well as the commercial understanding that all aircraft of a given type do not perform exactly alike. By open recognition of the requirement for subjective adjustments and by allocating a certain period of time for their accomplishment, a teamwork approach is typically adopted. This usually results in excellent results for both the contractor and the customer. The acceptance process used on commercial programs is directly applicable to the military programs with minor procurement practice changes required, and it should be considered.

Aircraft Data and Parts Management. The methods employed by both military and commercial procurement practices for the management of aircraft data and parts can dramatically affect program schedules. It would be very much to the Government's advantage to become involved in the process. As noted in the discussion on commercial practices, some airlines elect not to assume responsibility for parts or data acquisition, but they nonetheless actively participate in obtaining parts and data for the contractor in the interest of their program. When individual airlines are unsuccessful in persuading the aircraft or avionics manufacturers to cooperate in procurement, they often achieve their aims by lobbying through such organizations as the Air Transport Association (ATA) or the International Air Transport Association (IATA). The military procurement agencies should at least take an active role (preferably full responsibility) in this area because parts and data are always on the critical path of a program. Government involvement in this area will make a difference!

Concurrent Change Control. The ability of a commercial simulator to be concurrently updated with the aircraft during the design, manufacturing, and test phases of a contract is very important to the customer in ensuring prompt availability of a simulator which accurately reflects the aircraft. This process is seldom duplicated on military programs because of the rigidity of the procurement process and the complexity of simulator programs. But there are isolated exceptions: some complex military simulation devices were produced during the development of the operational hardware and configuration updates occurred in parallel. NASA, in development of the Apollo and LEM spacecraft simulators, ensured that the critical simulators were designed to the latest baseline with updates taking place throughout the simulator program. The NASA program management and engineering teams (both NASA and the contractor) worked together as a close team. Key individuals were given authority and key decisions were made when they were needed. The support concept (contractor support) permitted these highly critical programs to be conducted in a manner which concentrated on proper execution of design and testing and placed less emphasis on the supporting data and logistics considerations. This approach not only supported the schedule, but directly influenced the cost, since the streamlined methods positively influenced production efficiency.

The benefits to the user of concurrent change activity are not only desirable, but achievable. The Government must weigh the potential benefits against the potential impact of changes which would have to be made in procurement practices. A contractor support system (and the attendant reduction of program requirements) would provide an ideal foundation for concurrent change activity. Even so, changes in the procurement practice (permitting nearly instantaneous decisions and authorizations to proceed without laborious proposal submittal and evaluation) are the key to improving the process in a substantial and meaningful way.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE CONSIDERATION

Many commercial procurement practices can be applied to selective military programs; as this paper has attempted to demonstrate, these techniques do not offer a total solution to all military procurements, but they do present alternatives which in some instances provide a capability to reduce life-cycle costs and to shorten schedules.

Adopt Contractor Support Concept

The single most important procurement practice to consider is the extensive use of contractor support, a practice which can be fully justified when its costs are compared to the cost of organic support. Perhaps even more significant is the fact that the support concept dictates the other program requirements. The selection of contractor maintenance opens the door for a complete re-evaluation of these requirements. Because commercial airlines can operate their equipment with a fraction of the documentation and supporting material that is required by the Government, it seems entirely reasonable for the Government to consider emulating this approach where not constrained by environmental factors.

Structure Program Requirements To Reflect Support Concept

If contractor support is selected on a new procurement, the program requirements should be restructured to eliminate unnecessary items. The requirements for spare parts, support equipment, software documentation, drawings, logistics data, and manuals all need to be reevaluated carefully. Strong consideration should be given to requiring only those items necessary for the contractor to maintain the equipment, as defined by the contractor. These items can be easily reviewed to ensure that the option is preserved to recompete the support contract in the future. The reduction of requirements would not only reduce the procurement costs, but would streamline the simulator development and reduce the risk of schedule and cost overrun. The potential for further schedule reduction is also possible, depending on the extent of the reduction in program requirements.

Another key change feasible under a contractor support concept is the elimination of the restriction imposed on materials, parts, and processes. The use of good commercial practices in these areas will not degrade the performance of the simulator in its mission of training crew members. There is no reason to differentiate between an off-the-shelf computer complex with its many printed-circuit cards, and a simulator manufacturer's specially designed printed-circuit cards. Simulator manufacturers have proven the excellent quality and supportability of their product for many years.

Adopt Commercial Program Practices

Military procurement practices impose many restrictions which may not be necessary to control the development of ground-base training equipment. Consideration should be given to the possibility of adopting those commercial approaches which result in a more hands-off attitude (after careful selection of a qualified simulator manufacturer). Certain safeguards (warranty, updates, etc.), as used in the commercial procurements, could be employed so as to minimize risk. The reduction in procurement and life-cycle costs will far outweigh the risks; most important, the objectives of reduced costs and shorter schedules can be more readily attained. Consideration should also be given to the elimination of the various program plans and a reduction in the number of formal design and program review meetings. Certification of the company's procedures and capabilities could be considered as a way of ascertaining the competence of the contractor. These requirement reductions would not only reduce the contract costs, but the procurement team costs as well.

The methodology of commercial customer acceptance should be evaluated and adopted where feasible. This would require a change in the acceptance philosophy and would probably need to be supported by a "product champion" who is able and willing to make decisions readily. Again risks could be minimized by specifying certain periods for performance updates in the future to correct deficiencies and by the use of warranty to cover latent defects.

Government involvement in the timely availability of aircraft parts and data management would provide an opportunity to reduce critical path lead times. This could be done partially without any additional Government responsibility or risk, and should be strongly considered.

The ability to provide simulator configurations matching the customer's operational needs requires careful planning and prompt decisions. Streamlining the procurement decision process, as well as becoming willing to make these decisions without extensive documentation (as in commercial practice) will result in a more usable simulator.

In conclusion, the military and commercial simulator procurement methods are quite different and result in wide variance of costs, schedules, and program complexities. The application of commercial practices does seem feasible if certain changes are made in the support concept and on the part of the procurement team.

There seems to be no doubt whatever that cost-effectiveness and training effectiveness (through earlier availability of equipment) may be strongly augmented by adoption of some, any or all of the recommendations suggested here, and they should be fully exploited.

ABOUT THE AUTHOR

Mr. John S. Hussar is uniquely qualified to address the subject of both military and commercial simulation procurements. He has been employed by Link Flight Simulation Division of The Singer Company for 17 years and has been a key member in both commercial and military program offices including the position of C-130 Engineering Manager. In addition, he has been extensively involved in proposal activities and engineering design for a wide range of simulator equipment. Mr. Hussar is currently the Director of Engineering for the Commercial Simulation Systems operation of Link Flight Simulation Division in Binghamton, New York, and is deeply involved in all engineering aspects on many commercial simulator contracts. Mr. Hussar holds a Bachelor of Science degree in Electrical Engineering and a Master of Science degree in Industrial Management both from Clarkson College of Technology.

CONCURRENCY OF DESIGN CRITERIA – A KEY TO TRAINER READINESS

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ABSTRACT

The benefits associated with combat crew readiness are obvious. What may not be so obvious are the benefits associated with timely acquisition and availability of training and training devices. As new aircraft programs develop and present aircraft programs mature, the crews must either train on the operational equipment or wait until the associated trainers are developed or updated. If the trainers are developed and updated in concert with the aircraft program, the Air Force is provided not only with combat-ready crews at the correct time, but also at the correct cost. The key to keeping the training devices in concert with the aircraft is a Concurrency Program.

On the B-1B program, a complete concurrency program is being addressed. By complete, it is meant a program which addresses the two major issues associated with keeping the trainer concurrent with the aircraft:

1. Cost-effective development and distribution of the required design criteria data.
2. Inherent flexibility designed into the training device to accommodate changes in a cost-effective manner.

The benefits associated with combat crew readiness are obvious. What may not be so obvious are the benefits associated with timely acquisition and availability of training and training devices. According to the 1982 Defense Science Board Summer Study in their briefing report for training and training technology, "Training devices tend to be acquired too late to meet weapon system IOC, in some cases as much as by several years . . . For new training devices to be of greatest benefit to the weapon system they support, the training system should be in place at least by the time the weapon system is fielded." As new aircraft programs develop and present aircraft programs mature, the crews must either train on the operational equipment or wait until the associated trainers are developed or updated. If the trainers are developed and updated in concert with the aircraft program, the Air Force is provided not only with combat-ready crews (Figure 1) at the correct time, but also at the correct cost. The key to keeping the training devices in concert with the aircraft is a Concurrency Program.

Concurrency, as opposed to currency, incorporates a program approach whereby the trainer is developed and delivered to a specified schedule in concert with the weapon system. Currency deals with maintaining configuration of the training device, after delivery, to coincide with the weapon system.

As an example, the 757/767 flight simulators currently in use at the Boeing Flight Training Center were developed concurrently with the aircraft (Figure 2). This program emphasized the importance of extensive interaction between the customer and the simulator contractor to identify and jointly resolve design criteria issues.

Similarly, we are contracted to provide flight simulators for the E-3A/KE-3A Flight Crew Training system program prior to the first aircraft delivery.

The B-1B program, shown in Figure 3, is where both concurrency and currency are addressed. Because of the complexity of this weapon system and the magnitude of potential changes, it is an example of a program which must address the two major issues associated with keeping the trainer current with the aircraft:

1. Cost-effective development and distribution of the required design criteria data
2. Inherent flexibility designed into the training device to accommodate changes in a cost-effective manner

The first feature is a joint responsibility of the contractor and the government to provide the correct contractual and management framework necessary to have the right design data at the right time.

The second feature is a contractor responsibility to design flexibility into the trainer and a government responsibility to specify the requirement in the initial procurement.

Development and Distribution of Design Criteria Data

Ideally, the plan for the development and distribution of the trainer design criteria data will be inherent in the plan of the weapon system itself. Specifically, the weapon system contract is constructed to contain the requirement to develop and document all data necessary to faithfully simulate the weapon system. A contractual framework is thus provided for timely supplied data as well as for the weapon system designers to provide data interpretation to ensure both completeness and accuracy. Data of interest would be delivered from design reviews, engineering tests, and flight tests. This approach to source data acquisition is instrumental in a concurrency program and desirable in a currency program.

Typically, however, the weapon system development is maturing when the simulator program is commencing. In this situation, a good currency program can be implemeted by incorporating the following items:

1. Contractual agreements between simulator and aircraft contractors to provide continuing access to aircraft configuration data and change activity
2. A design criteria management process which provides identification and configuration tracking of design criteria sufficient to accomplish the simulator system design
3. Means to establish and track the traceability between simulator subelements and the design criteria using a Data Base Management System (DBMS)
4. Extensive customer/simulator contractor interaction to identify verifiable configurations and to resolve problems arising from inconsistencies and inadequacies in the available design criteria

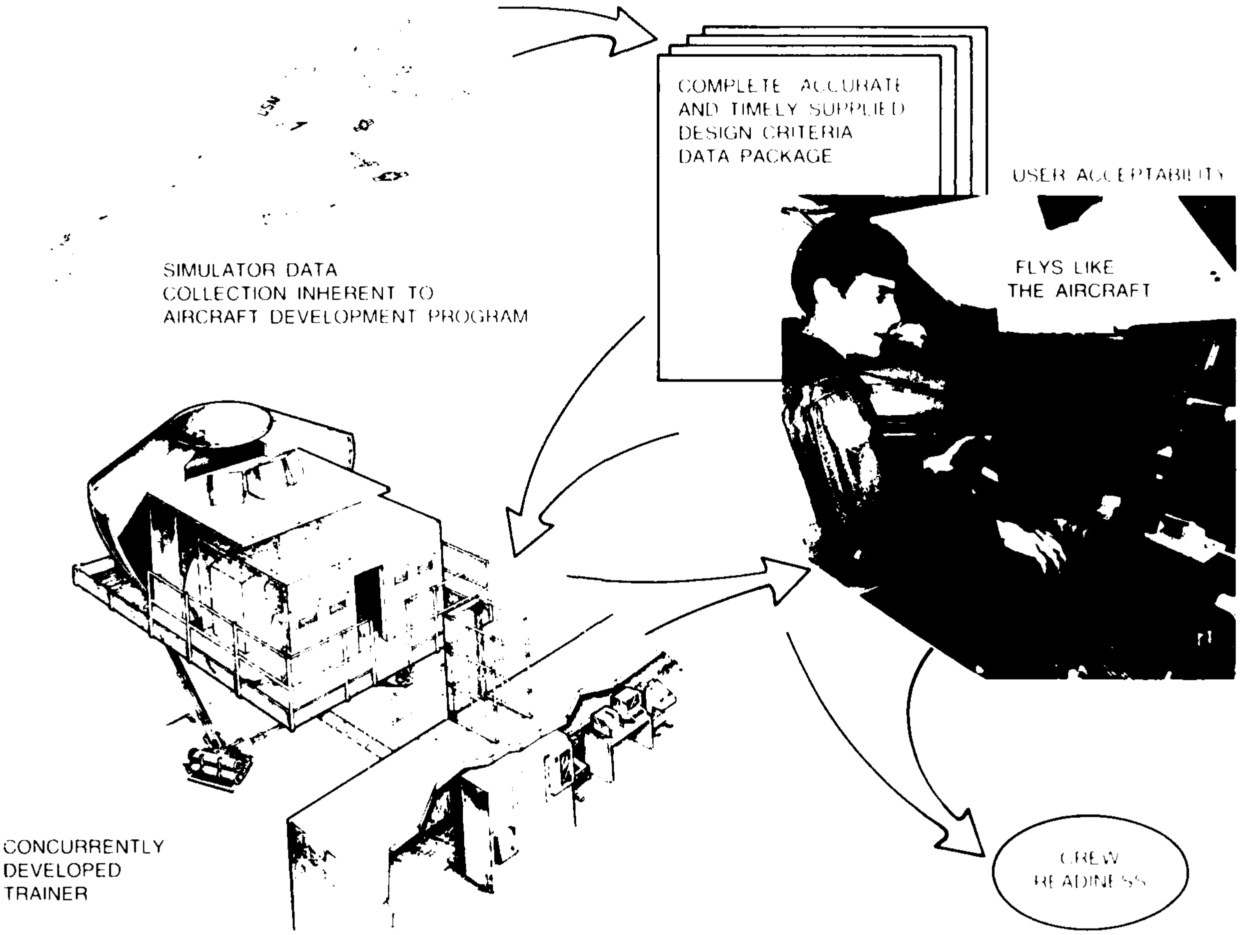


Figure 1 Concurrency of Design Criteria – A Key to Trainer Readiness

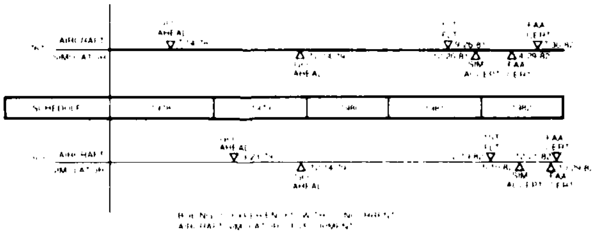


Figure 2 757/767 Aircraft Simulator Concurrency

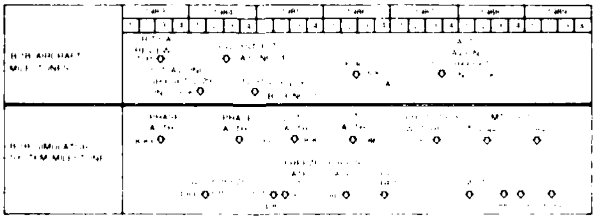


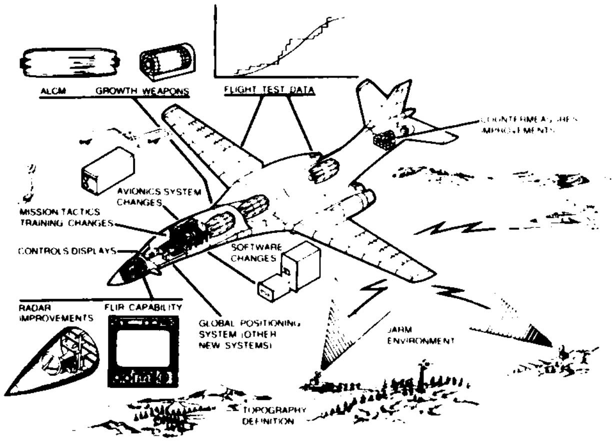
Figure 3 B-1B Aircraft Simulator Concurrency

These items, properly staffed and implemented, provide the simulator contractor with the necessary tools and design criteria to maintain currency with the weapon system. For this currency to be cost effective, the simulator contractor must go one step further and design a device which possesses inherent flexibility for accommodating weapon system updates.

Inherent Simulator Flexibility for Weapon System Changes

The concurrent development of the aircraft and simulator systems causes design criteria to be based on the aircraft configuration expected at the time of simulator deployment. Since a large amount of the initial simulator design will occur without the availability of complete flight test and technical order data, it will be necessary to work with predicted aircraft performance and preliminary design data while planning for inclusion of more detailed data, especially from flight test, as well as from other areas of weapon system updates.

This ongoing refinement of the weapon system design places an additional requirement on the simulator – namely to easily accommodate updates in the design baseline. As shown in Figure 4, the B-1B is an example of such a weapon system. A flexibility approach to each weapon system change area (see Figure 5) is examined below.



THE B-1B WEAPON SYSTEM WILL UNDERGO EXTENSIVE CHANGE OVER ITS SERVICE LIFE

Figure 4 B-1B Weapon System Change Areas

1. Operational Flight Program Updates – to increase flexibility in this area, the simulator should be designed so as to directly compile the aircraft operational flight programs (OFPs) without the need of recoding by software engineers. Examples of simulator designs providing this flexibility include: emulation of the on-board processors, cross-compiling of the OFPs, and use of the on-board processor in simulation.

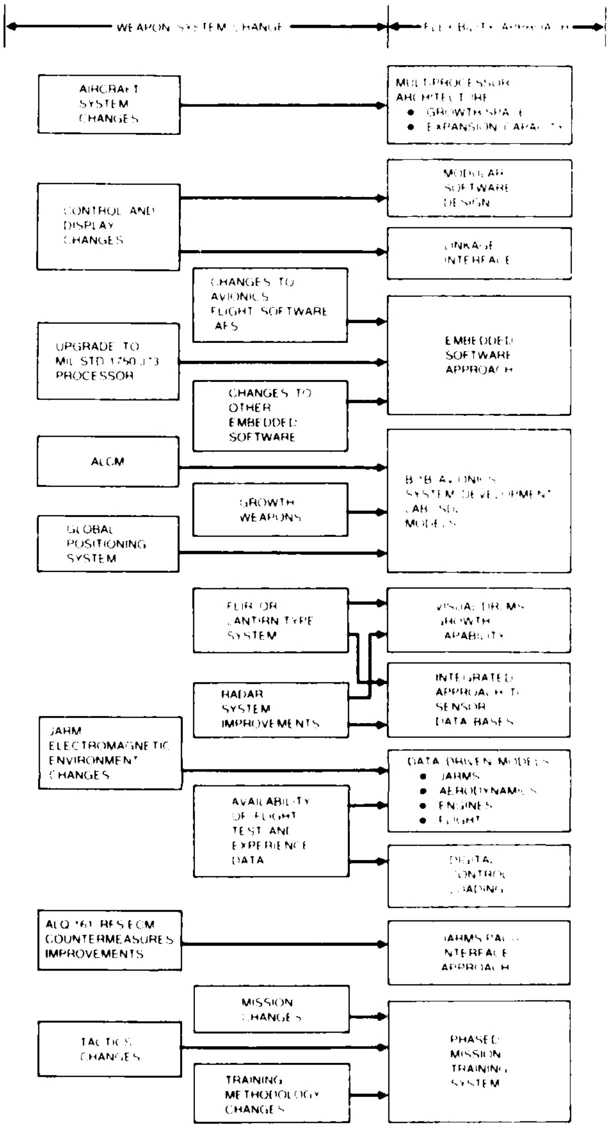
2. Weapon System Changes – several features can be incorporated into the simulator to minimize the impact of weapon system changes. These features include:

   a. A modular software approach to provide straightforward identification and isolation of changes to software elements

   b. Modeling approaches, such as data-driven models, which increase simulator update efficiency

   c. A modular, data-driven linkage interface system which permits the simulator to accommodate control/display/instrument changes with minor interface system impact

3. Electromagnetic Environment Changes – again modularized software which is table data-driven can accommodate quite easily the changes in the JARM (Jammer, Artillery, Radar or Missile) environment. For example, a modular program for jamming which determines jamming effectiveness from a data table using jamming-to-signal ratio, can accommodate new power densities and new frequencies based on data changes only.



BOEING'S FLEXIBILITY APPROACH WILL BE RESPONSIVE TO PROSPECTIVE WEAPON SYSTEM CHANGES

Figure 5 A Simulator Flexibility Approach

In addition to the flexibility features directed towards accommodating weapon system changes, flexibility is desired to accommodate changes in the simulator instructional features and in the computational system. Examples of such features include:

1. The use of shared memory as an intrastation communication area to provide extensive expansion capability within each station. Current typical shared memory systems can support up to 16 processors providing ample system expandability

2. Synchronization provided by a single master clock so that any number of additional processors can be added to a station by cabling to the intrastation synchronization interrupt.

3. Station-to-station transfers using direct memory access of shared memory areas under control of the station executive software All interstation transfers are accomplished by a single processor in each station. The addition of processors to any particular station will not impact the interstation transfers

4. A phased mission build process to provide mission generation personnel the capability of linking existing instructor page files to different mission profiles. Thus, a new mission can easily be created for a new geographical area using standardized mission events.

Summary

In summary, we find that planned and coordinated generation of the required weapon system design criteria data concurrently with a simulator program, which addresses design flexibility, provides the most effective approach to having the desired trainer capability at the desired time.

ABOUT THE AUTHORS

Mr. Casperson is the PDR manager for the B-1B Simulator System Program at the Boeing Military Airplane Company. In recent years, he has held positions in new business program management. Mr. Casperson holds a Master's Degree from Rensselaer Polytechnic Institute in electrical engineering. He was formally a member of the management staff of the Link Division of Singer as program manager for the Navy T-2C, the T-2E and the foreign C-130H simulator programs. Mr. Casperson has fifteen years of simulation experience, including eleven years in management.

Mr. Jerome Jonas is the KC-135 Simulator manager with Military Training Systems of the Boeing Military Airplane Company. He is currently responsible for all KC-135 simulator programs. He holds a Bachelor of Science degree in Physics and Electrical Engineering from Wichita State University. He was formerly Military Marketing manager for Automated Test Systems for Boeing.

DETERMINING COST AND TRAINING EFFECTIVENESS TRADEOFFS FOR TRAINER DESIGN: TEST OF AN EXPERIMENTAL MODEL

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ABSTRACT

This paper reports the status of an ongoing project to develop a macro model describing the decisions involved in developing training equipment. The purpose of the model is to assist managers in making such decisions by providing information concerning the tradeoffs between the cost and effectiveness of training provided by different configurations and choices of equipment. The goals of the current phase of the study were to determine the feasibility of collecting data to empirically test the model and turn it into a practical tool to be used in making decisions relating to trainer design and development, and to perform a preliminary test of the model.

Results of the field data collection led to the conclusion that the data necessary to test the model can be obtained. However, such measures need to be refined before the model can be turned into a practical tool. The preliminary test of the model performed in this study resulted in no major modifications of the model.

PURPOSE

This paper reports the status of an ongoing project to develop a practical model to assist managers in making decisions concerning training equipment. The model is designed to permit comparisons of the cost and effectiveness of alternative configurations of training equipment. The model will allow managers to make cost/benefit tradeoffs between the various characteristics that may be utilized in training equipment, and give both the military and industry guidelines to justify decisions relating to trainer design.

The purpose of the current phase of the study was two-fold:

(1) To determine the feasibility of data collection for empirical validation of the model, and

(2) To perform a preliminary test of the model.

BACKGROUND

In their 1982 Summer Study on Training and Training Technology, the Defense Science Board concluded that consideration must be given to training effectiveness during the design and development of military training systems. This conclusion was based on the fact that effective training is essential in order to maintain operational readiness (1). In a recent evaluation of operational trainers, the General Accounting Office stated that most training equipment is designed without due consideration to training effectiveness (2). It is essential, therefore, that tools be developed so that the effectiveness of training equipment can be estimated during the design and development phases. In this way, knowledgeable tradeoffs can be made between both the cost and effectiveness of training equipment during the development process.

The Air Force Human Resources Laboratroy concluded recently that no such practical model exists as yet (3). Such a model is necessary to aid both the Armed Services and industry in defining the requirements needed to design training systems that training personnel adequately and at a minimum cost. The current study is part of an ongoing project to help meet this need.

Development of an Experimental Model

A preliminary version of a model was described last year (4). All terms, such as "effectiveness" and "cost" were defined operationally for measurement both at school and on the job; cost included acquisition, operation, and support. A taxonomy was provided to describe the characteristics of a training device. Provisions were also made for specifying relevant characteristics of students, instructors, and training goals. A graphic depiction of the model is given in Figure 1.

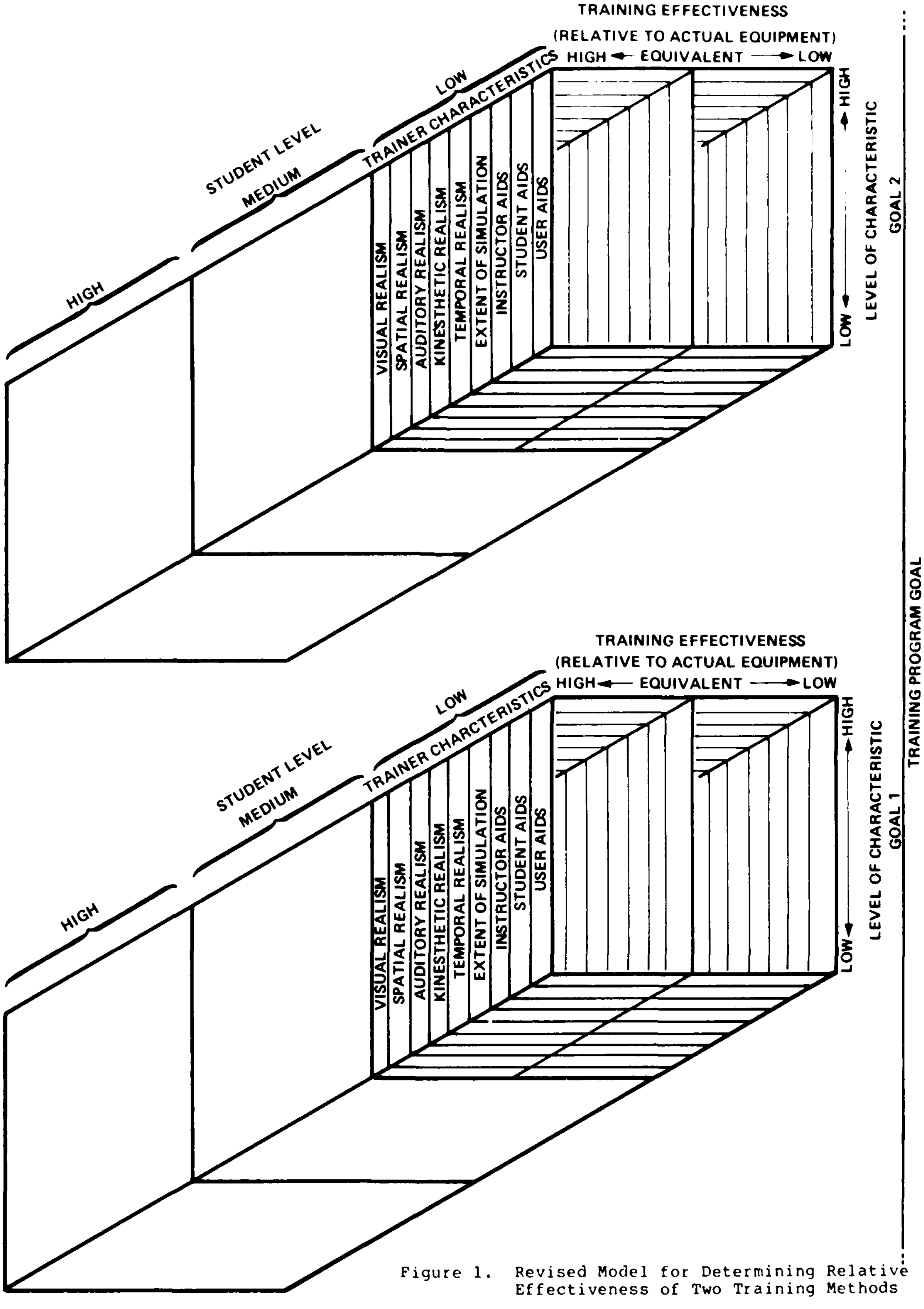

Figure 1. Revised Model for Determining Relative Effectiveness of Two Training Methods

PRELIMINARY TEST OF THE MODEL

Purpose

The purpose of this test was to examine the feasibility of collecting data needed to develop and use the model. The problem was to compare the effectiveness of training of F-16 maintenance technicians when either simulators or actual equipment had been used in training courses. Data were collected at Hill Air Force Base, Utah, and Hahn Air Base, Germany, where simulators were used since August 1979 and August 1981, respectively; data were also collected at Nellis Air Force Base, Nevada, where simulators had never been used.

The F-16 simulators consist of six free-play systems designed to assist in teaching maintenance courses in flight controls, communication, navigation, and electrical systems, and engine start, engine diagnostics and engine run for the F-16 aircraft.

Data Collection Instruments. Two sets of data collection instruments were used. A set of Behaviorally Anchored Rating Scales (BARS) was developed to assess technicians' performance in the field. Instructors, in the role of subject matter experts, were asked to create a series of critical incidents describing behaviors which differentiate between a good technician and a poor one. The incidents focused on specific technician actions closely related to the job, and differentiated between success and failure as a maintenance technician. The incidents were rated by the instructors on a seven-point scale with the scale value of 1 being very poor performance behavior and the scale value of 7 being very high performance behavior. Those incidents with the lowest standard deviations and means closest to 1 and 7 were then placed on a graphic type rating scale to be used as behavioral anchors for the scales.

There are two advantages to using BARS: first of all, the description of the scale points is written in terms that can be easily understood by the raters. Second, since the type of person who developed the scale is also the type of person who uses the scale, the raters have a vested interest in using the scales correctly (5).

The use of the BARS development technique in this study yielded seven specific scales:

(1) Safety: Behaviors which show that the technician understands and follows safety practices as specified in the technical data;

(2) Thoroughness and Attention to Details: Behaviors which show that the technician is well prepared when he arrives on the job, carries out maintenance procedures completely and thoroughly, and recognizes and attends to symptoms of equipment damage or stress;

(3) Use of Technical Data: Behaviors which show that the technician properly uses technical data in the performance of maintenance functions;

(4) System Understanding: Behaviors which show that the technician thoroughly understands system operation allowing him to recognize, diagnose, and correct problems not specifically covered in the technical data and publications;

(5) Understanding of Other Systems Behaviors which show that the technician understands the systems that interconnect with his specific system and can operate them in accordance with the technical data;

(6) Mechanical Skills: Behaviors which show that the technician possesses specific mechanical skills required for even the most difficult maintenance problems; and

(7) Attitude: Behaviors which show that the technician is concerned about properly completing each task efficiently and on time.

The second data collection instrument was a series of questionnaires for students, instructors, and technicians. These questionnaires were used to collect two types of information: (1) demographic information concerning respondents' background, training, and experience, and (2) subjective information such as respondents' attitudes toward training devices in general, and their perceptions and evaluations of the specific device with which they were working.

Data on training effectiveness were collected through student course test scores and Work Unit Code (WUC) information. A new system known as the Consolidated Data System (CDS) has been instituted for the F-16 aircraft that allows for more flexible and responsive maintenance data reporting than was previously available. This system relies on maintenance information recorded by each work center on Air Force Form AFTO 349, "Maintenance Data Collection Record," which is entered into the data base at each wing. The advantage of using the CDS is the ability to aggregate maintenance data in a more usable form and with flexibility as to which information is displayed. The information needed for the current study was which component was worked on (WUC), what action was taken, the time necessary to complete the action, and what work center performed the action.

The purpose was to determine whether maintenance data records, collected routinely, might provide data on the effectivness of maintenance training. In this case the issue was to see if technicians trained with simulators performed differently from technicians not trained with simulators.

Procedure. Data were collected using the three versions of the questionnaire (student, instructor, technician) to gather background data concerning the subjects and their opinions of training courses and devices. The BARS were used to determine the instructors' and supervisor's performance appraisals of those students having previously graduated the courses. This repeated use of the BARS was intended to help determine the validity of such subjective judgments, and to partially ascertain the relationship between judgments of technician performance at the school and the field levels. The distributions of subjects receiving these instruments are given in Tables 1 and 2.

Table 1. Breakdown of Questionnaire Respondents by Base and Status

	Hill	Hahn	Nellis
Instructors	8	15	10
FTD Students	26	13	19
Technicians	38	15	8

Table 2. Breakdown of Performance Assessments by Base and Status

	Hill	Hahn	Nellis
Current FTD Students	17	7	19
Current Technicians	44	13	10
Past FTD Students	0	11	37

The procedure for determining the maintenance productivity of specific work centers started with the choice of the specific work unit codes to be examined. Although there are six F-16 trainers which are of interest in this study, due to the small number of observations associated with the action codes included in several of the WUC's, it was not possible to gather sufficient data to analyze all six of these trainers. Two system-level WUC's were found to have a sufficient number of action code observations to be included. These were 14000, Flight Control Systems, which is applicable to courses in flight controls and instrumentation, and 23000, Turbofan Power Plant, which is applicable to courses in engine diagnostics. Within these system-level WUC's, two component-level WUC's were chosen for further analysis: 14A00, Primary Flight Control Electronics, and 23Z00, Turbofan Power Plant (F-100 engine). These WUC's were chosen for analysis because they were directly related to actions taught on the maintenance trainers and the number of observations was sufficient for analysis.

Results

Correlations between BARS ratings made by supervisors of technician's performance in the field and the ratings made by instructors of the same technician's performance in the school setting are shown in Table 3. The correlations are low, indicating that the success of a technician as measured by the BARS cannot be predicted from his performance in the training course. The only performance measure that shows a statistically significant relationship between school and field performance is the scale measuring "Use of Technical Data" (r = .5). This correlation indicates only a moderate relationship, with 25% (r^2) of the variance of the technicians' scores accounted for by their student scores. These results suggest that such ratings of student performance in school settings do not provide a valid predictor of performance in the field.

A repeated measures analysis of variance (ANOVA) on the BARS data suggested that there is an improvement in performance over time for both types of training (i.e., trainer or actual equipment) after the students graduate and perform maintenance procedures in the field. The one exception to this is the "Understanding of Other Systems" scale (see Table 4). Ratings given to the technicians who were trained using the actual equipment appear to be consistently higher than for those trained using the trainers (Figure 2). The ratings for technicians trained by the two methods, however (once again with the exception of the scale "Understanding of Other Systems"), appear to converge over time. The average length of time between course graduation and supervisor performance rating was three and a half months. This suggests that improvement in performance produced by different training methods dissipates as on-the-job training increases. The goal of devising a more effective training system, therefore, actually becomes one of producing competent technicians faster than by other methods.

Table 3. Correlations Between Performance Ratings (BARS) of Course Graduates as Students and as Technicians

Performance Measure	Pearson r
Safety	0.221
Thoroughness	0.169
Use of Technical Data	0.526*
System Understanding	0.381
Understanding of Other Systems	0.111
Mechanical Skills	0.156
Attitude	0.328

*$p \leq .05$
$N = 18$

Table 4. F Values for BARS Score Improvement Over Time (Repeated Measures ANOVA)

Scale	F Value	p
Safety	5.24	.036
Thoroughness	4.10	.060
Use of Technical Data	6.07	.026
System Understanding	4.16	.058
Understanding of Other Systems	3.22	.092
Mechanical Skills	6.26	.024
Attitude	13.92	.002

Although the differences between ratings of course graduates as students and as technicians are not all statistically significant at the α = .05 level, the trends are clear. Statistical significance is difficult to achieve with small samples, even though an underlying trend may indeed exist. It is important, also, to note that the average performance rating for both groups is above the 4.0 midpoint (halfway between the 1.0 minimum and the 7.0 maximum performance ratings) for each of the seven measures. This may be interpreted to mean that both types of training are producing at least satisfactory technician performance.

In the analysis of the WUC's data for WUC 14A00 it was found that the greater the degree of worker training, the better the productivity of the unit (see Figure 3). This was true for 17 out of the 18 data points. Only the remove after cannibalization action showed a slight reversal of this pattern. For WUC 23Z00, the same trend was found. In this comparison, training appears to bear some relationship to productivity (see Figure 4). The two highest trained at 74 percent, were both more productive for each action code than the least trained base, at 59 percent.

Discussion

The first goal of the current study was to determine the feasibility of collecting practical data for use in validation of the model. The work unit code data show promise for being valid on-the-job measures of training effectiveness. This can be seen in the comparisons of performance of technicians trained in FTD courses *versus* those who had not received such formal training. However, the WUC's data as used in the current study need refinement for use as a measure of training effectiveness.

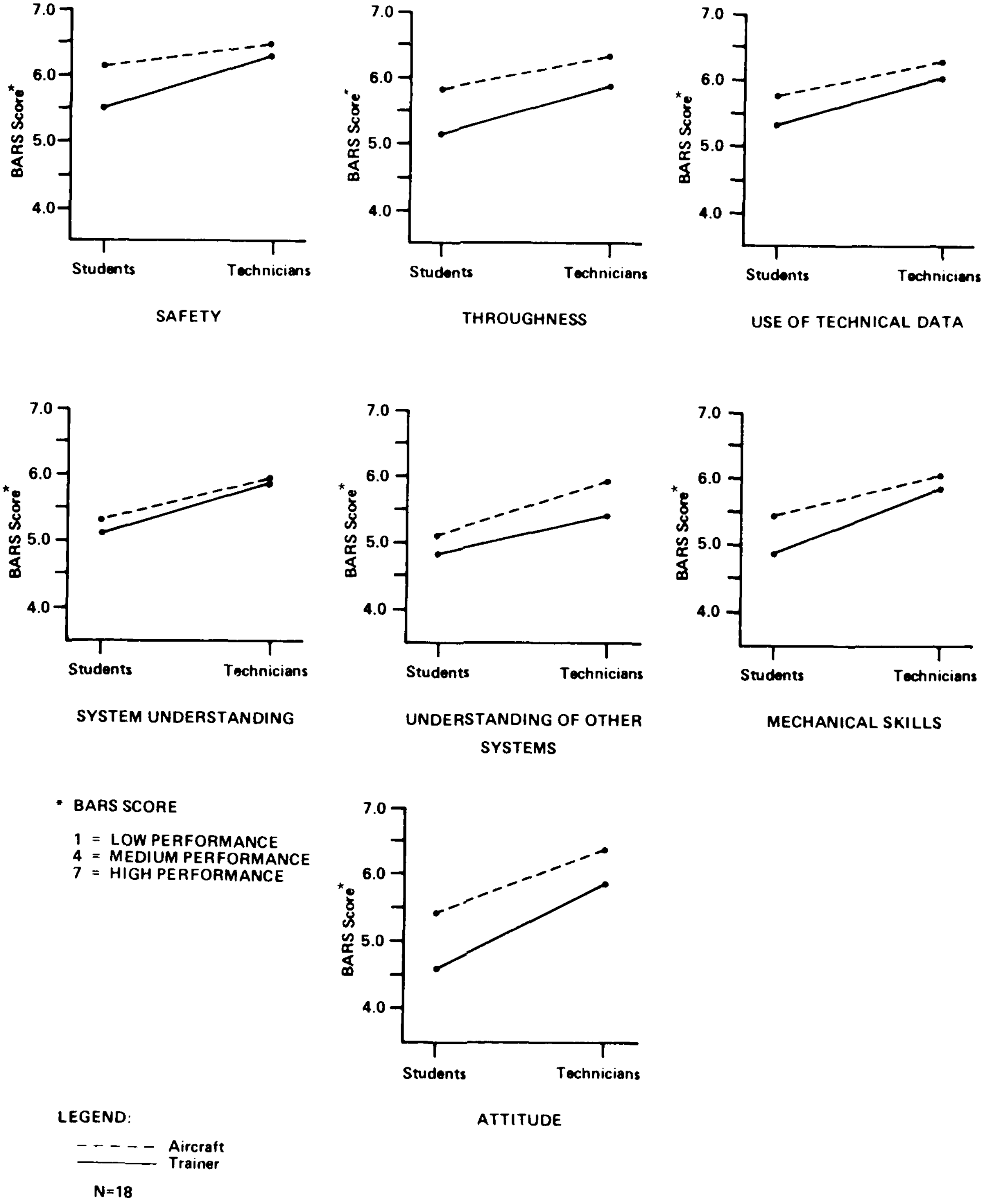

Figure 2. Cell Means for BARS Repeated Measures ANOVA Between Course Graduates as Students and as Technicians

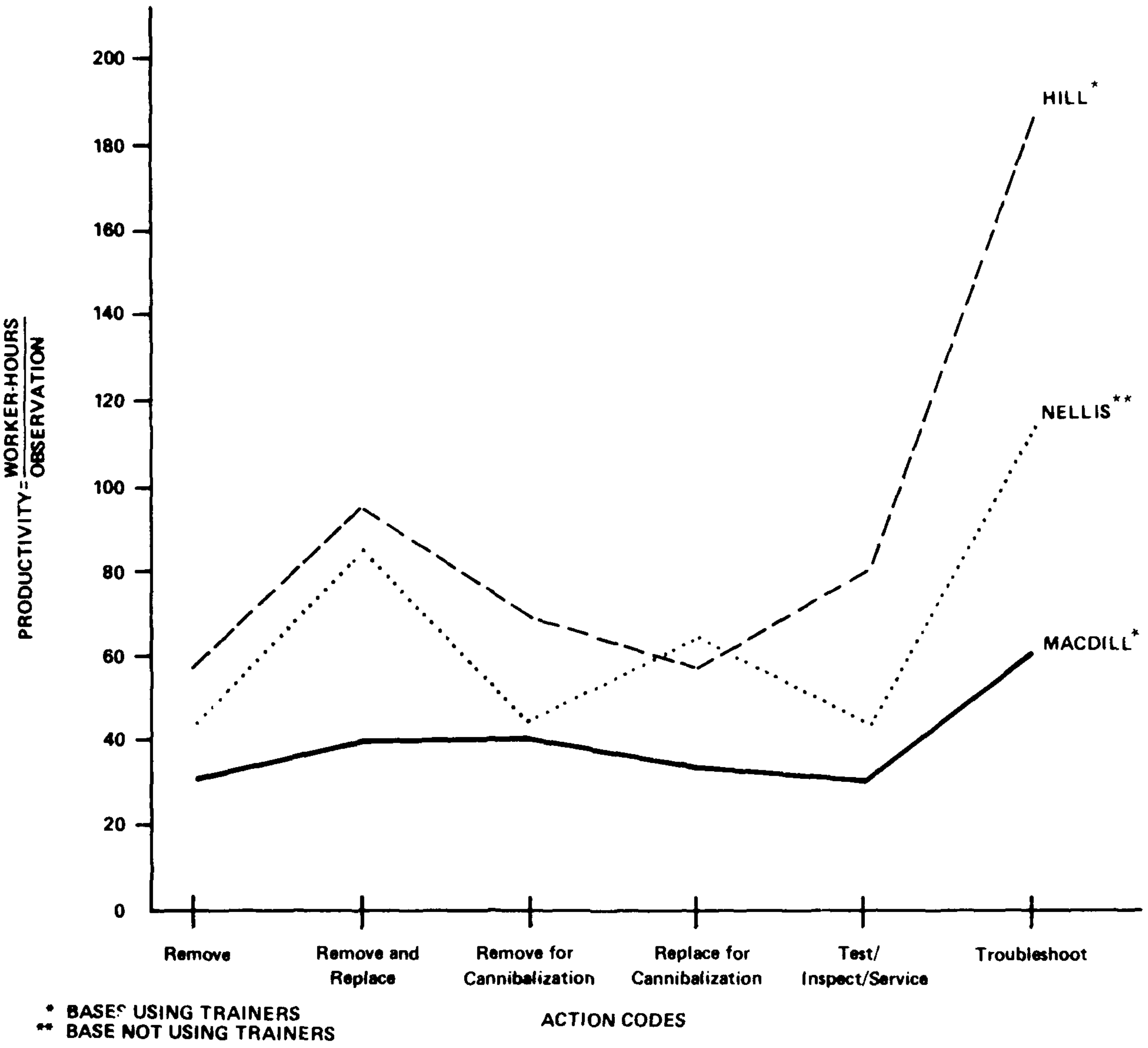

Figure 3. Training: Wing-to-Wing (14A00)

Some problems inherent to the Air Force maintenance data collection system may limit its accuracy as a measure of performance relevant to training. For example, problems with data recording and data entry could lead to biases or inaccurate data analyses. Second, while WUC's that are associated with actions taught using maintenance simulators can be identified, these WUC's tend to be very specific. In the refinement of the WUC's data as measures of field performance it will, therefore, be necessary to take this fact into consideration in order to develop the most useful measure of training effectiveness possible. Finally, in the interpretation of any data based upon WUC's information, one must also consider the environmental influences on maintenance technicians which occur in the field and which may lead to differences in performance between bases that are not due to training (6).

The second goal of the current study was to perform a preliminary test of the training effectiveness model. The BARS data (i.e., rating scales) suggested differences in th performance on the job between students trained on simulators or actual equipment. These differences lessen as on-the-job training increases. However, only ratings on one measure ("Use of Technical Data") at school are correlated significantly with the same measure on the job. Several questions need to be answered. First, do the technicians trained with the trainers eventually perform as satisfactorily as those trained with the actual equipment? Second, is the additional on-the-job training necessary to bring a trainer-taught technician up to

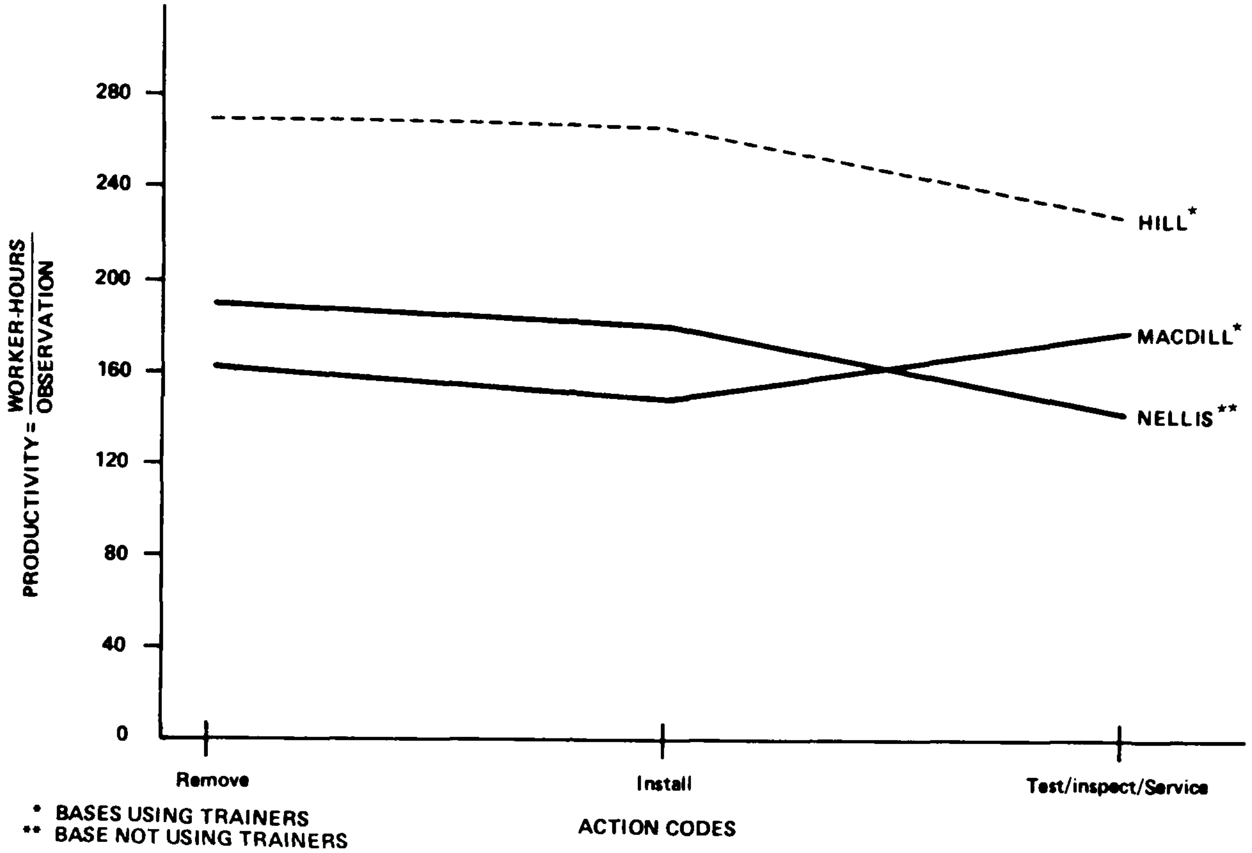

Figure 4. Training: Wing-to-Wing (23Z00)

a satisfactory performance level equivalent to that of actual equipment-trained technicians worth the cost? The answer to these questions can only come from a longitudinal study that controls for confounding variables. Particular care must be taken to control for the length of time subjects have spent in aircraft maintenance, since this is likely to have a strong effect on performance. Those trained on the actual equipment should be compared to those trained on the individual trainers as the data indicate the possibility that some trainers may be doing a better job of preparing technicians than other trainers.

FUTURE DIRECTIONS

Several steps need to be taken to develop a model that can be used to make decisions regarding tradeoffs between cost and training effectiveness. First, a more rigorous validation of the training effectiveness model must be made. The model should be tested with real world data and be modified as required. Second, an overlay for the training effectiveness model must be developed which relates the various design parameters to their costs. Finally, these two sections must be synthesized so that tradeoff equations between cost and training effectiveness can be developed, and the model turned into a practical tool. The outline of these steps is given in Figure 5.

It will also be necessary to quantify the design parameters used in the model so that they can be meaningfully related to the other variables of the model. This requires several steps. First, quantitative scales must be developed for the dimensions of realism and of instructional aids used in the model. This can be accomplished through the use of scaling methods, such as the Coombs Unfolding Technique, which determine the intervals between various points on a qualitative scale, as in the current model. Concomitantly, it will also be necessary to refine the effectiveness measures (i.e., field performance) so that they are as meaningful as possible. When these two steps are accomplished it will then be possible to collect field data on a representative sample of training equipment to determine their configuration in terms of extent and degree of realism and instructional aids, and their resulting effectiveness for a given training goal. These data can then be used to validate and/or refine the model.

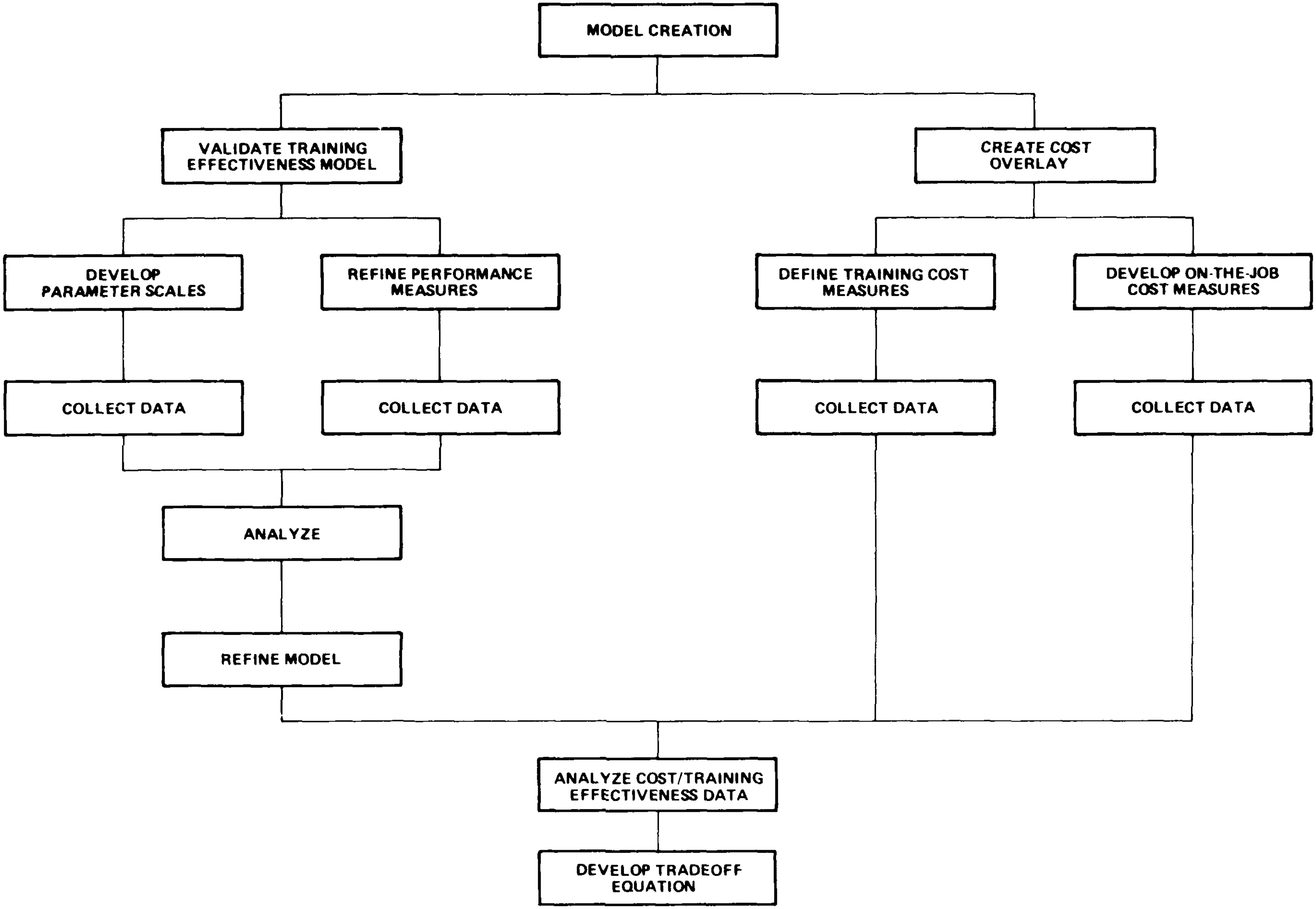

Figure 5. Flow Diagram of Model Validation

The second step in developing the working model into a practical tool is to develop a cost overlay. This requires not only data on the costs of alternative components in a trainer, but also data on the cost of additional on-the-job training necessary for a course graduate to attain minimum proficiency in the field. When this has been accomplished it will then be possible to develop working equations which allow tradeoffs between cost and training effectiveness to be made during the design and development of a training device.

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COST-EFFECTIVE AND EFFICIENT MAINTENANCE TRAINING DEVICES: A USER ACCEPTED DESIGN PROCESS

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ABSTRACT

In response to a USAF need for cost-effective and efficient training devices for the F-16 aircraft, a design process which was largely adapted from U.S. Air Force instructional design procedures was used and modified to ensure the efficient integration of these devices within the USAF training and logistics environments. Two specific and unique training device suites were conceptualized for the F-16 Fire Control and Armament systems. Physical and functional characteristics were specified for each training device suite to meet the specific hands-on training needs for Fire Control (AFSC 326X6C) and Weapons Control (AFSC 462XO) maintenance technicians.

BACKGROUND

Requirement

The F-16 System Program Office at Wright-Patterson AFB, Ohio, required the conduct of an analysis to determine the optimum maintenance training device(s) to support USAF organizational maintenance training for two Air Force Speciality Codes (AFSCs). These two AFSCs are the Integrated Avionics Specialist (AFSC 326X6C) and the Weapons Maintenance Technician (AFSC 462XO), each respectively working on the Fire Control System and the Armament Systems of the F-16 aircraft. An original study conducted in 1977 had indicated the need for the development of maintenance simulators for the support of maintenance training for the F-16 Fire Control and Armament Systems, however, a reevaluation of the original concept to determine the optimum media was required.

Constraints

Two primary factors of concern associated with the development of these training devices were cost-effectiveness and the ability to accommodate changes in hardware and software as a result of F-16 aircraft Engineering Change Proposal (ECP) or Technical Order procedures modification. Cost-effectiveness entailed maximizing training effectiveness, i.e., the accomplishment, proficiency and maintenance of desired training objectives, while minimizing development and life cycle costs. Inherent within the ability to update hardware and software on the training device is the timeliness associated with making the required changes in order to provide a training environment consistent with the operational environment.

Learning Environment

The training devices were to be designed to support organizational maintenance training at the Field Training Detachments (FTD) and similar training environments. The target population included students having graduated from Air Force Technical Training Centers, and students who were cross training from different aircraft communities. Following training at the FTDs, students would then be assigned to the operational environment. Training device design therefore had to account for the integration of the device(s) into the curriculum to ensure that it both supports the curriculum and provides the required reinforcement for training of skills and procedures.

PROCESS

Available Air Force procedures using the Instructional System Development (ISD) process for the systematic identification of skills and knowledge to be taught in order to ensure successful training, included the Air Force Pamphlet, Handbook for Designers of Instructional Systems, (AFP 50-58), the 3306th Test and Evaluation Squadron, Procedural Handbook and the Air Force Human Resources Laboratory, Maintenance Training Simulator Design and Acquisition - Handbook of ISD Procedures for Design and Documentation. These procedures were reviewed in order to determine their applicability to the objectives of this study. The AFP 50-58 and the 3306th Procedural Handbook did not adequately address the details in determination of a requirement for training devices nor the selection of required training devices. On the other hand, the AFHRL Handbook, originally developed to supplement the procedures in the aforementioned documents, provided a detailed and comprehensive process for training equipment design. This latter process, although adopted from the start, was determined to be too lengthy and incorporated unnecessary steps for the purpose of this study. For example, with respect to component fidelity, the AFHRL Handbook provides an extremely detailed and labor intensive procedure for determining levels of fidelity defined as High (H), Medium (M) or Low (L) for each component. This information was then consolidated by task and groups of tasks prior to eventually describing the simulated components in detail. In the procedure used for the F-16 systems a description of the physical and functional characteristics for each component was immediately derived from those skills and knowledge that were determined to require a training device. The difference between the two processes is as follows. In the first instance, a significant amount of time was devoted to defining the level of fidelity (H, M or L) for each component. In the second instance the levels of fidelity were immediately established by describing what the components must "look" and "feel" like and what stimulus and/or equipment feedback were necessary for the performance of each hands-on task. The streamlined procedure in this latter case was a timesaver for the purpose of this study.

In addition, the AFHRL Handbook did not describe a process for identification of applicable alternatives and selection of a final design for training systems. There are two advantages in using such a selection process. First, the hardware and software concepts will be defined for the training device manufacturer; second, they will have been defined by the same team that performed the front-end analysis. On one hand, a more definitive specification is handed the manufacturer; on the other, no learning curve will have to be established for the team performing the trade-off analyses and final selection.

Using the aforementioned USAF documents as a study reference, a streamlined approach was designed and implemented, and the principle elements of this approach are described in this paper.

ANALYSIS

Data Collection

Initial data included information contained in appropriate USAF Technical Orders (TOs) for the F-16 aircraft. These included General Vehicle, Fault Isolation and system specific manuals from which an understanding of the operational system, and a preliminary assessment of the scope of work was made. More detailed documents, such as engineering drawings, were required further along in the analysis process. TOs also included the applicable Job Guides for the Fire Control and Armament Systems which provided the step-by-step procedures the technician would perform for a given maintenance action.

A prime source of relevant data were the training activities at FTD and at TAC (Tactical Air Command, the operational squadrons). One reason for this source selection is that user dissatisfaction with training programs can be the result of several factors such as course design or instructor preparation. Therefore, it is important to interview instructors and maintenance technicians to identify specific problems and desired features for the training devices.

Additionally, existing data related to the performance of F-16 systems such as field performance reports and frequency of repair records were also reviewed. Data contained in those items were useful in developing a comprehensive listing of malfunctions which were anlayzed for training requirements.

Task Analysis

Preliminary Task Listing. Initial task listings were generated using the USAF Technical Order System. Those TOs that applied to any and all work performed by AFSCs 326X6C and 462X0 at the organizational level and on the particular block aircraft configuration (Block 10), were used for initial task identification. Additional sources of information were used during the validation of the initial task listing to include USAF Subject Matter Experts (SMEs) and General Dynamic's field representatives and in-plant engineers.

Valid task descriptions represent the basic data source upon which the entire front-end analysis rests. In order to ensure the technical accuracy and completeness of the data gathered, tasks derived from the technical documentation were verified by E-Tech ISD personnel with (1) TAC F-16 Aircraft Generation Squadron maintenance supervisors and technicians and (2) ATC Field Training Detachment SMEs.

Validation. A two step process was used to verify the initial task listing. First, each task for each subsystem of the Fire Control System and the Armament System was reviewed and verified by SMEs for technical accuracy and completeness, down to subsystem components and lowest replaceable units. Second, all subtasks, elements steps and procedures associated with each task were reviewed and verified by SMEs for completeness and accuracy. Subtasks and task element additions, modifications, or deletions discovered during reviews were recorded.

Sites visited for the validation process included MacDill AFB, Tampa, Florida, and Hill AFB, Odgen, Utah.

The validated task listing was then used to group common tasks which were classified into one of the following four categories:

- Operational Check-Out Procedures
- Fault Isolation Techniques
- Corrective Actions
- General Maintenance

Tasks to be Trained. With the help and guidance of FTD instructors, the validated task listing was compared with the prospective student entry level skills at course entry and, based on FTD curriculum requirements as described and defined by USAF Plans of Instruction (POIs), Course Training Standards (CTSs) and Specialy Training Standards (STSs), a listing of tasks to be trained was developed. Normally at this point, the tasks to be trained would have been categorized into three groupings. The first grouping would be those tasks requiring classroom training for knowledge and introduction to systems, procedures and maintenance activity. The second grouping would be those tasks requiring hands-on reinforcement or practice with the aid of a training device. The third grouping would include those tasks requiring an on-the-job training (OJT) environment to be learned. This study focused only on the second grouping, the hands-on tasks to be trained.

Hands-On Tasks to be Trained. Each step and activity associated with each task to be trained was further analyzed. This analysis yielded a set of behavioral requirements (skills/knowledge) for the performance of each step. Those skills and knowledge that were determined to have a training requirement were then compared to established criteria to determine which required the support of training equipment. Criteria included:

- Difficulty of execution
- Unique environmental conditions requiring special training
- Timing or error criteria
- Special use of test equipment
- Personnel and equipment safety
- Frequency of performance

Only those skills selected for hands-on training formed the basis for the description of specific component characteristics to be represented on the training device.

Component Characteristics. The components identified as a result of the selection of skills requiring hands-on training would be those components, which when put together in some combination, would comprise the sought after training device. The level of fidelity of each component was determined by describing only the required physical and functional characteristics necessary for the performance of each hands-on skill. The grouping of these components which was to yield desired training device alternatives was dependent upon identifying the hands-on training requirements for each category of tasks.

Hands-On Training (HOT) Requirements. Further analysis revealed that each category of tasks previously classified had its own set of hands-on training requirements. For example, the hands-on training requirements for the Operational Check Out Procedures emphasized sequencing of activities and responding to feedback from equipment. Specifically, in order to perform an operational checkout, the technician/trainee had to be able to:

1. Manipulate specific controls or given components in a sequential order,

2. Respond to hardware cues which are part of the sequence, and

3. Observe the displays as required to complete the procedure.

This type of student-equipment interaction description was developed for each category of tasks and formed the basis for describing the configuration of applicable training devices.

Training Device Physical and Functional Characteristics. The physical and functional characteristics for each possible training device alternative were based on the aforementioned component characteristics and hands-on training requirements for each category of tasks. For each system, fire control and armament control, physical characteristics described what each component should look like, how it should function mechanically, and what is to be observed from the result of the hands-on manipulation. Functional characteristics described the interface requirements for the components and subsystems to meet hands-on training requirements. These characteristics were documented in detail and were to be used in the development of prime item specifications for each training device suite.

SELECTION

The result of the analysis process was a description of the training device characteristics necessary to meet HOT requirements for the F-16 Fire Control and Armament Systems. The training device characteristics were those physical and functional features of a training device that described the size, shape, and general appearance of the device, together with the visual, aural or other sensory information it must provide.

Selection Criteria

A selection process was designed to choose training hardware which would meet the training device characteristics. The selection process was comprised of several steps:

- Establishment of selection criteria
- Identification of training hardware options
- Identification of viable software options
- Selection of options to meet requirements of each task group
- Trade-off analysis on the options
- Selection of a Final Approach to the training hardware problem

To select hardware from the identified alternatives, criteria were established which would provide a basis for that selection. The criteria were:

- Component Fidelity
- Update Capability
- Reliability of Trainer
- Maintainability of the hardware/software
- Cost of hardware/software

Component Fidelity. There are two areas of fidelity considered in this criteria.

First, physical fidelity is a measure of how much the trainer will look like the actual equipment. This was important for remove/replace activities or operational check procedures because the entry level skills of prospective students were low and they were relatively unfamiliar with the aircraft. Secondly, functional fidelity indicates how much the trainer acts like the real equipment. This refers to displays, sounds, movements, etc. Functional fidelity is important when the trainee must be presented indications which provide cues or feedback to his/her responses. This was of particular importance to the F-16 fault isolation training requirements, because voltage and current readings must reflect the faults selected, and respond to the trainee's fault isolation activity.

Reliability. When a training device is relatively free from frequent failure in the training environment, it is considered to be reliable. For purposes of this analysis, staff engineers and subject matter experts evaluated each option for reliability based on past history of candidate systems.

Maintainability. Maintainability refers to expense due to periodic parts replacement and use of consumable supplies, and to requirements for adjustmenets and calibration of system components. Maintainability was evaluated in the same manner as reliablity.

Update Capability. Update capability refers to the ease with which training device hardware and software can be updated or changed to reflect changes in the parent weapon system. Since the F-16 is an ever evolving system, training devices must be designed to accommodate changes in the aircraft system, which have an impact on the hands-on training requirements.

Cost. Cost of training devices, although not necessarily related to the training capability of the device, must of course be a selection criteria. The cost of all systems was compared for both hardware and software requirements.

F-16 Trainers

In the case of the F-16 trainers, a wide range of training devices was considered from actual F-16 aircraft to low fidelity trainers. Guidelines were based on the needs of training device characteristics and the HOT requirements. An expert panel of SMEs and engineers was formed to select training hardware. F-16 aircraft have severe limitations as training devices, since faults cannot be programmed because aircraft cannot be put in a "down" status. Squadron commanders frown on this. Actual equipment was eliminated as a training hardware alternative. Alternatives which were identified as viable for training device designs included:

Aircraft Peculiar Trainers (APTs) - designed to look and act like a portion of the aircraft, e.g., the cockpit.

2D/3D Panels - panels which contain 3D replications of aircraft components and 2D respresentations of others, and in total represent a complete portion of an aircraft.

Computer Assisted Instruction (CAI) - in the case of the F-16, this was defined as interactive video trainers.

Corrective Action Trainers (CATs) - training hardware which is a physical mock-up of the applicable portions of the aircraft, but is not a functional representation.

Software. Software designs are almost endless in variety. The designs considered were chosen by staff engineers and were validated by client engineers as feasible. Those options in software design chosen were:

- Operational Software - designed for aircraft operation, but adapted to meet required training device characteristics.

- Table Driven Software - based on Technical Order procedures and is total replication of the Technical Order procedures.

- System Modeled Software - a mathematical model of the operational characteristics of each actual equipment component represented on the trainer.

There are advantages and disadvantages to each option. Basically, the most flexible and easiest to update is the System modeled software, because components are modeled individually and the software program can be done in modules. The least expensive to produce is the table driven. Operational software may be the best choice where actual equipment makes up a major portion of the trainer.

Expert Panel. Selection of training hardware and software was done by the project team in conjunction with a panel made up of USAF subject matter experts and training directors, and General Dynamics F-16 engineers. Training device options were identified with the help of an automated company produced survey technique, and presented as possible approaches to the problem.

Panel Selection Process. A preliminary selection of training device hardware and software was presented to the panel. The panel was asked to validate the required training device characteristics, in view of the training requirements. Two significant points were soon made by the panel, which had major impact on device design. These points were:

- Instructional features are costly characteristics on a training device which the USAF wanted to avoid if possible.

- Software was not desired which replicated technial manual procedures with minimum flexibility for deviation, or which did not react similar to the actual equipment.

Instructional features were defined as those components of a training device which were not used to affect the operation of the trainer as a replication of an aircraft system, but which assist the instructor in controlling the learning environment. Examples of instructional features are devices which record scores or with which faults can be inserted. Since class sizes are expected to be small, no instructional features were required for monitoring or recording student activities. Fault insertion was required because lessons and student scenarios are designed around faults to be trained.

Software selection was dependent on the training hardware selected and the task category to be trained.

Figure 1 depicts the hardware options chosen by task group.

	Task Category			
Alternative	Operational Checkouts	Fault Isolation	Corrective Actions	General Maintenance
A	APT[a]	APT	APT	CAT[b]
B	APT	2D/3D[c]	CAT	CAT
C	2D/3D	2D/3D	CAT	CAT
D	CAI[d]	CAI	CAT	CAT

Figure 1. Alternate Training Devices Formed by Combinations of Training Hardware Types for Each Category.

The final configuration and rationale for selection of those configurations are discussed in the following section.

Hardware Selection - Fire Control System. The final recommended approach for the fire control system trainers consisted of three part task trainers designed to operate as a suite.

The recommended FCS training device suite combines an Aircraft Peculiar Trainer (APT) for the performance of Operational Checkouts, a 2D/3D Panel for Fault Isolation procedures, and a Corrective Actions Trainer (CAT) for Corrective Actions and General Maintenance tasks (See Figure 2). Each training device can be operated as a separate trainer and will be described according to their physical and functional characteristics in the following paragraphs.

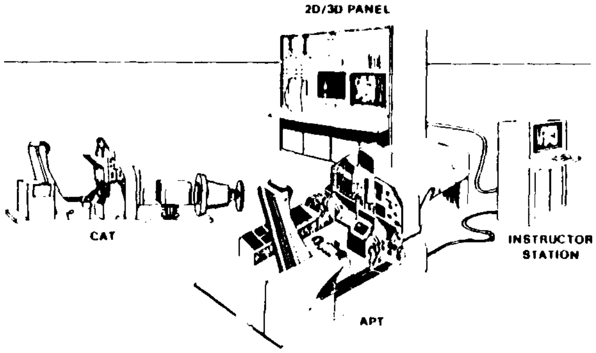

Figure 2. Training Device Suite Fire Control System.

- Aircraft Peculiar Trainer

The Aircraft Peculiar Trainer (APT) for the Fire Control System (FCS) consists of those components whose physical and functional fidelity are required to meet the HOT requirements arranged in the configuration of a cockpit. See Figure 3 for a pictorial representation.

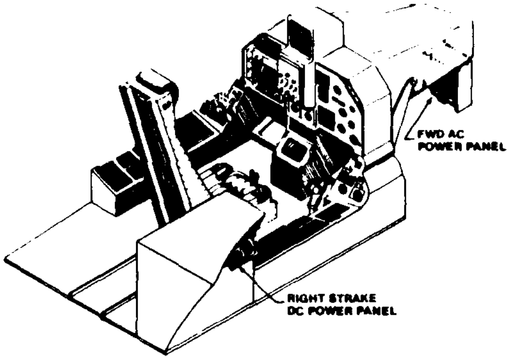

Figure 3. Aircraft Peculiar Trainer Fire Control Sytem.

Operational checkouts and fault indications require observable indications on equipment within the cockpit. These observables are called equipment feedback. In order to replicate this feedback in the training environment, training software controlling the APT is a mathematical model of the operational software of the components used in the maintenance-related tasks. Training software will be modeled with the level of detail necessary to perform required operational checkouts.

Software will provide at a minimum, the requirements called for by the appropriate job guide steps for operational checkouts as identified and annotated in the functional specifications.

Applicable cues and malfunction codes as called for by the selected fault codes described in the functional specifications will be provided by an interface with an instructor station. The instructor will have the capability of inserting the preselected fault codes from the list provided in a menu format. The inserted faults will provide signal interruptions to the training software which will translate into the non-observance of expected feedback and indicate to the student that a malfunction has occurred with a malfunction code. The instructor's fault insertion capability will be further detailed with the description of the instructor station.

Software will also be provided to monitor any student activity which would cause injury to personnel or damage to equipment. A visual and/or audible alert will be automatically presented via an interface with an audiovisual prompter, e.g., rear-projection screen.

- 2D/3D Panel for Fault Isolation

The 2D/3D Panel will consist of a flat panel fastened on metal frames mounted on casters. The flat panel will contain those required components with which the student would interact in order to satisfy hands-on training requirements for fault isolation tasks. These components are described as follows and are illustrated in Figure 4.

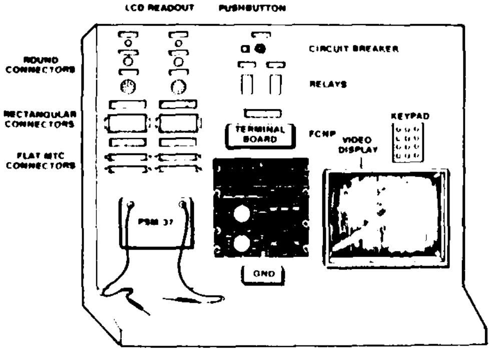

Figure 4. 2D/3D Panel
Fire Control System Trainer.

Three types of electrical connectors will be displayed on the flat panel: round, rectangular, and flat multiple termination connectors (MTC). Each electrical connector will have above it an LCD display that will be used to identify the desired connector.

The multimeter used to measure voltage, current and resistance must replicate the external physical characteristics of the existing test equipment.

Two relay sockets will be represented by contact points. The number and identification of each contact point will be representative of actual relay sockets. An LCD readout capability above each relay will be provided.

The 2D/3D Panel will be used for practicing the hands-on training (HOT) requirements for fault isolation procedures. The HOT requirements entail use of the fault isolation manual and the measurement of voltage current and resistance on electrical connectors, relays and terminal boards. These components are represented on the 2D/3D Panel. The remaining components represented on the panel are for ensuring the procedural continuity of the fault isolation process.

Software controlling the fault isolation process will meet the requirements as described in the appropriate fault isolation steps for those selected fault codes described in the specifications.

Malfunction selection and insertion will be done via the instructor station.

The student will have the capability of calling up any particular electrical connector, relay, terminal board or circuit breaker by keying in on the keypad the identification number which will subsequently be displayed on the LCD readout above the corresponding terminal desired. This terminal would then have the same functional logic as the one called for by the fault isolation step of the particular fault code selected.

The student will also have the capability of calling up on the video display screen a listing of all the components that need to be removed or installed for the particular fault code selected. He/she would then select the appropriate component corresponding to the component in the fault isolation step that needed to be removed or installed. The student would then respond via the keyboard to indicate the desired action on that particular component. Wiring repairs and other similar Corrective Actions will be treated in the same manner on this device.

- Corrective Action Trainer (CAT)

Since the hands-on training requirements are identical for several Line Replacement Units (LRU), selected components have been identified as those which need to be represented on the CAT. This training device is illustrated in Figure 5.

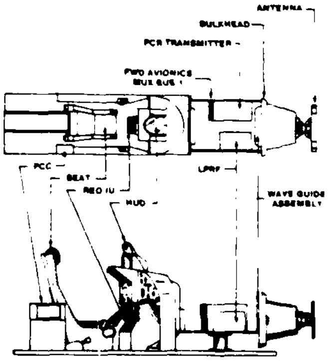

Figure 5. Corrective Action Trainer
Fire Control System.

Physical characteristics necessary to satisfy the hands-on training requirements for removal and installation tasks are described in the specifications.

- Instructor Station

The instructor will have the capability of inserting fault indications and symptoms into the APT prior to or during a student performance of operational checkouts.

The instructor will have the capability of selecting a particular fault code, choosing which Corrective Action the student is to perform, and inserting the fault isolation logic into the 2D/3D Panel.

The instructor station will also enable the instructor to input certain parameters necessary for the development of information that is normally stored in the operational software. For example, in order for the APT to compute and display magnetic heading on the compass card, the instructor must have the capability of entering true heading, magnetic variation and ground track.

A CRT design with keyboard will fulfill the instructor station physical requirements.

Hardware Selection - Armament System. The final recommendations for the Weapon release system was a single trainer to represent those portions of the aircraft associated with the weapons release systems.

USAF students enrolled in the FTD Organizational Maintenance courses for the F-16 Weapons Maintenance Technician (AFSC 462X0) are composed of recent graduates of the Basic Weapons School at Lowry AFB, Colorado, and technicians undergoing cross-training from another aircraft to the F-16. The need to provide these students with hands-on training to support course training objectives in the following areas of instruction was verified:

- Stores Management System
- Stores Management System MUX BUS
- M61A1 Gun System
- Weapons Suspension System

The training provided in these systems includes procedures for accomplishing Operational Checkouts, Fault Isolation, Corrective Actions, and General Maintenance activities. The training device requirements necessary to provide these students with adequate hands-on training capabilities were determined and listed during the task analysis.

- Training Device Suite

The recommended Armament System Trainer shall be one device consisting of three platform mounted hardware modules which are electrically and electronically interconnected. These modules are the APT, 2D/3D Panel, and Instructor Station. System simulation and component control shall be accomplished through a trainer computer program which models the aircraft operational software and provides correct component response and subsystems interaction. The conceptual arrangement of the Weapons Control System Trainer is depicted in Figure 6. A more specific delineation of the trainer's physical and functional characteristics follows.

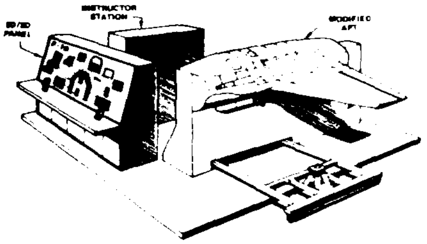

Figure 6. Training Device Suite Weapons Control System.

- Physical Characteristics

The APT was described to conform externally in size and shape to the fuselage section of the F-16 which contains the M61A1 gun system and the centerline weapons station. It contains the M61A1 gun system complete with the Ammunition Handling System and related components, i.e., handcrank, hoist assembly, dummy rounds, gun port, access panels and doors plus those additional items normally associated with gun installation and operation. Electrical and hydraulic provisions were specified to ensure proper gun and ammunition handling systems operation for training purposes. Safety systems and equipment specified in the Gun Safe for Maintenance requirements shall be provided. A stub wing formed to the F-16 wing configuration and containing Weapons Station #3 attached to the left side of the fuselage section. The wing attaching points were designed to allow stub wing detachment for ease of shipping.

The wing station was described, together with the centerline weapons station, weapon pylons and the required interface units, and related matrix assemblies. Electrical interconnections which conform to the F-16 installation shall be provided with the weapons stations. Figure 7 depicts the conceptualized APT (modified).

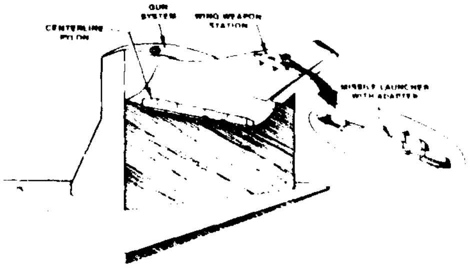

Figure 7. Aircraft Peculiar Trainer Weapons Control System.

A 2D/3D Panel consists of the cockpit controls and components required to provide Weapons Control System hands-on training. These components were arranged on the 2D/3D Panel and visually related to their corresponding location on a top view of the F-16 cockpit consoles. The 2D/3D Panel comprises the student station for operational control of the Weapons Control System Trainer.

Proposed panel placement of components are illustrated in Figure 8. All electrical and electronic connections required to ensure proper component operation individually and as part of an integrated system were provided. Electrical and manual safety interlocks, guards, covers, etc. were included where required to provide proper system operation and/or protection.

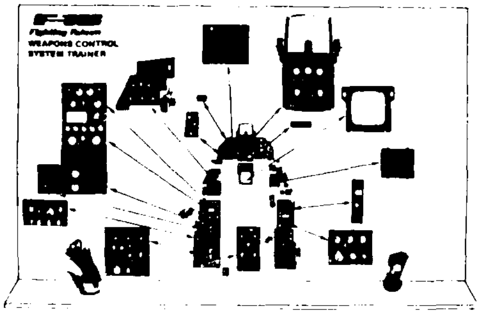

Figure 8. 2D/3D Panel.

The instructor's station will be located out of direct view of the student but will be situated so that the student can be seen by the instructor while at the station. The instructor station will be used to control the training device for normal and emergency operation.

- Functional Characteristics

The Armament System Trainer shall provide the subsystem functions and interactions needed to allow realistic performance of the weapons system operational checkouts listed in the specifications.

The trainer shall contain the capabilities to allow selective insertion of weapons system faults into the operational program. Correct fault symptoms shall be displayed by the subsystem(s) affected.

These faults require use of test equipment to accomplish voltage, resistance and continuity checks. Interpretation and clearing of fault codes (MFL's) is required in addition to performing operational checks where called out in the T.O.s. Trainer operation will allow complete performance of those fault isolation procedures necessary to determine the fault(s) and initiate corrective action.

With the exception of the Throttle Grip Assembly, the APT section of the Weapons Control System Trainer will contain the capabilities necessary to satisfy the corrective action (remove/install) and follow-on maintenance requirements for the components selected by USAF SME's in the expert panel session, and listed in the specification.

Additionally, capabilities for the following M61A1 Gun System checks, adjustments, and servicing not otherwise specified shall be included.

General maintenance procedures associated with the Weapons Control System revolve largely around component location, access door operation/panel removal and installation, connection and disconnection of ground servicing equipment (electrical, cooling, bleed air), systems power up/power down, memory loading, test unit preparation, and Weapons System initialization. These capabilities must reside within the Armament System Trainer.

Corrective action (i.e., remove/install) hands-on training requirements exist for the Throttle Grip Assembly because of the large number of small items which comprise its mechanical mechanism and their criticality to its proper functioning. Additionally, the removal and installation procedure is complicated because of the relative inaccessibility of the throttle grip as installed in the F-16. Incorporating the physical restrictions that surround its normal installation appears to be feasible only in a Corrective Action Trainer (CAT) that is separate from the Weapons Control System Trainer.

The CAT will be a lightweight, portable, tabletop type trainer housed in a protective case with detachable cover. Figure 9 contains a conceptual presentation of the Corrective Action Trainer.

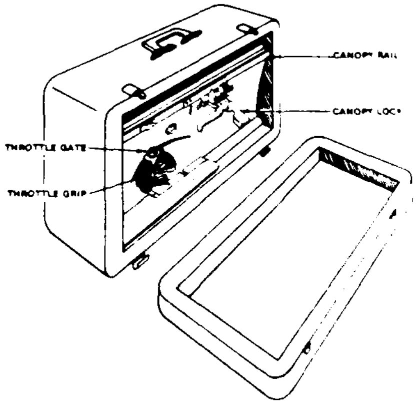

Figure 9. Corrective Action Trainer Weapons Control System.

AD-A142 774 PROCEEDINGS OF THE INTERSERVICE/INDUSTRY TRAINING EQUIPMENT CONFERENCE (5..(U) AMERICAN DEFENSE PREPAREDNESS ASSOCIATION ARLINGTON VA 16 NOV 83

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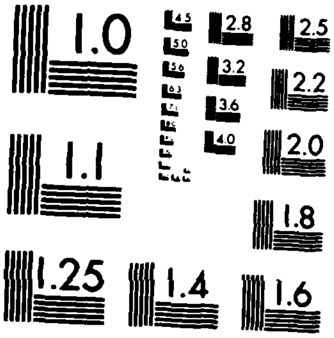

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Software Selection. Software design selection was somewhat more complex, and was based on the training need of the individual groups of tasks. The operational checks for the types are to be done from applicable technical orders, but there was a requirement for the devices to replicate actual aircraft indications if the trainee deviated from the technical order procedures. System modeling of each component was necessary to meet this requirement. For the fault isolation (FI) trainer, the table driven module was acceptable, since each fault has specific readings for given locations. The trainee is responsible for following the manual and selection the proper locations. Update of the FI trainer requires only an enlarging of the table driven matrix, since faults would not interact with each other. Operational software models were used on the armament trainer since the computer which controls the proposed trainer is also taken from the aircraft and interfaces with pylons, gun and control systems.

SUMMARY

There were several advantages to selecting these devices, which have been reiterated several times since acceptance by the Air Force. These are very cost effective trainers for three reasons. First, they are relatively simple, designed to teach only what was required (hands-on training), relegating other instructional requirements to more cost effective media. Their simplicity also resides in that these devices were designed with only the necessary fidelity required for the accomplishment of training. Another factor contributing to the devices' simplicity is inherent within the established hands-on training requirements for each category of tasks involved with the Fire Control and Armament systems. By identifying the type of student behavior (HOT requirements) common to as many tasks as possible for each system, you only need a representative sample of components to teach the hands-on skills instead of the multitude of components that are available. The Fire Control and Armament system device concepts teach all necessary skills, but do so with a minimum number of components and with only the required fidelity and no more.

Second, these training devices can be updated with relative ease and do not render the entire training suite inoperable from either a hardware or software standpoint during the update work. This is so from a hardware standpoint because each device is a stand alone system, and from a software standpoint because first, the functions of each subsystem and component are individually mathematically modeled to reflect the operating characteristics and second, a separate procedures monitoring software provides for the type of augmented feedback the student would need in the event of an improper procedure or unsafe action. This software approach is a key factor in ensuring the training devices' cost effectiveness given the operational and administrative constraints in the Air Force. The following is an example of how changes in the aircraft affect the training device configuration and/or the instructional content the student receives. Any Engineering Change Proposals (ECP) during the life cycle of the F-16 may affect not only subsystem/component configurations but also the Technical Order (TO) system. The student uses the TOs to perform operational checks using Job Guides or to troubleshoot using the Fault Isolation manuals. The software modeling approach in this case is most flexible and easier to update because subsystems/components are modeled individually and the software program can be done in modules. The separate procedures monitoring software which is based on the steps called out for in the TOs would be subject to change if procedures in the TOs would change as a result of the ECP. However, since the procedures monitoring software is separate from the software which gives component feedback to the student (as opposed to augmented feedback) the impact of the inherent delays in publication cycles of the TOs resulting from a change in procedures on training effectiveness will be minimal. The student would still be able to receive the same feedback he/she would be getting in the operational environment pending the update of the technical order system.

Third, considerable time savings, which invariably can be translated into cost savings, resulted not only because of the streamlined approach previously outlined but mainly because USAF User Command personnel were heavily involved from the beginning in the design and selection processes, and were able to give unofficial acceptance of conceptualization and design far in advance of the final recommendations.

Finally, the functional requirements for the Fire Control and Armament systems are presently being used as a basis for developing a Prime Item Development Specification for the manufacture of required training devices. In addition, the authors are involved in a follow-on contract issued to assist the training device manufacturer in ensuring the training devices meet established training requirements.

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Training Capabilities
"The Facility Part of the Equation"

By

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ABSTRACT

The theme of increased readiness through training has an inherent assumption that adequate facilities either exist, can be modified, or can be built to house computerized training devices. Too often adequate facilities do not exist or require long lead times to acquire. Training capabilities can become a myth to the realities of not having an adequate facility or of having modern training equipment fail because of facility deficiencies such as high temperatures and power spikes. But what are adequate facilities for computerized training devices, and how do we acquire them? This paper will review the time phasing and types of funding available within the Department of Defense for construction projects, design concepts of a flexible modular training building including security and environmental considerations. Without understanding the time phasing for acquisition of training facilities, the effectiveness of training devices can be reduced to zero.

1. ACQUISITION OF NEW FACILITIES VIA THE MILITARY CONSTRUCTION PROGRAM (MCP)

Agencies within the Department of Defense acquire new facilities via the MCP (3300) appropriation and in the Air Force in accordance with AFR 86-1. The lead time for a project greater than one million dollars is usually five years from planning to completion of construction. Thus in early 1983 the planning must be done for a Fiscal Year (FY) 86 funded facility to be completed in 1987. The following are illustrative FY 86 MCP MILESTONES shown on Figure 1:

- In 1983 the user identifies a requirement, receives approval to proceed with detail studies, prepares a Military Construction Data Sheet DD Form 1391, starts a design criteria study/project book;

- The Major Command (MAJCOM) includes the project in the 1985-89 submission in July 1983. It is mandatory the facility project be 35% designed by Sept 84 for an FY86 MCP. To obtain this milestone the project must be included in the 1985-89 plan so design can be started in early 1984;

- Major Command (MAJCOM) 1986-1990 Budget Review Jul 84;

- Air Force and Office of the Secretary of Defense (OSD) Review Sept-Dec 84;

- Congressional Review and Approval - Jan-Sept 85;

- FY86 Appropriation becomes Law on 1 Oct 85.

- Other MILESTONES would reflect a minimum 60-day period to select and hire an architect-engineer to design the facility, and a minimum 60-day period to award a construction contract for a one to two-year construction effort.

Congressional approval and MAJCOM review dates do vary but the chart reflects the milestone sequences.

Minor Construction Projects. Construction projects for a single undertaking which cost less than one million dollars, and provide complete and useable facilities or improvement to an existing facility are Minor Construction Projects.(1) They are called specified minor construction if identified in the annual Congressional submittal. These require the same lead time as the MCP described above. A minor construction project considered exigent (or urgent) can be submitted for approval at the time the requirement is defined. Upon approval of the Major Command and HQ USAF/LEE the facility design can be started and upon completion of the design, funds can be requested for construction. This is often a one year cycle. The difference between the specified and exigent minor construction is: 1) the approval level, 2) the time required for approval, and 3) the intense competition for the limited funds in the exigent category. Figure 2 shows the approval levels for an Air Force Human Resources Laboratory/Operations Training Division (AFHRL/OT) MCP, Minor Construction and Equipment Installation Project.

For all MCP projects the DD Form 1391 must show: a well defined requirement reflecting program funds and manpower; funds and schedules for equipment and construction completion; detail construction costs; location at a specific base or site; size and the environmental impact of the new building. A design criteria study for R&D facilities and a project book for MCP will provide most of this information. After the project is submitted to Congress, to the House and Senate Authorization and Appropriation Committees, the location, size and cost cannot be changed.

Another method of obtaining an adequate R&D Training or Simulator capability is to modify an existing building in accord with the criteria of

SCHEDULE FOR FY86 MCP

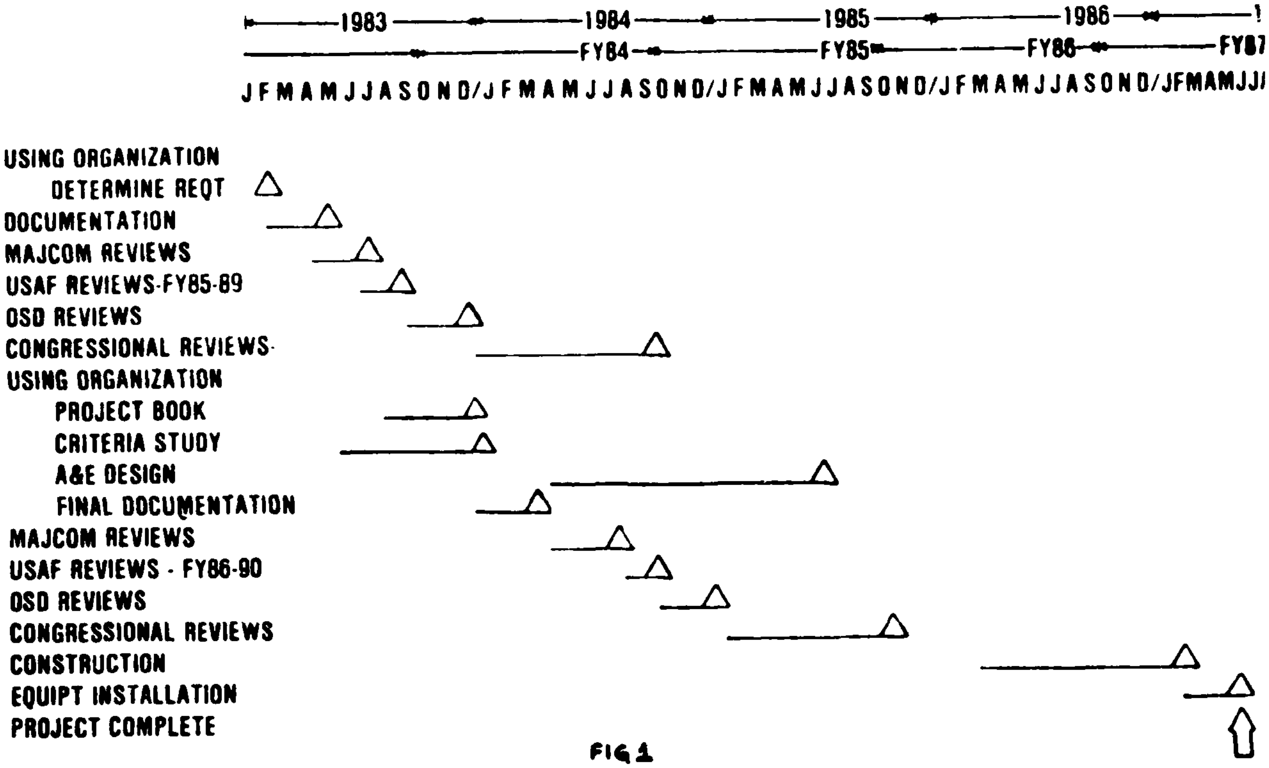

FIG 1

APPROVAL LEVELS

FIG 2

MILITARY CONSTRUCTION PROGRAM (MCP) (AFR 86-1)

PROJECT COST		HRL	AMD	AFSC	AF	SAF	OSD	CONGRESS
MCP	OVER $1.0 MILLION	X	X	X	X	X	X	X(S&C)
Minor Construction	$.5 - 1.0 MILLION	X	X	X	X	X	X	X(S)
(P-341)	$.2 - .5 MILLION	X	X	X	X	X	-	-
(1)	0 - $200,000	X	X	.	-	-	-	-
	0 - $75,000	X	.					

NOTE: (1) $200K LIMIT PER BUILDING/YEAR

(.) APPROVAL LEVEL REDELEGATED (S) STAFF REVIEW (C) COMMITTEE REVIEW

EQUIPT INSTALLATION (AFR 80-22)

	HRL	AMD	AFSC	AF	SAF	OSD	CONGRESS
ANNUAL CONGRESSIONAL NOTIFICATION (RD-4)	X	X	X	X	X	X	X
OVER $300,000	X	X	X	X			
75-$200,000(2)	X	X	X	(3)			
0-$75,000(2)	X						
TO $300,000 (APPROVAL PRIOR TO RD-4	X	X	X	X			
SUBMISSION)			75	200	200	300	

NOTE: (2) NEW EQUIPMENT PURCHASED & INSTALLATION COST UP TO TOTAL COST OF $1.0 MILLION

(3) NEW EQUIPMENT PURCHASED & INSTALLATION COST EXCEED $1.0 MILLION TOTAL IS AF APPROVAL

AFR 80-22 Par 3, "Installing R&D Equipment." False floors, shielding, special foundations, secondary utility work, air conditioning and mechanical ventilation are included in an R&D equipment installation project.(2) These modifications are accomplished with R&D funds. Another method is to use maintenance funds to modify an existing structure but this is limited to $200,000.

2. FACILITY CONSIDERATIONS

A training simulation facility usually consists of four areas: Computer area; Simulation or Training area; Office area; and Support area (Figure 3). The COMPUTER AREA should contain features such as: tight-fitting raised floors with static-free sectional carpeting; air conditioning and humidity control in accordance with the equipment manufacturer's specifications; an electrical system with dedicated electrical circuits and circuit breakers for the computers, a separate circuit for lighting and receptacles and other building power, and a grounding system; an AC power protection system for the entire electrical system; fire protection system with detection alarms for smoke and heat and a Halon (1301) protection system(3); safety items such as battery operated emergency lights and electrical cutoff switches.The Halon system provides a non combustable gas. There must be enough Halon avaiable to fill the room and deprive a flame of oxygen. The system release points should be located close to expensive as well as combustable materials in the training area ie., hydraulic fluids, petrochemicals, cockpits, crew stations, and the computers. Halon is used for fire protection instead of water and avoids the possibility of water damage to computer equipment and electrical shocks to people in the event of an emergency. Of course the room with Halon must be evacuated in the event of any emergency. For new buildings the computer area can have a 18 inches sunken floor with the raised computer floor on the same level as the corridors and other rooms. This avoids the need for ramps and steps. The 18 inches space under the floor serves as an air conditioning plenum to provide cold air into the bottom of the computers and as an electrical trough for all the interconnecting cables and wires. The need for a tight-fitting floor with static-free carpeting is to retain the cold air in the plenum for air conditioning purposes but also to prevent the computer room from becoming a refrigerator: A comfort zone temperature is $72^{\circ} \pm 2^{\circ}$ but computer cooling temperature requirements may be as low $55^{\circ} \pm 2^{\circ}$. One solution for having comfortable work areas in computer rooms is to have terminals and work space on the concrete floor level rather than the raised floor level. The floor to ceiling height in a computer room should be a minimum of eight feet. Separate circuits, grounding system and AC power protection systems are considered essential to establishing and maintaining electrical integrity for computer operations.

The Simulator or Training Areas should contain such features as: 1) air conditioning and humidity control in accord with the equipment manufacturer's specifications and this is often not as cold as the computer area, 2) sufficient space from the bottom of the simulator or other training equipment and the floor. This is for maintenance purposes and for accessibility to cables; 3) the same electrical, fire protection and safety considerations as noted for computer areas.

The Office and Support Areas require similar electrical services noted for computer areas. To have both areas as flexible as possible, the use of electrical equipment such as desk top computers, CRT Terminals, word processors and printers should be considered in the location of receptacles and distribution of power loads. The interior decoration of the office areas should reflect a pleasing environment with proper lighting (see section on lights) furniture, colors, use of paneling and rugs. Studies at TRW Inc. indicated a high increase in programmer productivity when working in a pleasant environment and more comfortable offices.(4) The institutional green, gray or white cinderblock walls(5) and gray office furniture next to the radiator is not recommended. It does not stimulate productivity, longevity, or employee morale. The Air Force Standard of 130 square feet per person in office areas is encouraged. The use of modular office funiture with sound-absorbing fabric-covered partitions could reduce this to 100 square feet per person.

Before reviewing Design Concepts, the relationship between the User and the Architect - Engineer (A-E) should be explained. The A-E will take the Users requirements (routine and mission necessary) and develop a layout and plan for a facility to accomplish the mission. Too often the User thinks, "I'll wait for the A-E to tell me what I need." The design criteria type of study will define what is needed. The User should specify his mission requirements which include the technical, administrative, support, health, welfare and morale aspects of work and training areas for people to effectively use for 8 to 10 hours a day. From the very beginning the User should work closely with the A-E and the Base Civil Engineer to obtain a facility that enhances the training mission.

Design concepts should include the following:

a) Flexible and Expandable Areas. The four areas discussed should be designed as separate rectangular or square sections with each section having expansion capabilities both interior and exterior to the building. No one section should be totally surrounded by another section. There should be at least two exterior areas for external expansion for each section. Figure 3 reflects this concept in a two-story, four-section simulator/training building. The computer, simulator, and training areas are located on the below ground level floor to use the earth to contain electromagnetic radiations and emissions from the equipment as well as for physical security and environmental control. Another configuration would be the U-shape building that can be expanded into a square.

b) Environmental Considerations. Lighting-Electromagnetic Radiation and its Psychophysiological Impact.

Extensive clinical and laboratory data indicate that profound psychological and physiological effects can be routinely induced in humans, animals and plants by exposing them to the radiation emissions of conventional "Cool White" fluorescent lamps, in contrast to fluorescent lamps which simulate the electromagnetic spectra of terrestrial solar radiation in both the ultraviolet (UV) and visible wavelengths.(6)(7)8)(9) Ordinary window glass reflects or absorbs much of the "biologically active" spectra of natural outdoor sunlight. Having closed windows and rooms without windows has sealed-off these spectra. The psychophysiological manifestations of spectral deficiencies include: increased stress and fatigue, increased levels of depression, increased blood pressure and serum cholesterol levels, and Vitamin D deficiency.

Solar radiation can be specifically defined and it is rather stable in the proportion of radiation emitted in the near ultraviolet (320-380 nanometer-nm) and visible (380-750nm) regions, whereas the middle ultraviolet (290-320nm) region varies with the angle of the sun. The specification of artificial light sources for the simulation of the full visible and invisible balanced ultraviolet spectra of terrestrial solar global radiation (i.e., sun + sky) for use in general indoor illumination are as follows (10):

Correlated Color Temperature: 5500 to 6500K

Color Rendering Index: 90 or greater

Near Ultraviolet Radiation: (UVA, 320 to 380 nm) 220±60 microwatts/lumen

Middle Ultraviolet Radiation: (UVB, 290 to 320nm) 15± microwatts/lumen

Fluorescent lamps which simulate natural outdoor sunlight in both the visible and ultraviolet spectra are highly recommended. At AFHRL/OT we are testing the "Vita lite" of the Duro-Test Corporation. If obstacles to learning such as fatigue, headaches and eyestrain can be minimized by optimizing the indoor electromagnetic environment with daylight simulating lamps, the cost benefit trade-offs will be very significant.

The building exterior such as the terrain, trees, shrubs should be utilized to take advantage of the existing environment rather than treat it as an enemy to be overcome with bulldozers and extra air conditioning. Reprocessed water can be considered for use exterior to the building for such items as watering lawns or other esthetic features. In the southern part of the county the use of solar and geothermal energy devices should also be considered.

c) Energy and conservation. The energy conservation initiatives are driven by actions involving energy system optimization.(11) There will be changes in the design practice with "life-cycle costing and sensitivity analysis becoming very important."(12) Computer-Aided Engineering and Architectural Design System (CAEADS) as developed by the US Army Corps of Engineers will have far-reaching benefits.(13) Consideration should be given to siting the building with few windows along the southern or western side of the building in order to reduce heating and air conditioning costs. The offices and support areas where sunlight may be desired should be located in the NE and NW side of a building with windows on the North and East sides of the building. High bays with no windows should be located on the west side of buildings and in a two-building complex one building should be located to provide shade to the other one. The Naval Facility Engineering Command has a five-step plan to save energy which includes use of outside air instead of return air on an air conditioning system when conditioning outside air requires less energy than using the return air. (14) The AFHRL/OT Laboratory Annex includes this feature. Cost trade-off studies between using commercially available power with a low investment cost versus generating power are recommended. The Air Force has done both. Power line problems consist of blackouts, brownouts, fluctuating voltage and noise or transients superimposed on the line. The first problems can be solved with Uninterruptible Power Systems (UPS). All Air Force UPS are centrally procured through Air Force Logistics Command (AFLC) channels from the Chesapeake Division, Naval Facilities Engineering Command under a fixed price, indefinite quantity contract for the following KVA sizes: 50, 100, 200, 250, 400 and 500.(15) Too frequently the noise or transient problem is overlooked. For training facilities with a high reliance on computers it is essential to have an AC power protection system. The degrading effects of short duration transient voltages on solid-state semi-conductors and integrated circuits are of prime concern to the users of electronic computers and equipment. The effects can inflict immediate and extensive damage to vital circuitry to on-line equipment and can result in equipment failures. The associated costs for replacement equipment and delayed training or the research missions can be prevented with an AC Power Protection System with the technical features and Electrical Specifications covered in Report-AFHRL-TP-82-38 by Mr Weldon M. Dube'. The desired features are:

1) Automatic status and monitoring capabilities
2) Resettable digital counter for transient readout with 36 to 48 hours ride-through if power is absent
3) Remote control panel with fully independent operating controls, status indicator and digital readout
4) Field repairable "downtime" of less than one hour so that on-hand replacement modules can be rapidly installed.
5) Protection available 100% of the time even if the utilities are blacked out and no power is available to the facility.

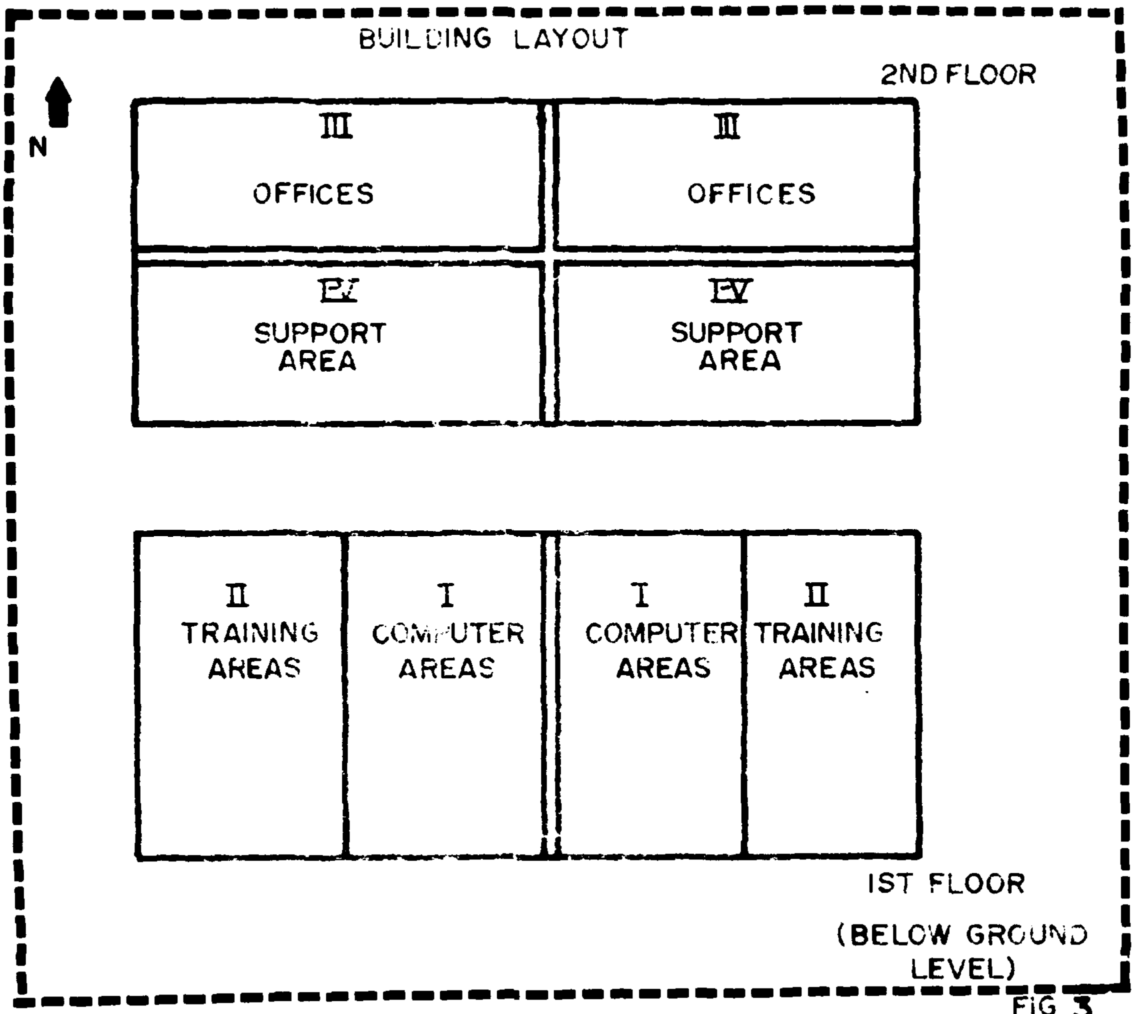

FiG 3

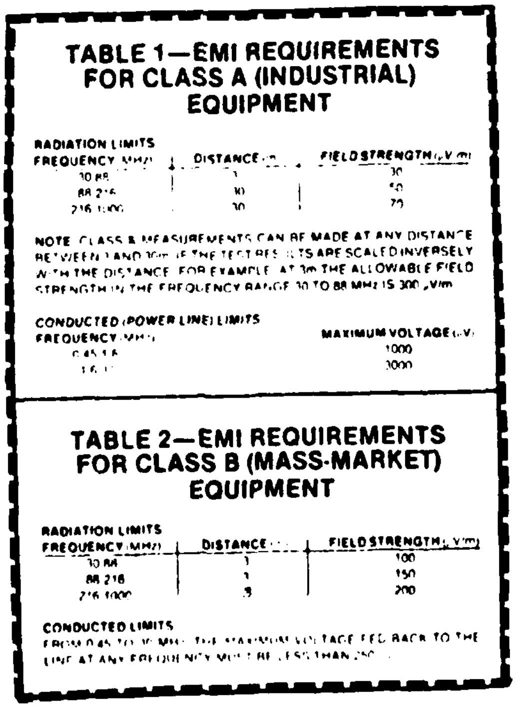

TABLE 1—EMI REQUIREMENTS FOR CLASS A (INDUSTRIAL) EQUIPMENT

RADIATION LIMITS

FREQUENCY (MHz)	DISTANCE (m)	FIELD STRENGTH (µV/m)
30-88	30	30
88-216	30	50
216-1000	30	70

NOTE: CLASS A MEASUREMENTS CAN BE MADE AT ANY DISTANCE BETWEEN 3 AND 30m IF THE TEST RESULTS ARE SCALED INVERSELY WITH THE DISTANCE. FOR EXAMPLE, AT 3m THE ALLOWABLE FIELD STRENGTH IN THE FREQUENCY RANGE 30 TO 88 MHz IS 300 µV/m

CONDUCTED (POWER LINE) LIMITS

FREQUENCY (MHz)	MAXIMUM VOLTAGE (µV)
0.45-1.6	1000
1.6-30	3000

TABLE 2—EMI REQUIREMENTS FOR CLASS B (MASS-MARKET) EQUIPMENT

RADIATION LIMITS

FREQUENCY (MHz)	DISTANCE (m)	FIELD STRENGTH (µV/m)
30-88	3	100
88-216	3	150
216-1000	3	200

CONDUCTED LIMITS

FROM 0.45 TO 30 MHz, THE MAXIMUM VOLTAGE FED BACK TO THE LINE AT ANY FREQUENCY MUST BE LESS THAN 250 µV.

FIG 4

There are signal line protectors expressly designed to protect signal/data/telephone lines from transport over-voltages caused by lighting, heavy machinery, electric motors, generators, etc.(16)The small investment of 5 to 25,000 dollars in AC power protection systems is considered essential when you relate the impact of a power or equipment failure to the training mission i.e., lost time and additional costs to repeat the training if schedules permit; completing training without repeating the "lost" portions because the training schedules can not be slipped; the time and cost to replace damaged equipment could mean a major rescheduling of several classes; and the increased potential for accidents in darkened training areas.

To maintain desired temperature control in the buildings, it is important to have the thermostat control accessible only to facility engineer/maintenance personnel and not in public areas where anyone can make changes. Most Air Force bases use an Energy Monitoring Control System. Other energy conservation techniques includes turning lights off in all areas that are to be vacant for more than several minutes; i.e., offices, conference rooms, support areas, and even restrooms in the evening. A trade-off study between fluorescent lamp replacement and electric costs has shown that any time a room is to be vacated for more than a couple of minutes, the fluorescent light should be turned off.(17) A free hot water making machine can reduce or eliminate the number of individual coffee making machines and mini-kitchens in offices.

d) Security. The two major systems for security are physical and electronic. The type of problem or threat must be identified when selecting protection devices. Is it an external enemy or is it an internal problem? Physical Compromise is a compromise of information by loss, theft, capture, unauthorized viewing or photography, recovery by salvage or physical means. Physical security protection involves techniques as 1) key locks, 2) electronic card keys with photo identification which give immediate printed reports. Equipment failures of key locks are more probable than intrusion tampering. 3) security guards which require three shifts for 24-hour protection plus replacements for lunch, rest periods, vacations and illness. 4) closed circuit TV or other detection devices to monitor intrusion into a building as well as for rooms with high value equipment or classified data. Designs for high security locking systems and secure window barriers will be published in the Naval Facilities Engineering Command Physical Design Manual (DM-13).(18) Electronic Security is concerned with preventing the loss of or compromising classified data via electronic emanations. A compromising emanation is an unintentional data related or intelligence bearing signal which, if intercepted and analyzed, discloses the classified information transmitted, received, handled or otherwise processed by any information-processing equipment. We should note there is a National Policy on Control of Compromising Emanations. To appreciate the problems of electronic security, the following is a brief review of definitions, regulations, possible solutions and assistance. Definitions: The Physical Control Zone (PCZ) is the space surrounding equipment processing classified information which is under sufficient physical and technical control to preclude a successful or hostile intercept of any classified information from within this space. The Controlled Access Area (CAA) is the complete building or facility area under direct physical control which can include one or more limited Exclusion Areas (a secured room for RED information-processing systems equipment and wirelines), and controlled BLACK Equipment Areas or any combination thereof. Spaces within a facility which are not under direct physical control but to which access is controlled (administrative office, halls, restrooms) are not a part of the actual CAA but are considered as a part of the overall Physical Control Zone. RED/BLACK is a concept that electrical and electronic circuits, components, equipments and systems which handle classified plain language information in electronic signal form (RED) must be separated from those which handle encrypted or unclassified information (BLACK). Under this concept, RED and BLACK terminology is used to clarify specific criteria relating to and differentiating between such circuits, components, equipments and systems and the areas in which they are contained. Equipment TEMPEST Radiation Zone (ETRZ) is a zone established as a result of TEMPEST equipment radiation characteristics. The zone includes all space within which a successful hostile intercept of compromising emanations is considered possible. The Air Force (AFR 100-45), the Defense Communications Agency and the National Security Agency have regulations covering all phases of Electronic Security.

For additional information, Government employees can obtain 80 hours of training at the TEMPEST Officer Course L30ZR3016-006, PDS Code QVJ conducted at the USAF Technical Training School, Lackland Air Force Base, Texas. Industry and Government personnel with security clearances can also attend a 40 hour course titled "TEMPEST Design, Control and Testing" presented by Don White Consultants Inc, of Gainsville, VA. Firms have TEMPEST/EMI Departments which also provide consulting services. The Air Force Cryptological Support Center, San Antonio Texas is another source of information.

The Federal Communication Commission (FCC) regulations on Electromagnetic Interference provides some unclassified emanation data (Figure 4). An understanding of the problem can be obtained by looking at the EMI test methods used by the FCC. A description of how they satisfy their test requirements from 30MHz to 1000MHz is covered in an article by Glen Dash.(19) He notes that, "Most radiated emissions arising from computer equipment stem from attached I/O cables. When the equipment under test (EUT's) digital logic changes state, RF current pulses cause radiation from pc board traces and wires. Because the attached I/O cables are long wires they are the most efficient radiators below 100 MHz." He also notes that "FCC rules, as now interpeted, permit computer manufacturers to test without attached cables but require peripheral manufacturers to test with attached cables. And all I/O cables must be driven by an active source, such as a computer. To remedy this situation, the FCC Office of Science and Technology is considering new regulations. These regulations will require the Computer equipment be tested with attached cables and that the cables be moved during radiation detection." It is important to note that the FCC is concerned with EMI emissions and has established peak level emanations (Figure 4) whereas TEMPEST concern is with data related emanations.

The National Security Agency has an Industrial TEMPEST Program. The Subcommittee on Compromising Emanations (SCOCE) has a TEMPEST Qualifications Special Committee (TQSC) which issues a Preferred Products List. Accreditation is given to those products that have fully complied with all applicable TEMPEST requirements.

Solutions to satisfy the training/simulator/computer facility emanations problem involves modifications to either the equipment or the facility. It is important to identify the emanation db and frequency level before a solution is proposed. The equipment mods could be as simple as using aluminum or lead enclosures or tapes. It could be a design change which does not significantly increase the transport delay time in equipment performance. As noted above the SCOCE has a Preferred Products List of equipment which have been tested. Security for ADP equipment must be part of a facility plan. Possible solutions for new or existing facilities include armor shielded walls or very thick concrete walls, locating the computers and other equipment in the below grade basement with an RF shielded basement ceiling, fenced enclosures several hundred yards away from the building, separate power filters for the RED & BLack electrical power lines, signal filters and telephone filters, plastic coupling of all water pipe lines going into classified work areas, and a common ground for all pipes. If the classified work area is small, an RF shield room can be obtained. At AFHRL/OT Williams AFB we developed a specification for an 8 ft x 12 ft x 8 ft high modular RF shield room which included communication and power filters, assembly, electrical connections and a test to NSA 65-6 and MIL-STD285. On competitive bid we obtained this room for approximately $15,000 from Lectro Magnetics Inc of Los Angeles, CA.

e) Other Design Features. This includes: Uninterruptable Power Supply (UPS) which should not be confused with an AC Power Protection System; accommodations for the handicapped (20) in restrooms, dining areas, elevators, at special water fountains and with ramps at entrance points which will enable the handicapped to better use facility services. Safety features in accord with AFR 88-15 (CG) Section 1-38, "Air Force Occupational Safety and Health (AFOSH) Program." Student or crew lounges should be planned rather than to have these functions in an unused or office area. Secretary or typing areas should include sound absorption material such as acoustical tile, rugs, curtains or other fabric on partitions. Conference rooms should be designed with projection booths, speaker equipment, light dimmers, acoustical materials, microphone and telephone outlets for telephone conference meetings. If protected information is to be discussed in telephone conferences, then secure voice and video processing equipment with associated filters should be used. Parking lots should be designed with a light sensor controlled night lighting and special spaces for bicycles, motorcycles, small cars and vans.

3. CONCLUSIONS

A training or simulator facility is a technical complex that requires coordination and integration of all resources if it is to be acquired when needed. Good planning and design before it is built or modified will provide a building that enhances the opportunities to optimize the training mission. By working with the Base Civil Engineer and MAJCOM Civil Engineer, the major MILESTONES of the 3-year cycle for processing and approval of the DD Form 1391 through the Military Construction Program review to Congress can be identified and achieved. Success results from: 1) having accurate and meaningful information on the DD Form 1391; 2) working closely from the start with the Base Civil Engineer and the Architect Engineer; 3) defining, integrating and funding the MCP, manpower, and equipment requirements to accomplish the training mission; 4) planning a modular facility that provides necessary space for today's mission; 5) having flexible and reliable electrical service via AC Power Protection System and UPS to handle electrical abnormalities such as spikes, lightning strikes, blackouts or brownouts; 6) designing air conditioning for computer areas to meet manufacturer's specifications with controlled comfort zones for employees; 7) providing for physical and electronic security, and 8) having a pleasant office and healthy environment which includes color, fabrics, rugs and daylight simulating lights. The above suggestions are based on many years of combined facility engineering experience but should not be considered an inclusive list. Following these suggestions will result in the timely acquisition of a facility that enhances the effectiveness of the training mission.

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VISUAL CUEING EFFECTIVENESS: COMPARISON OF PERCEPTION AND FLYING PERFORMANCE

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ABSTRACT

Growing emphasis on simulation of low altitude and air-to-air tactical scenarios has greatly increased the requirement for simulator visual systems capable of providing the pilot high-fidelity out-of-the-cockpit cues. Evaluation of visual system performance through simulator flying studies has been the primary measure of system quality. Such studies can be costly and time consuming, and often they provide equivocal results. The present set of experiments was conducted to investigate the use of psychophysical measurement methodology to provide a quick, low-cost evaluation of the altitude cueing effectiveness of simulator visual displays. Experiment I examined altitude perception in several visual environments. Experiment II was a validation effort, in which flying performance was evaluated in selected visual environments. In Experiment I pilots made altitude estimates based on static and dynamic presentations of visual displays containing texture and varying sizes of 3-dimensional objects. Best-fitting power functions were used to relate perceived altitude to actual altitude. In Experiment II Air force pilots flew the Advanced Simulator for Pilot Training F-16 through five selected visual environments at 600 kt and 150 ft AGL. Reliable difference were found as a function of display variables. In environments which provided strong altitude cues, pilots were able to fly very close to the designated altitude. In environments which provided poorer cues, pilots flew substantially above designated altitude.

INTRODUCTION

As a result of the current trend in flight simulation toward tactical flight and combat scenarios, a need exists for methodologies to evaluate the effectiveness of visual system displays in providing out-of-the-cockpit flight cues. The simulator visual system presents the pilot with a variety of cues needed to perform the task. These range from airspeed, altitude, and navigation cues to cues relating to the presence, range, and behavior of threats and targets. Simulator flying studies have been performed to determine the effectiveness of texture (1), color (2), and three-dimensional objects (3) in providing low-altitude flight cues. While such studies provide the ultimate measure of the effectiveness of a visual system display in providing cues needed to perform simulated flight tasks, they can have severe methodological limitations. The requirements of such studies for simulator time, subject time, and development time are great. Simply to study the effectiveness of one type of visual cue can require as much as 50 hours of simulator time, even if only a small number of subjects is run. Therefore, only a limited number of visual environment displays may be investigated.

In order to perform the parametric studies required for the design of effective simulator visual environments, techniques are needed for assessing the cueing effectiveness of visual displays quickly and at low cost. Such techniques might be used to screen candidate displays so that only the most effective need be examined in more comprehensive simulator flight studies.

De Maio and Brooks (4) have used a free modulus altitude estimation task to evaluate the altitude cueing effectiveness of flight simulator visual environments. Five environments were investigated, which varied in the density of 3-dimensional objects and in the level of detail of individual objects. Object density was found to have a potent effect on altitude perception. The present set of experiments extends the findings of De Maio and Brooks to more detailed visual environments and investigates the relationship between altitude perception and flying performance.

EXPERIMENT I

The purpose of Experiment I was threefold. The primary purpose was to extend the findings of De Maio and Brooks to a very high object density environment. A second question of interest was the relative effectiveness of other types of environmental features than those used by De Maio and Brooks in providing altitude cues. The third question was a methodological one concerning the procedures used to evaluate cueing effectiveness.

Since the altitude judgements normally made by pilots are made at speed, there was some question regarding the appropriateness of the assumption underlying the static altitude estimation procedure for evaluating environmental cues which would be used in a dynamic context. De Maio and Brooks made the assumption that the distribution of objects in the static display provides essentially the same altitude cue information as does the flow of objects in the dynamic display. In Experiment I this assumption was tested by using both static and dynamic presentation modes.

METHOD

Subjects

Subjects were 21 A-10 pilots. None had had any previous experience with the Advanced

Simulator for Pilot Training (ASPT).

Apparatus

Three ASPT visual environments were used. These were created by varying the level of scene complexity in an extant ASPT environment design to support low altitude flight. The most complex environment (Cond 1) consisted of a valley floor approximately 1/2 mile wide and covered with a hand-modeled texture pattern. On each side of the valley floor were mountains approximately 4000 ft in height. Inverted tetrahedrons ("trees") with white bases were randomly placed on the floor and mountain walls at a density of about 700 per square mile. These trees had three heights: 35, 50, and 75 feet.

The intermediate complexity condition (Cond 2) consisted of the same mountains and textured valley floor without the trees. The minimal complexity condition (Cond 3) consisted of only the textured valley floor.

Three presentation modes were used: a static slide presentation (SL), a dynamic video tape (straight and level flight, A/S = 450 kt) presentation (DT), and a static video tape presentation (ST). The ST condition was used because the image quality was substantially poorer in the video tape than in the slides. This condition permitted determination any decrement which might have been caused by the image quality difference.

Eight altitudes were presented. Altitude varied between 50 ft and 400 ft in equal log intervals. This distribution was used to provide a uniform distribution of data points for the log-log linear fitting procedure.

Procedure

Two groups of subjects were run in a briefing room at Davis-Monthan AFB. Image size was seven ft X seven ft. One group (N=12) viewed the presentations in the order SL-DT-ST. The second group saw DT-SL-ST. Condition ST was always presented last because it was not of interest in itself but was merely a control condition to be used in the event that performance in condition DT was substantially poorer than expected.

Stimulus and interstimulus intervals for condition SL were determined by the cycle time of a carousel projector set for eight sec display. The video tape was edited to provide 6- to 8- sec stimulus intervals and 3- to 4- sec interstimulus intervals. Subjects were instructed to estimate the altitude (AGL) in the first stimulus presentation. Subsequent estimations were to be made relative to the first. Three runs of 24 trials (three environments X eight altitudes) were made through each display condition without feedback.

RESULTS

Data were analyzed by first converting actual and perceived altitudes to logarithms. A least-squares, linear function was then determined for each subject's data (Kling and Riggs, 1971). The slope (b) of this log-log, linear function was taken as a measure of the altitude cueing effectiveness of each environment. The first run in each display condition was not analyzed. A repeated measures analysis of variance (display condition X environmental complexity) was performed on the slope data. The results of this ANOVA are shown in Table 1. Seven post-hoc comparisons were made by means of a Dunn test at the .01 level of confidence.

Table 1
Results of repeated measures ANOVA on slopes of the altitude estimation functions for five visual display conditions

SOURCE	MEAN SQUARE	D. F.	F-RATIO	P
TOTAL	.113	149	-	-
DISPLAY CONDITION	1.684	4	39.6	.001
ERROR	.043	116	-	-

Slopes for the nine display X complexity conditions are shown in Table 2. There was no significant effect of image quality in the static presentation modes (CR = .211, DIFF = .09). Dynamic presentation lead to better altitude perception in environmental condition 3 (CR = .177, DIFF = .352) but not in Cond 2 (DIFF = .077) nor in Cond 1 (DIFF = .064).

The question of the effect of environmental complexity on altitude perception was addressed by three comparisons: 1/SL V 2/SL, 2/DT V 3/DT 1/DT V 5/DT. None of these differences was significant (CR = .271, DIFF = .243, .104 and .125 respectively).

Table 2
Mean altitude estimation slopes in experiment I

ENVIRONMENT	DISPLAY CONDITION		
	SLIDE	DYNAMIC TAPE	STATIC TAPE
1	.78	.84	.55
2	.54	.61	.58
3	.37	.72	.29

DISCUSSION

Experiment I was conducted to answer three questions. Two of these questions (static v dynamic presentation and cue equivalence) can be answered by examining the results of Experiment I alone. In order to make a parametric evaluaton of the effect of object density on altitude perception the results of De Maio and Brooks and of Experiment I need be examined.

With regard to the necessity of dynamic presentation, evaluation of the cueing effectiveness of two-dimensional texture does seem to require this presentation mode, but the cueing effectiveness of three-dimensional objects can be evaluated using static presentation. Apparently observers are able to perceive the distribution of discrete objects in the environment and to use this information as they do optic flow information. When environmental details are not discrete but instead form a continuous, two-dimensional mosiac, the density gradient information is not accessible to the observer, and optic flow information is necessary for the perception of altitude. Since the static presentation mode is both simpler and less expensive, this should be the preferred mode whenever possible.

A limited answer to the cue equivalence question can be obtained from the results of Experiment I. Two-dimensional texture (at least the pattern used in the present work) can provide an effective altitude cue, which is enhanced neither by the addition of large three-dimensional objects (Cond 2) nor by the addition of small three-dimensional objects (Cond 1). A caution is appropriate at this point, however. Since the texture pattern used in the present work was hand modeled, it is by no means representative of texture patterns in general. We cannot conclude from the present data that any texture pattern can provide an effective altitude cueing, nor do we know what attributes of a texture pattern lead to effective altitude cueing. A number of texture patterns needs to be evaluated in order to ensure that the factors contributing to altitude cueing effectiveness are understood.

To begin to address the question of what level of object density is adequate for accurate perception of altitude, the results obtained by De Maio and Brooks for very low density environments are examined along with the present data. Figure 1 shows the slope of the altitude estimation function versus object density in the two experiments. Also shown is a best-fitting exponential function. This function is not intended to model the process of altitude perception but only to serve as a tool for equating the cueing effectiveness of different environments. This function becomes asymptotic at roughly b=.8. It is generally safe to assume that gains in performance are trivial past the point where the functon is 90% complete. The 90% point occurs at b=.7 or the equivalent of about 12 to 15 objects per square mile. In order to address the question of how much is enough, it is necessary to determine the relationship between altitude perception and flying performance. A second experiment was performed to address this question.

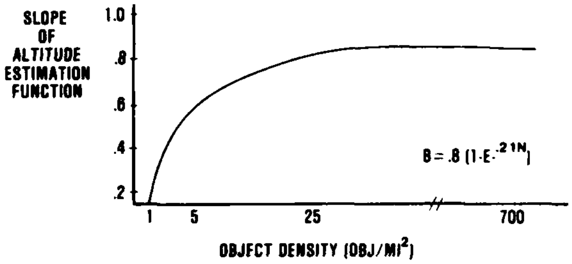

Figure 1. Altitude estimation slope vs object density

EXPERIMENT II

The purpose of Experiment II was to determine the ability of pilots to maintain altitude based on out-of-the-cockpit cues in selected environments, whose altitude cueing effectiveness was determined above. In this regard Experiment II can be viewed as a validation of the use of altitude perceptibility as a metric for the ability of a visual environment to support low altitude flight. This in-simulator validation can also be of use in determining what level of altitude cueing effectiveness is adequate to support low level flight.

METHOD

Subjects

Twelve Air Training Command instructor pilots at Williams AFB volunteered to serve as subjects. Of these, three were eliminated from the analysis due to unreadable data tapes. None of the remaining subjects had had any previous experience with ASPT.

Apparatus

Flying was performed in the ASPT F-16 simulator. Neither instruments nor Head-up displays (HUD) providing altitude, pitch, bank, vertical velocity or flight path angle information were available to the pilot. Five visual environments were used. Three were from De Maio and Brooks (Conds D-1, D-2, and D-5), and two were from Experiment I (Conds 1 and Cond 3). These five conditions spanned the range of cueing effectiveness levels obtained in the two experiments.

Procedure

Subjects were given a 15-minute practice period to get accustomed to the F-16 simulator. During this period they flew in two of the test environments (Conds D-1 and 1) with full instrumentation but only airspeed on the HUD.

Subjects flew two experimental runs through each environment with the cockpit instruments occluded. On each run the pilot was to fly the length of the course at 600 kt and 150 ft AGL. At a specified point the pilot performed a Whifferdill and then flew back to the start point at the same airspeed and altitude. The order in which subjects flew the five environments was counterbalanced to control for first order effects. Altitude AGL was recorded at 30 Hz.

RESULTS AND DISCUSSION

Data from the Wifferdill portion of the task were omitted from the present analysis. Only the level flight portions were considered. A target altitude was determined for each run by averaging the local altitude minima and maxima on that run. Mean target altitudes for each level of altitude cueing effectiveness are shown in Figure 2. When the dynamic altitude estimation slope is used for Cond 3, the correlation between mean slope and mean target altitude is -.98 (P < .01). This result demonstrates the validity of the altitude perception metric for evaluation of the ability of visual displays to provide the pilot information needed to maintain altitude. The superior prediction of flying performance obtained with the dynamic presentation evaluation of texture demonstrates the need for dynamic evaluation of altitude cueing effectiveness of this display feature.

Results of an analysis of variance on the target altitude data are shown in Table 3. Post-hoc analysis by a Dunn test showed that Cond D-2 was significantly worse than the average of Cond D-1 and Cond 1 (CR = 17.7, DIFF = 77.2, P < .01). Slopes associated with this comparison were .5 and .8, respectively. The difference between Cond D-2 and Cond D-5 was non-significant (DIFF = 51.8). Associated slopes were .5 and .2. Differences between Conds 1 and D-1 and between Conds 1 and 3 were also non-significant (DIFF = 12.5 and 7.7, respectively). These results support the previous conclusion that an environment giving an altitude estimaton slope of about .7 is necessary and sufficient to support maintenance of altitude in low altitude flight.

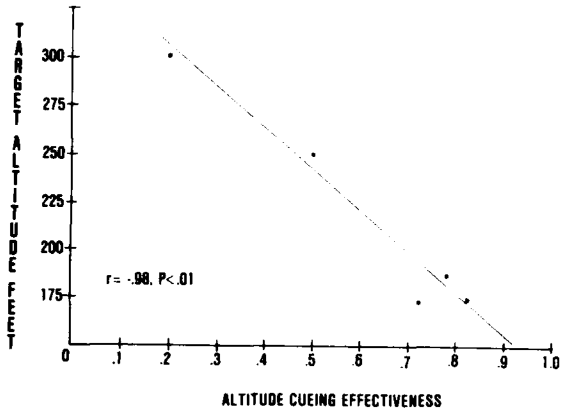

Figure 2. Target altitude vs altitude estimation slope

Table 3
Results of one-way ANOVA performed on target altitudes in five visual display environments

SOURCE	MEAN SQUARE	D. F.	F-RATIO	p
TOTAL	5100.49	44	-	-
ENVIRONMENT	29194.05	4	13.65	.001
ERROR	2138.35	32	-	-

There is one difficulty with the conclusions presented above. That is pilots report Cond 1 to be much easier to fly in than Cond D-1 even though they maintain altitude no better. The reason for this seeming discrepancy can be seen in Figure 3. Figure 3 shows examples of subjects' ground track in the two environments. It can be seen that ground track variability is much higher in Cond D-1 than in Cond 1. This difference results from the lack of distinctive features in Cond D-1. It is likely that the difference in subjective evaluation stems not from a difference in altitude cueing effectiveness but from differences in ground track cueing effectiveness. In order to specify completely the effectiveness of simulator visual environments in providing information needed for low altitude flight, research is needed to determine what aspects of the visual environment are relevant to ground track cueing and how they relate to flying performance.

CONCLUSIONS

1. Altitude perceptibility (slope of the altitude estimation function) is a valid metric of the ability of a simulator visual display environment to provide a pilot information needed to maintain altitude in low level flight. When an environment containing three-dimensional objects is evaluated, static presentation may be employed. Evaluation of the cueing effectiveness of two-dimensional texture requires a dynamic presentation mode.

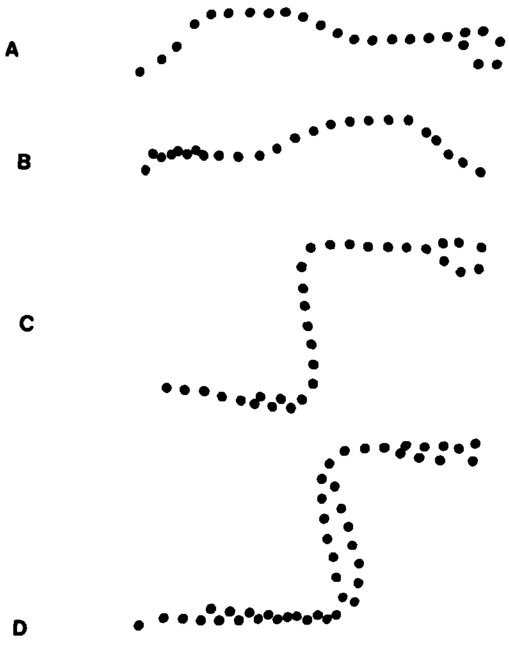

Figure 3. Examples of ground tracks, Cond 1 is shown in 3a and 3b, Cond D-1 is shown in 3c and 3d

2. A potent cue for altitude perception comes from the distribution, or flow, of environmental features. Perception of this information improves as the density of features in the visual environment increases. For three-dimensional objects a density of about 12 to 15 objects per square

mile is necessary and sufficient for maintaining of altitude. Equivalent cueing effectiveness (b = .7) can be provided by a two-dimensional texture pattern. A weak altitude cue is also provided by information about the aspect of individual objects, but the effectiveness of this cue is poor compared to that of gradient/flow cues.

3. A second aspect of visual cueing effectiveness was identified having to do with ground track control. This aspect of aircraft control involves initiation and control of turns. Visual cues required for ground track control are those which permit identification of roll-in and roll-out points. Unlike altitude cues, which must be uniformly distributed throughout the environment, ground track cues must be placed around particular decision points. A complete evaluation of the ability of a visual environment to support low level flight requires measurement of its ability to provide both altitude related information and ground-track related information.

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DMA AND CIG: A SHOTGUN WEDDING

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ABSTRACT

The DMA data base and its future enhancements have been hailed as the general solution to creating visual data bases for CIG. DMA centered approaches have proven marginal or ineffective, however, in providing visual support of low altitude flight, since DMA stresses navigation rather than flying skills.

The imagery presented by the CIG system must tell the pilot where he is relative to his map, and where he is relative to the ground. These are two very different objectives, and emphasizing one may compromise the other. Heavy emphasis on 'capture criteria' (for map fidelity) has historically resulted in systems which do an inadequate job of supporting low level flight, a task which depends on high 'scene density'. This paper examines the capture criteria and scene densities required to support such missions, and quantifies critical aspects of a 'nap of earth' data base. We will examine various constraints inherent in CIG systems, and their influence on what can be achieved. We also will discuss data base definition strategies, including the use of DMA data, to see where traditional approaches have been deficient in providing the required visual cues. Then we will present an approach which combines DMA data, new mathematical methodologies and data base design strategies, and current production hardware, to meet both the capture criteria and scene density needs of 'nap of earth' missions.

INTRODUCTION

Whole mission simulation is a multifaceted technological challenge. The total integration of instrument, radar, sensor and visual reinforcement requires the mastery of a variety of technical disciplines. The task is made even more demanding because the processes which create and support various aspects of the simulation are becoming ever more complex and disparate, while the need to correlate these aspects gets steadily stronger.

Computer generated visual imagery is one of the most demanding of these facets. Visual imagery must correlate with and reinforce information being received from other sources, including radar, infrared and radio navigation systems. It must support those aspects of flight navigation which are based on looking out the window: general topography, major terrain characteristics and significant cultural features which serve as navigational waypoints must be recognizable and correlatable with other navigation processes. Finally, the visual imagery must support flight skills by conveying to the pilot an accurate sense of spatial and dynamic relationships. Users are requiring these capabilities to be achieved with increasing effectiveness in ever larger and more complex visual environment data bases. DMA data has been increasingly relied on to provide the real world and radar correlations required in such systems.

THE DMA CONTRIBUTION

The Defense Mapping Agency Digital Terrain Data Base proceeds from, and is designed to efficiently support, radar driven navigational needs. The DMA data source provides two basic categories of information in the form of terrain files and culture files.(1) The terrain files contain terrain elevation values, in meters, corresponding to sample points along a regular grid in latitude and longitude. Currently, terrain files are available in two levels of sample spacing, Level 1 and Level 2. The latitude spacing of the grid is 3 arc-seconds for Level 1 and 1 arc-second for Level 2, while the longitude spacing varies from 3 to 18 arc-seconds (Level 1) or from 1 to 6 arc-seconds (Level 2), in order to keep the grid approximately square. The absolute accuracy requirements for terrain data are specified as 130 meters horizontally and ±30 meters vertically for both Level 1 and Level 2.

Culture files are also available in two levels of detail: Level 1, which provides a generalized description and portrayal of planimetric features which meet relatively large minimum size requirements; and Level 2, which provides a more detailed description and portrayal of features which meet somewhat smaller minimum size requirements. The absolute accuracy requirement for culture file data is 130 meters for Level 1 data, and 26 meters, point to point, for Level 2 data, with the additional constraint that Level 1 and Level 2 feature detail must be compatible. Vertical accuracy specifications apply only to vertical obstructions of 46 meters or greater, and an accuracy of ±10 meters is specified for such features.

DMA AND NAVIGATIONAL CUES

The essential role of navigation cues in a visual data base is that of guiding the pilot along a course marked by a sequence of recognizable milestones, from a point of origin to a destination. The cues which are ultimately used will depend largely on the type of mission to be supported, the flight altitude domains, the strategic or tactical nature of the task and the characteristics of the terrain being overflown. Features which can be important navigational cues in an expansive desert landscape can be totally insignificant in a highly forested, hilly terrain. A segment of terrain designed to support high altitude navigation may not require the density of cues needed to support navigation at lower altitudes. Navigational needs will often be different in one portion of the data base than in others. The data base designer may capitalize on such differences in order to concentrate navigational cues where they are most significant.

The required spatial frequency of navigation cues tends to be relatively low at all altitudes. In real world missions the frequency of navigational waypoints is dictated by pilot workload constraints, and tends to be determined by flight time intervals of between 15 and 60 seconds. For tactical missions involving high speed low altitude flight, the spatial distribution of specific navigational features can be quite sparse while still providing an excess of waypoints which can be used during the mission.

The DMA terrain elevation data provides a natural starting point for the definition of large scale terrain topography for both the visual and radar simulations. A variety of approaches have been used to transform the data, correct errors or inconsistencies, and convert it to forms displayable by computer image generators. The nature and scale of the data provide sufficient correlation to fulfill navigational needs of the visual environment. However, a preliminary analysis of the cultural files suggests that much of the wealth of data contained in these manuscripts is not designed to support the visual data base design task, nor provide effective imagery for 'nap of earth' or low altitude flight. Positional information, dimensions, material descriptions and coverage factors are potentially useful in providing cultural navigational cues and generic terrain embellishment for optical flow, however.

OPTICAL FLOW AND LOW LEVEL FLIGHT

At high altitudes there is little danger of crashing into the ground, and ground topography is of interest primarily to support navigational goals. In flight profiles very close to the ground, however, a high percentage of visual cues must be designed to support terrain avoidance and flying skills such as those employed to stealthily approach targets without being detected by potential threats. The lower a pilot tries to fly, the more he depends on key characteristics of the visual scene in front of him. His attention gradually shifts from cockpit data sources to the outside world; as his work load increases he must extract from the visual scene better information at faster rates in order to avoid impact with the terrain. This ability depends on a complex set of visual factors, including the optical streaming of scene details away from a single fixed image point (the "aim point"), the rate of motion of image details, relative parallax shifts, and the emergence of successive levels of detail (including any absolute size cues).

Some work has been done in attempting to quantify these factors and transfer them into a computer generated visual scene. Early attempts at providing these cues with abstract repetitive surface texture (i.e. checkerboards) were comparatively unsuccessful. Once pilots had calibrated the texture to determine how many wavelengths above it they should fly, holding a constant height above terrain was very easy. Such training does not transfer well to the real world, since it is based on strong artificial cues which may be absent in the actual mission. More recent research(2) has suggested that a mixture of surface texture and three dimensional features is required, and that these cues should be distributed throughout the image plane so that a certain density of cues per solid angle is maintained. This last requirement ties the spatial density of cues to the minimum flight altitude, and suggests some simple rules for computing this density.

NATURE AND DENSITY OF NOE FLIGHT CUES

John Sinacori, as quoted from reference 2 above, suggests that "the dominant perceptual strategy used for NOE point to point flight is motion perspective (optical flow) augmented by other mechanisms, such as linear and aerial perspective, interposition, shading, texture and apparent/familiar size, if and when their corresponding stimuli are available." He establishes a suggested minimum distribution of textural elements in the visual scene which is quantitatively related to the mean height of the pilots eye above the ground surface. He suggests that appropriate stimuli to support the motion perspective perceptual strategy should consist of a random distribution of textural elements of varying size, shape and contrast, whose mean spacing is approximately one eye height. He cautions that the estimate is preliminary and emphasises that such an element spacing is deemed a minimum texture level needed to reveal surface shape using motion perspective. He further states that although regular patterns or highly coherent texture may reduce pilot workload they should be avoided. Such regular patterns as checker boards invite the prospect of learned responses and negative training.

Within the framework of the motion perspective (optical flow) mechanism, additional strategies suggest themselves which relate to other perceptual mechanisms in both a complementary and a supplementary role. Sinacori states that "what should reduce workload and/or improve performance is the addition of coherent objects that more easily facilitate a static perception of terrain surface shape and observer position relative to that surface." He further asserts that "The addition of vertical objects should also reduce workload and/or improve height holding performance", and suggests a mean separation of vertical objects of about three to five eye heights. The inclusion of 3D objects such as trees, bushes and rocks, in addition to contributing optical flow cues, provides parallax cues and information about relative sizes of known objects which can be particularly valuable at slower speeds or when performing hover operations.

Sinacori provides a specific example of an NOE data base designed around the preceeding notions. He uses a portion of the Fort Hunter - Liggett area to postulate a helicopter NOE mission near the Nacimiento valley. Adequate ground truth is achieved with about 1000 polygons per square kilometer (this density roughly corresponds with direct skinning of the DMA terrain elevation grid). A dense 2D polygonal enhancement is added to the terrain to further define surface shape and provide optical flow, and 3D enhancements (trees) are added at a density of between 6000 and 12000 trees (roughly 100000 polygons or 300000 edges) per square kilometer.

IMAGE GENERATOR ISSUES

The above example suggests strongly why historical attempts to simulate NOE imagery have proven inadequate. The typical design strategy has been to convert the DMA terrain elevation data set into a terrain skin by a straightforward linear process which results in a similarly sized output data set; the terrain is then further embellished with cultural and organic features to provide optical flow and navigational cues. With this strategy, the basic problem is how to produce, store, read, manage and display the resulting very large data base. The gulf between current capabilities and such a system is measured in orders of magnitude, not small incremental improvements. The following general discussion of these problems acknowledges that all existing CIG systems have analogous limitations.

Data Base Size

A rough metric of data base size would be to express the production and storage requirements in terms of bytes per polygon (or face). This metric would include the overhead of data base management structures, all raw geometric information, and topological information required to assemble the scene. A value of 200 bytes per face is close enough for our analysis. Referring back to Sinacori's NOE example, a modest 25 by 25 kilometer data base would require roughly 13 Gigabytes of information. A large area tactical data base of several hundred thousand square kilometers modeled to a density of 100000 polygons per square kilometer would be prohibitively expensive to produce, and would require hundreds of very large disks to store.

Disk Bandwidth and IG Memory

There is a direct relationship between data base density, aircraft velocity and the amount of data that must travel between the on-line (disk resident) data base and the IG memories each second. If the sample data base has to support speeds of 100 knots and a general visibility of two kilometers, then about four Megabytes of information would be moving from the disk to the IG each second. The amount of IG memory required to contain all scene details within this visibility limit would be nearly 250 Megabytes.

Data Base Management

The image generator must select from the entire data base two very important subsets of data. The first is that portion which must reside in IG memory because it is closer to the viewer than the system visibility limit. This subset is continually changing as the simulated aircraft moves within the overall gaming area, but will generally represent a small fraction of the total data base. The rate at which this subset changes may be comparatively low, so this task is typically performed as a background task over multiple field times in the general purpose computer which hosts the disk. The amount of work required to perform this cull is related to total data base content. Processes which are adequate for typical production data bases whose densities are 10 to 100 polygons per square kilometer will be inadequate for the sample NOE problem.

Culling and Display

From this data an even smaller subset is extracted which consists of scene details which may be within the display windows. This second subset is usually culled to include only the simplest permissible representations of scene elements (level of detail selection), and only those surfaces which are front faced and large enough to be useful in the displayed image. The second cull processes only the data which survives the first cull (and resides in the IG), but it must be performed once every field, and on a much richer and larger set of image elements. The IG must extract those scene elements which are maximally useful to the viewer, while rejecting many others, and while preventing the artifacts of this management from distracting the viewer.

SOME HELPFUL OBSERVATIONS

All of the above might suggest a very bleak outlook for those simulator users requiring an effective NOE capability. Incremental linear advances in CIG technology are not likely to catch up to these needs as fast as the needs are evolving. What is required is a different way of looking at the problem, and a totally different strategy for dealing with the requirements. Fortunately, some helpful observations spring to mind.

First, there are two fundamentally different types of scene detail to deal with. Optical flow to support flight skills is almost entirely supplied by dense generic details with a high spatial frequency content, while the navigational "specificness" of the data base is due to very low frequency characteristics of the terrain topography and related cultural cues. This suggests that we ought to try to discover ways to "re-use" optical flow related scene details, so that many visual representations can be drawn from a small number of actual elements. We must then find a way of combining these reusable optical flow details with a terrain underlayment which is specific enough to meet our navigational requirements.

Second, perhaps we can discover a data base management strategy that implements level of detail selection while also providing for the physical subdivision of geographic data base areas into smaller areas. This would give us a way to manage the data base so that rejection of unneeded scene detail occurs in pieces as large as possible, expediting the data base culling process.

CT5: EXPLORING PARTIAL SOLUTIONS

The Evans and Sutherland CT5 image generator marked a number of significant departures from historical practice in the CIG field. Primary among these was the processing of image details by area rather than scan line,(3) and the implementation of all data base management functions in the IG hardware.(4) Each of these notions brought fundamental changes to the character and capability of the image generator. The rigorous application of antialiasing technology in the Display Processor achieved new levels of image quality, while increased basic capacity throughout the IG was augmented by much more efficient data base management. These improvements were accompanied by a better than linear capacity response of the system in areas where NlogN or N-squared responses were the rule in previous systems.

A Hierarchical Data Base Structure

The decision to implement the data base management function as a hierarchical tree was largely driven by the need to sort scene details in a front to back order. A powerful extension of list priority techniques, Cellular Priority, was developed to address the CT5 sorting problem. Its key property was the hierarchical subdivision of the overall data base priority problem into a tree of many nested simple problems. Within such a process visibility decisions about major data base elements propagate automatically to smaller elements. A similar property attends the data base management and culling process. Some key ingredients of this structure are particularly important to the NOE data base management problem.

A cell is a volume in model space represented by a decision node in the data base tree. The primary function of the cell is to provide a choice between either a simple or a complex representation of some portion of the data base, based on the distance between the cell and the viewer. Either choice can consist of a null (the item is so far away that nothing need be displayed), an object (a collection of polygons and light strings), or a mesh. A mesh is a collection of cells with a rule for their visual ordering. The mesh is thus the primary structure in the cellular priority process. The mesh can also be used to subdivide a region of model space into several smaller regions; this is the primary mechanism used to control the degree of detail that will be unfolded before display or rejection of data base elements.

The data base tree is the structure of meshes and objects organized by their association into cells; it is processed by testing cells and ordering meshes. Processing ceases along any subpath in the tree when the cell choice indicates either an object or a null. Processing will continue when the cell choice indicates a mesh. The order of processing in the tree is determined by the ordering rules contained in each mesh. At every stage of processing the IG attempts to prove that the item being processed is unneeded because it does not appear in any display window. The rejection of an item means the termination of processing along that subpath in the tree; unneeded portions of the data base tree are thus pruned off as early in the process as possible.

Capacity of the Object Manager

Processing of the data base tree occurs in the object manager (OM). The major task of the OM is to reject as much of the data base as possible, as soon as possible, and in pieces as large as possible. As the overall content of the data base increases, so does the content of the pieces which will be tested, and in many cases subsequently rejected. Each additional level of data base tree structure exacts a fixed amount of processing time, while increasing the total data base content by a multiplicative factor. Tree trace processing time thus grows linearly with data base depth, and logarithmically with total data base content.

Instancing in the IG

The CT5 image generator supports the reusing of data base items in a general and extensive fashion. A mesh or an object can be referenced from multiple cells in a data base, and each reference can include a positioning vector to plant the mesh or object in a particular place. All data base structure and scene detail which ultimately results from an instance will also be moved to the new location. By cascading levels of instanced meshes, very extensive and complex data base structures can be quickly created. For example, an entire forest can be built from a single IG resident tree and a very compact nested and instanced mesh structure. This allows a nearly total decoupling of memory requirements from apparent displayed density, and significantly reduces the amount of data which must be transferred from the disk.

Paging from Disk to IG

The object manager traces the data base tree to identify data blocks which may be needed to draw the image, but which are not currently in IG memory. This is done as a background task over several field times. The pager algorithm performs memory block allocation and garbage collection as well, and communicates data block requests to the general purpose computer. Data transfers from the disk to the IG occur by direct memory access. The hierarchical data structures which support data base management within the IG also suffice to control disk to IG processes; no secondary software management structures or tables are needed. This process can support a very high rate of continuous data flow from the disk to the IG.

CT5A: THE NEXT STEP

The CT5A system was the logical outgrowth of a characterization study of CT5. This study resulted in a better understanding of the data base management problem and how CT5 solves it, identified major new data base design and development strategies, and proposed a set of system modifications to significantly increase basic capacities while effectively supporting the new modeling approaches.(5) These new features significantly improve the ability of the system to address the NOE simulation problem by allowing visual data bases of over 500000 polygons per square kilometer to be processed, as the following discussion will illustrate.

Fade Level of Detail

Fade level of detail helps mask the switch between two levels of detail by fading the retiring scene element out as the replacement element is faded in. The transparency capability of the system is used to effect the switch, which is based on range and can occur at several selectable rates. This greatly reduces the visual distractions associated with level of detail switching, and allows these transitions to occur much closer to the viewer. This helps the system concentrate on processing details which are large enough to be valuable to the viewer, and significantly increases the apparent richness and complexity of the image.

Using Multiple Levels of Detail

In a visual scene, the most complex representation of an image detail will only need to be presented when the viewer is very close to it. At larger distances a much simpler representation is adequate and at still larger distances only the proper suggestion of bulk, shape and color is needed. In an extensive evenly distributed array of such details, most of them can be displayed using the simplest version. For a constant number of on screen polygons, the geographic density of such an array can be much higher if multiple representations are employed. Additional leverage is obtained by using fade level of detail to further shorten the transition distances.

Using Multiple Levels of Scale

In order to provide usable cues over a range of flight altitudes the data base must contain a selection of cue details of varying sizes and spacings. At close ranges the smaller cues will provide the bulk of near scene detail; at longer ranges the small cues will have been managed out of the scene, and the larger cues will be needed. One result of this strategy is that the angular distribution of cues in the observers field of view is nearly homogenous throughout the image, instead of being severely compressed against the horizon.

A Mathematical Design Methodology

A rigorous mathematical process can be used to design such a data base. The mission flight profile is used to establish the number and types of levels of scale, and the density requirements of each level. Components of the data base are then identified and characterized as to number and complexity of levels of detail. Level of detail transition strategies are defined, taking advantage of factors which can help minimize IG load. A global instancing strategy is developed to separate reusable generic scene features from specific details, and minimize the total modeling effort. The interaction of each data base portion is analyzed, and a composite IG load level is computed. The data base development can then proceed, confident that mission visual requirements will be met without overloading the system.

THE BASIS SET NOTION

The pursuit of structured and modular data base development strategies grew out of a desire to decouple the data base development cost from the geographic extent and total content of the data base. A first step in this direction was to separate the problem into two distinct portions: the specific terrain underlayment, and a reusable set of organic and cultural 2D and 3D components which could be used to embellish this base terrain. The actual ornamentation of the terrain would add those specific features which are navigationally important, and additional generic enhancements to increase realism and optical flow.

Lineal features such as roads and rivers presented an interesting problem. They had to be visually continuous across terrain boundaries, while adhering to the topological properties of the terrain underlayment. A process for providing these features was developed which represented roads by instancing predefined road segments. These segments were modeled in a set of road types, segment lengths, and segment orientations. From a comparatively small set of these elements specific, if somewhat stylized, roads can be built.

Three dimensional specific terrain presented a still more difficult problem. The fundamental elements of a strategy were identified during the course of extensive experiments aimed at the NOE problem. What ultimately emerged was the concept of a basis set: a set of scene components which exhaustively satisfy a class of local boundary conditions. We developed methods for identifying and defining a terrain basis set from a given set of constraints and fidelity requirements. Algorithmic ways of choosing terrain basis set elements to provide required specificness were explored, and basis sets with comparatively few elements were found to provide adequate ground truth and topographic complexity.

USING TERRAIN BASIS SETS

A terrain basis set consists of a number of patches of terrain which can be made to fit together in various ways by translating each element with respect to its neighbors. In the general case, basis set elements need not be either planar or similarly shaped, but the selection process must ensure that adjacent patches have compatible properties along their shared boundary. Because each patch can be offset in Z as well as X and Y, terrain features much larger than any one patch are easily created; the degree of fidelity preserved in this process depends on how large the basis patches are relative to the topographic features of the terrain. Many algorithms for skinning real terrain with a basis set are possible; DMA terrain elevation data provides one particularly good starting point.

Each terrain patch can be thought of as a place holder in the terrain skin. Its visual representation can be a simple polygon, or a complex scene component with embedded level of detail and dense 3D embellishment. The patch can provide additional subdivision of the terrain surface to increase scene complexity, although this additional complexity will be generic in nature. The basis set can include terrain patches with various lineal features, such as roads and rivers modeled at various orientations. Specific 2D and 3D features can be associated with the instance of a patch to provide navigationally specific embellishment.

Implementation of a terrain basis set brings other significant changes to the data base development process. The total amount of geometry that needs to be modeled is dramatically reduced, since only one version of each basis set element must be created. Thus the modeler can spend much more time optimizing the artistic aspects of each patch while dealing thoroughly with how the patch loads the IG. This approach substantially separates the geometric modeling problem from the organizational and hierarchical problems, and in effect puts a lid on the total amount of scene elements which must be created. The data base designer is thus freed of a great deal of modeling busywork, while being strongly induced to concentrate on and optimize the hierarchical aspects of the data base.

The basis set approach also alleviates several of the major IG bottlenecks which heretofore prevented effective NOE imagery. The terrain basis set and the embellishment components constitute a comparatively small amount of data, and most of this data will probably reside in the IG memories all the time. Traffic at the disk interface is greatly reduced, and most of the disk to IG transfers involve blocks of management and structure data, not geometry. Because the basis set elements enjoy a very high reusage factor, the apparent visual density of the scene is much higher.

A SPECIFIC NOE EXAMPLE

Let's see how all of these strategies can be brought together to solve a specific problem. We will reconsider the original Hunter - Liggett NOE problem, and derive a data base design which provides the high level of visual cueing required without exceeding the capabilities of the CT5A. DMA data will be used to define the offset vectors and assign associated basis set patches.

Our goal is to display 3000 polygons in the forward hemisphere of the pilots field of view. This will provide an adequate reserve of system capacity for complex target areas and detailed threat aircraft. We will need to have about 10000 active polygons in the vicinity of the viewer in order to display 3000 after FOV and backface culling. The data base will have four levels of scale, designed to support flight over an altitude range of three to 100 meters. One of these is the terrain skin itself; the other 3 are various sizes of trees, shrubs and rocks. We will arbitrarily divide the total polygon allocation to give the terrain 2500 polygons and each level of scale 2500. The data base design will anticipate an overall size of 25 by 25 kilometers and a general visibility range of two kilometers.

If all 2500 of our terrain polygons are used to define a single level of detail terrain skin within the two kilometer visibility range, the average area of each polygon will be about 71 meters square. We will instead provide two levels of detail. Within 350 meters of the viewer the average terrain polygon area will be 34 meters square; between 350 and 2000 meters an average of five of these polygons will be gathered together and replaced by a single polygon. The low level of detail polygons will be specifically defined while the high level of detail will be instances chosen from a terrain basis set. This will require the compilation and storage of about 108000 polygons for the terrain low level of detail; about 2200 of these will reside in the IG memories at any one time.

The smallest level of scale will be provided by randomly distributed shrubs and rocks up to three meters in size. We will provide three visual representations for each item: three, seven and 15 polygons. These might correspond to a simple tetrahedron tree, a tree with a trunk and shadow, and a tree with several tiers of leaves. We will use some of this capacity to provide 2D ground textural cues by depicting collections of rocks and pebbles; this will help provide the proper spatial distribution of cues when the pilot is closest to the ground. Since we are using fade level of detail, the level of detail changes can take place at 20 and 40 meters, and the simplest representation can be entirely removed from the scene at 80 meters. With these parameters the spacing of ground texture cues (rocks) is about two meters. Vertical cues (trees) are available every nine meters, and the total number of active polygons is the desired 2500.

Each terrain patch has an average of 29 of these small items on it, with each item requiring 15+7+3 polygons, for a total of about 725 polygons. Scene elements for the middle level of scale will be about twice as large, with corresponding increases in spacing and transition ranges, and the large level of scale will be two times bigger still, depicting trees up to 12 meters in height. These other two levels of scale will add another 181 and 45 polygons respectively, to each terrain basis patch. Thus the total number of polygons required to create each terrain patch is about 950. If we decide that a basis set of 31 patches will provide adequate terrain fidelity, the total number of polygons in the entire basis set will be about 29000. Nearly all of these will probably reside in the IG memories; adding in the 2200 low level of detail terrain polygons gives a total memory requirement for this data base of about 31000 polygons. Data rate between the disk and IG memories would be about 30 polygons per second. Note also that the overall size of the data base can be expanded without changing the amount of IG memory required or increasing traffic at the disk.

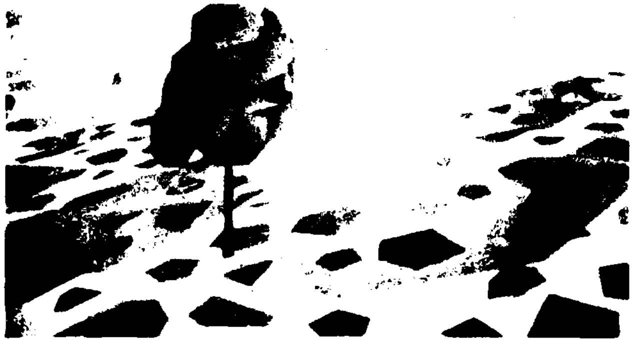
The density of the resulting data base is around 520000 polygons per square kilometer, counting only the most complex version of each scene element. The optical flow requirements suggested by Sinacori have been met, and this data base can be expected to properly support flight down to three meter eyeheights. The total amount of real modeling effort is very small, since most of the detail is generic and can be produced by compile time software tools. None of the IG limitations have been reached, and a large cushion of performance has been left to allow substantial enhancement of local target areas. The terrain fidelity is as good as DMA level 2 data will provide.

A SAMPLE BASIS SET

A preliminary NOE terrain basis set is shown in figures 1-4. The amount of geometry included in the basis set is designed to provide a nominal amount of cueing to support NOE flight at altitudes of around three meters everywhere in the data base. This sample was designed to closely accomodate Sinacori's recommended design

Figures 1-4

Views of Sample NOE Terrain Basis Set



parameters. Cultural and natural detail can be added, as well as specific navigational cues and target deployment areas. Many variations of terrain basis set geometry can be designed and used in the data base interchangeably. The sample photographs were taken with a horizontal channel field of view angle of 70 degrees.

SOME PROBLEMS REMAIN

These techniques add a very useful new tool to the data base designers kit; like other tools, it may not be the best solution for every problem. While the above strategy gets us a long way down the road, some significant problems remain. We have separated much of the geometric data from the management information, and have found ways to reuse the geometric data with fairly high leverage. The data base now derives its specificity from the structural data which organizes the basis set elements; while this is a much more efficient and compact type of data, there are still limits to the amount that can be created, stored and processed. The NOE example above will exceed these limits if the total geographic area is greatly increased. One solution is to decrease the geographic density of the structure information by using larger basis set terrain patches. Trading off terrain complexity for larger gaming areas may well be a viable solution, since a larger data base implies a higher flight velocity and altitude.

The inclusion of specific lineal features such as roads continues to be difficult and inefficient, and adding specific 3D cultural features requires additional effort. The process described above does allow the merging of specific scene details onto the instanced patches, but much of the advantages are reduced. This is also an area where the DMA data source is not especially helpful; the Level V and subsequent forms promise to alleviate some of this problem. As we continue to define better and more automated data base development strategies, and hardware which processes such data bases more efficiently, better cooperation between DMA and those who specify, develop or use these data bases can be very beneficial.

CONCLUSIONS

The 'nap of earth' mission places extraordinary demands on current CIG technology. Historical methods of producing and displaying such data bases have been inadequate. A fundamentally different way of dealing with the problem has been examined. This new approach uses the concept of a basis set to create specific terrain from reusable terrain patches and scene components. This methodology is supported by new data base design and production strategies, and by powerful features within the CT5A hardware. Together these provide the capability to produce and display visual data bases which effectively support 'nap of earth' training missions. DMA data can be used in this process to provide terrain fidelity and correlation with other simulation processes, and has the potential to substantially automate the data base production process.

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AN ADAPTIVE CBT COURSEWARE AUTHORING SYSTEM TO MEET THE NEEDS OF MILITARY AUTHORS

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ABSTRACT

The use of computer-based training (CBT) is rapidly becoming more widespread within the military services. Courseware production, historically the most cost and labor intensive area of CBT, will become more difficult with the decline in availability of capable authoring personnel. Reasons for this decline and a potential solution--the development of advanced authoring systems--are discussed. A description of one such system, called ADAPT™ (for the TICCIT® CBT system), is presented.

As training requirements in the military services become more critical and training resources such as fuel and instructor personnel become less available, the use of computer-based training (CBT) has increased dramatically. CBT systems are becoming less expensive, less bulky, and more capable with new hardware (such as microcomputers and videodiscs) and software developments. The authoring of courseware remains the most critical and cost/labor intensive part of CBT development, but, unfortunately, the availability of capable authoring personnel in the military is on the decline.

CBT COURSEWARE AUTHORING IN THE MILITARY

Military organizations with responsibility for production of CBT courseware must not only deal with the normal problems encountered in CBT production but must also cope with the following personnel problems:

1. Lack of personnel with the aptitude required to create on-line instruction using conventional authoring languages.
2. Lack of personnel experienced in the development and production management of CBT materials.
3. Rapid turnover of personnel due to periodic reassignment.

We will discuss each of these briefly below.

Lack of Personnel with an Aptitude for CBT

The lack of personnel with the aptitude required to put instruction on line is a special case of the general problem confronting the military services in the 1980s and 1990s. The problem is the lack of manpower due to the decline in the population of 18 to 25 year olds. The military services must compete during these years with all other branches of society for the best of these young people. In the absence of a draft, it is likely that the most talented of these young people will either pursue advanced educational opportunities or seek well paid positions in business and industry.

In addition to the problem of securing individuals with good general intelligence, the military services will find it especially hard to recruit young people with aptitude in computer-related areas. As the computer industry becomes a dominant force in the United States, competition for such individuals will become particularly intense.

Lack of Personnel with Experience in Developing CBT

Training personnel in the military services have, for the most part, only had experience with workbook and stand-up instruction, with little or no opportunity to work with computer-based instruction. Those few military personnel who have worked with CBT are likely to have had contact with the early (and largely experimental) efforts to implement CBT in the military. As a result most military personnel responsible for training are either inexperienced with CBT (and, therefore, do not like or trust it) or may be biased against it based on prior experiences.

Even when men and women in the military services demonstrate ability for and interest in developing CBT materials, there is no clearly defined appropriate career path for such personnel. In fact, even if an individual acquires advanced training in the systematic design of CBT instruction in general or the authoring of on-line material in particular, there may be a negative incentive in terms of career advancement to remain in the CBT field.

Rapid Turnover of CBT Personnel

Given the normal rapid turnover of personnel in the military and the lack of a defined career path in CBT, the few trained and experienced CBT personnel that do develop at military authoring sites are usually rotated to other assignments, often just as they become proficient and when they are most needed.

These factors severely complicate the task of military organizations that seek to become cost-effective producers of CBT. Some of these problems such as lack of a CBT career path require high-level changes in the military services to cause any lasting improvement. Others such as the decline in computer aptitude may be effectively combatted through the use of advanced authoring systems such as the one discussed below.

AUTHORING SYSTEMS

Authoring systems are on-line editing packages designed to aid the author in the development of courseware. Authoring systems interface with the author through an on-line editor, which usually takes a nonprogramming format. Authoring systems can provide aid in a variety of areas such as front-end analysis for a course, the development of individual displays within a lesson, and course management.

In the past the method for authoring courseware was usually a programming language, ranging from general-purpose languages like BASIC or PASCAL to specialized languages optimized for courseware production like TUTOR for PLATO® or TAL (TICCIT® Authoring Language) for TICCIT. (The latter type are very powerful but require considerable training to master fully.) On-line courseware authors, therefore, must either be programmers or have a programming aptitude. The profile of authors available for the military, however, demands that authoring be independent of programming as much as possible.

Authoring systems may be presented in various formats including prompt-driven, menu-driven, and programming.

Prompt-driven

Prompts are questions presented to the author by the on-line editor. A prompt-driven authoring system leads the author through the authoring process by asking a series of questions. Prompting is very effective for the new author but quickly becomes unnecessary as the author gains experience. There are simply too many options to be able to individually question more than just the basic ones. Also, authors soon learn the options used most frequently, at which point the prompts inhibit efficient authoring.

Menu-driven

In a menu-driven authoring system, many options may be presented simultaneously on each menu. This allows authors to move more rapidly through the production process. Also, commonly used instructional templates, such as particular practice item formats, can be presented quickly and repeatedly by menus. Unfortunately, menu-driven authoring systems normally must contain multiple levels of menus because of the large number of options required in a sophisticated CBT environment. As with prompt-driven systems, authors quickly learn those options that are most frequently used. At this point the authors need shortcuts around the majority of the menus.

Programming

Specialized programming authoring languages remain the most powerful and flexible means of authoring CBT materials. Invariably, there are times when even the best of menu-driven formats cannot adequately support the production of a particular instructional requirement. At that point the programming format is required. The major problem with such languages is the need for extensive training and a programming aptitude.

Each of the above formats has its advantages and disadvantages. An ideal authoring system, then, could use all three formats at different times depending on an author's aptitude and current expertise. One such system is currently being developed by Hazeltine Corporation. The design considerations in this system should prove useful in any CBT environment. The remainder of this paper presents a description of this authoring system.

ADAPT^{TM}: A MULTILEVEL AUTHORING SYSTEM

Hazeltine Corporation, manufacturer of the TICCIT CBT system, in conjunction with the rehosting of that system to run on a microcomputer, is currently developing a new authoring system to meet the requirements of military CBT authors discussed above. The guiding considerations for this new system, called ADAPT^{TM}, are that different authors possess different levels of expertise and that different instructional objectives require different presentation strategies. The authoring system, therefore, may be entered at a variety of levels depending on the current ability of the author and the instructional design requirements of the material being authored.

We may think of a lesson file in ADAPT as being created at any position within a two-dimensional matrix of authoring expertise versus instructional design model. (Figure 1 presents a schematic representation of this concept.) Along one axis are levels of editor formats based on those discussed above. Along the other axis are various instructional design presentation strategies for developing lessons for particular classes of instructional objectives (such as concept classification, rule using, linear procedures, simulations, etc.) plus the option of having no embedded strategy. Since the intended audience for ADAPT is not instructional designers, these strategies will be presented in terms that will be meaningful to the military author. When creating a file, the author selects the point in this matrix that represents his or her current need--the intersection of the desired authoring level and the appropriate instructional strategy. (Eventually, the front-end analysis capability of ADAPT will lead the author to the selection of the strategy.)

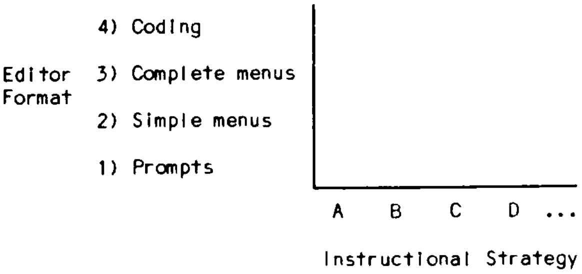


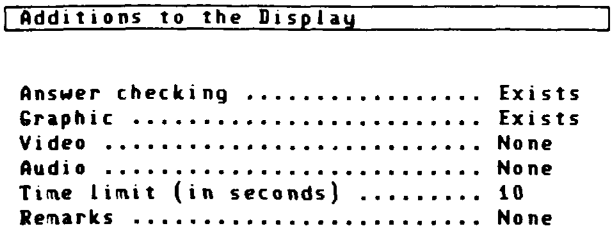
Figure 1--Matrix representing the ability to select authoring level and instructional strategy for an ADAPT file.

Authoring Expertise

There are four levels of editor formats available ranging from level 1 (the lowest) to level 4 (the highest):

Level 1, for the novice author, is a prompt-driven format in which the author is led through the authoring process by means of a series of questions (prompts). These prompts cover a limited set of options for the beginning author to consider. The author provides the data required for these prompts by answering yes/no questions and by typing English-like data statements.

When the author no longer needs to be led step by step, he or she may move to level 2, which abandons the prompts and directly presents the same limited set of options through simple menus. Figure 2 presents one such menu.

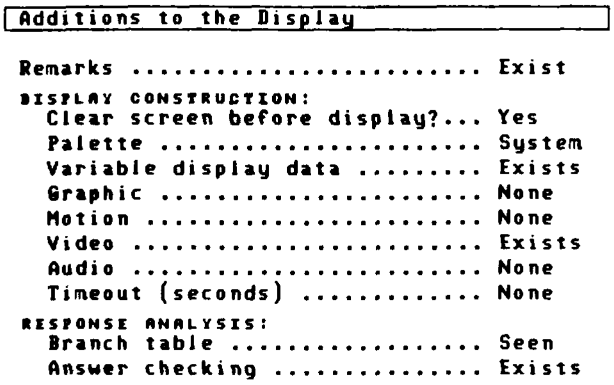


Additions to the Display

Answer checking	Exists
Graphic	Exists
Video	None
Audio	None
Time limit (in seconds)	10
Remarks	None

Figure 2--Level 2 additions menu.

Level 3, for the intermediate author, presents the full set of options through complete menus. Some of the new options may require the author to supply data in a coded syntax. Figure 3 presents the level 3 version of the menu presented in Figure 2. (Note that color, which is an important aspect of ADAPT, is not visible in these figures.) Level 3 represents a powerful authoring capability with which the bulk of courseware at most sites may be authored.



Additions to the Display

Remarks	Exist
DISPLAY CONSTRUCTION:	
Clear screen before display?	Yes
Palette	System
Variable display data	Exists
Graphic	None
Motion	None
Video	Exists
Audio	None
Timeout (seconds)	None
RESPONSE ANALYSIS:	
Branch table	Seen
Answer checking	Exists

Figure 3--Level 3 additions menu.

Level 4, for the advanced author, is the programming authoring language with its complete capabilities and flexibility. Here, the author creates program code using the required syntax. Some menus are available at this level if desired to simplify options such as the scoring and sequencing of practice and example items.

Raising Levels

An important feature of ADAPT is that a file authored at one level may be raised at any time to a higher level. At all levels the author is creating programming code such as that at level 4. It is only at level 4 that the author sees this code directly. The various lower levels are simply editing formats that lie between the author and the resultant code. For example, a menu for answer checking under level 3 presents all the options associated with a COMPARE command at level 4. At level 3 the options are listed; at level 4 the author must know which options he or she needs to add. (Even at level 4, on-line advice about which options are available and how each is used is available.)

Instructional Presentation Strategies

At the creation of a file, the author may select an embedded instructional presentation strategy that is suited to the particular objective being taught. These strategies are included to ensure the instructional soundness of the on-line material, particularly as an aid to the author lacking in instructional design experience. This is accomplished by listing the required and optional instructional components (e.g., objective, generality, practice items, helps, etc.) for each strategy as well as the requirements within each component (e.g., answer checking for a practice item). The authoring system can even lead the author through the process of picking the appropriate strategy.

Display Creation

We will now look at the creation of an individual display in some detail. (Ultimately, it is possible to consider any student presentation as being a series of screen displays presented to the learner. The particular sequence of displays and the details of each display will depend on what the learner does while using the material.) The authoring of each screen is enhanced through the use of two components: (1) a display page and (2) an "additions" menu.

The display page is a clear screen on which the author may type directly (i.e., in the desired position and color) all text that will unconditionally appear on the resulting student screen.

The additions menu is a listing of options by which the author can modify the contents of the display. At ADAPT level 2 these options include answer checking, graphics, video and audio sequences (including the overlaying of text/graphics on the video frames), and a time limit. (See Figure 2.) Author documentation of the display is also available through this menu. Further options are available at level 3, such as graphics animation sequences (motion), color palette, and conditional text (variable display) data based on the run-time environment. (See Figure 3.)

All of the level 3 options are available at level 2 if they are specifically requested by the author. Once a higher level option is invoked on a lower level additions menu, the option will remain on the menu. This ability is facilitated by the nature of the menus themselves. An author may choose an option by either touching it with the light pen or by typing the first three letters of the option name on the bottom line of the terminal screen. The latter method allows the use of options that do not currently appear on the screen. It also allows options to be chained (i.e., a sequence of options may be typed at the same time), thus avoiding the need to see all the intervening menus. This feature alone removes one of the major problems associated with menu-driven authoring formats.

At level 4 the display page for unconditional text remains the same, but the additions to the display are accomplished through the use of specific programming commands which the author inserts in command sections following the display page. For example, graphics are provided through GRAPHIC commands, answer checking through COMPARE commands, and conditional text data through SHOW commands.

On-line Training

The large amount of training required before authors can efficiently produce useable courseware has been a problem with authoring languages in the past. In ADAPT the initial training requirement is minimized, first, by the prompting format at level 1 (which leads the author through the authoring decisions) and second, by the limited number of options available at levels 1 and 2.

Training for level 1, then, involves basic instruction in the use of the ADAPT editor (getting started, labeling files, etc.) and explanations of some of the options to be prompted. In addition to the training, explanations of current options are always available within the editor through the ADVICE key.

For level 2, the only additional training required is in how to move among menus and the explanation of any new options (still from the limited subset) that were not addressed by the prompts at level 1.

Level 3 requires training for the new options available. For the most part, though, the menu structure is the same as for level 2--just more options per menu. In addition, some of the new options require coding syntax to enter data. This represents a higher sublevel within level 3 with appropriate training necessary.

Level 4 involves the use of commands and full programming syntax. Since these commands have the same names as the menu options they represent, to some extent the training requirement is lessened. Similarly, the syntax learned in level 3 is also used in level 4.

Thus, there is a discrete training requirement at each level and sublevel. This training will be presented on-line and with hard copy job aids and review materials. The editor will be aware of the current level of training accomplished by each author and can interrupt whenever an author attempts to raise a file to a level for which he or she has not been trained or use an option not yet presented in the training. At that point the author may choose to ignore the editor's warning and proceed with the option or level change, or the author may receive the necessary training at that time and then proceed. At some sites the editor could even lock out particular authors from certain levels or options.

CONCLUSIONS

An advanced authoring system like the one described above is a potential solution to some of the problems faced by the military in the authoring of CBT courseware. Such a system can overcome a lack of programming aptitude among military authors by removing the need for programming. A great deal of the instructional material can be input by personnel lacking programming skills or experience. Material requiring such skills can then be left to those individuals able to input them. Similarly, the authoring system can overcome the lack of CBT design expertise by providing built-in instructional models that help ensure that the on-line material is fully consistent with the most effective teaching and learning strategies available. Such an authoring system thus helps to alleviate the problem of rapid turnover by quickly allowing new authors to produce useable material. This allows a site to make better use of its authoring personnel even if there is no change in the rate of personnel turnover or in the incentives for remaining in a CBT authoring role. Also, the on-line training will help those authors with an aptitude for programming more quickly master the advanced authoring capabilities and techniques.

ABOUT THE AUTHORS

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DR. DAVID STONE is an instructional design supervisor for Hazeltine Corporation at its Training Systems Center. In that capacity, he is responsible for the supervision of all instructional design staff and for instructional design research and development. He has conducted research in the design of computer-based job aids and techniques for organizing technical presentations. He holds a Ph.D. in educational psychology from Cornell University.

User Friendly Authoring Languages: An Alternative Approach

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ABSTRACT

Two general types of programming languages have been developed for computer based educational systems. The first type of language, which is patterned after such high order languages as PASCAL or FORTRAN, provides great programming flexibility. However, its structured, syntactical constructs require either that an experienced programmer be involved in lesson generation or that instructional personnel become skilled in sound programming techniques. Its use frequently results in other problems as well, such as communication difficulties between instructional and programming personnel in the implementation of the lesson design and development process. To avoid these problems, the second type of language was developed. It allows instructional personnel to generate on-line instructional materials without acquiring sophisticated programming skills. This second category of languages is often thought of as being "user friendly." Such languages usually take an algorithmic approach to instruction and rely heavily on prompting as the means of lesson program entry. They serve very well for many applications, but their use has not been without problems. Not the least of these problems has been a lack of flexibility in the presentation and creation formats. This paper describes the OMEGA authoring system, a lesson authoring approach that provides instructional personnel with the positive features of both of the above language types. The approach has been implemented on an educational system that includes capabilities for the integrated use of interactive videodisc and three dimensional simulation. The paper first relates some basic facts about computer systems in general, and then discusses the various aspects of user friendliness in the context of educational programming. It then describes and evaluates both the traditional and OMEGA approaches to user friendly authoring.

Users of educationally oriented computer systems have a limited number of authoring language options available to them. Most systems are equipped with two types of authoring languages. The first type offers the author a great deal of flexibility in instructional design, but requires a very sophisticated knowledge of computer programming to be used effectively. The type, which is advertised by manufacturers as "user friendly," requires little or no computer background, but limits the author to a relatively rigid instructional presentation format.

Today's instructional environment requires a language option that is more adaptable than either of the two discussed above. An author's computer background can range from nonexistent to extensive, and instructional applications vary from simple to extremely complex.

This paper describes the OMEGA authoring system developed by the Training Systems Department of the Grumman Aerospace Corporation. OMEGA was designed to bridge the gap between the language option types discussed above. It combines adaptability to any level of computing ability with the flexibility and power required for sophisticated instructional applications.

The paper first discusses a few basics of computers to define terms used in the discussion that follows. That discussion begins with a description of the various aspects of user friendliness. It then describes and evaluates the approaches that have traditionally been taken toward making educationally oriented computer systems user friendly. Finally, the OMEGA approach to lesson authoring will be described and evaluated.

COMPUTER ESSENTIALS

A computer is basically a piece of machinery that uses electronic means to manipulate data. The machinery -- called "hardware" in computer jargon -- consists of a processor and various support items known as "peripherals." These peripherals allow the processor to communicate and interface with the outside world. Some peripherals (e.g., keyboards and card readers) are called "input" devices; they allow the user to give information to the processor. Other peripherals (e.g., printers and terminals) are known as "output" devices; they allow the processor to display information for the user. Mass memory is one of the most important peripherals in a computer system. It stores data that is not currently being used by the processor, but which will be required at some future time. This memory is both an input and an output device, since the processor "reads" from it or "writes" to it.

Computer hardware is controlled by programs, or "software." These programs are nothing more than structured sets of instructions that can be understood and executed by the computer's processor. Programs control the sequence and nature of the processor's interactions with its peripherals and the way it manipulates and formats data.

Programs can be written in various computer "languages," which, like human languages, consist of a vocabulary and syntax. The "vocabulary" of a computer language is the set of instructions (also called commands) it contains. Its "syntax" is the set of rules governing the way in which the instructions must be structured. Many different languages have been developed for computers over the years, and several language options are usually available for any given computer.

The most fundamental language for a computer is its "machine language." Each instruction in machine language is a series of binary states, commonly represented by 1's and 0's. Machine language is considered fundamental because all programs, no matter what language they are written in, eventually become machine language. It is the only language a computer "understands," and is unique to a particular processor.

Programs can be written directly in machine language, but it is very difficult to do so. To make the programming task easier, a second type of language, known as "assembly," was developed. There is a one to one correspondence between assembly language instructions and machine language instructions; but the instructions in assembly language are easily recognizable mnemonics, and are therefore much easier to work with than machine language instructions. Programs written in assembly language ("source code") are mechanically converted into machine language programs ("object code") by a utility program known as an "assembler." Like machine languages, assembly languages are unique to a given processor.

Although programming in assembly language is much easier than programming in machine language, it is still a tedious and time-consuming task. For this reason, various "high order" languages (HOLs) have been developed. Source code written in these languages is translated into object code using utility programs known as compilers or interpreters. HOLs differ from assembly language in that a single command normally corresponds to a structured group of machine language instructions.

High order languages usually have been developed with specific applications in mind, e.g., arithmetic computation, large data base management, string manipulation, or instructional delivery. Their specific design orientations make it relatively easy for programmers to write programs for their intended applications, but programming for applications outside of those for which the language was designed can be very difficult or inefficient.

Source code for a program written in either assembly language or an HOL is usually composed at a computer terminal using some sort of editing program. The code thus produced is put into a logical entity, known as a "file," in computer memory. This file is used as input to the assembler, compiler, or interpreter, as appropriate, to produce object code. This object code is put into another file. When executed by the computer, the object code causes the computer to do the things desired by the programmer.

A note of clarification is perhaps in order here. The user friendly language options provided for educational computing systems sometimes make it appear that lesson authoring is something other than programming. Despite appearances, however, it is important to remember that the author is actually writing a computer program. It doesn't matter what the author's instruction set looks like or how the instructions are specified. When the data that is entered becomes machine language, the computer treats it the same as any other data base. Ultimately, programs must be written in some computer language, and the instructions in that program must be translated into the machine language of the computer being used.

ASPECTS OF USER FRIENDLINESS

A system that is user friendly is one that is easy to learn and use. There are two approaches to making a computer authoring system user friendly. One deals with the language to be used, while the other deals with the means of producing source code in that language, or editing.

Language

It is obvious that a language with complicated syntax is less user friendly than one with a simple and straightforward syntax. In addition, an instruction set consisting of mnemonics that are natural and meaningful to the author will be easier to use than one whose instruction set is unnatural.

These are the aspects of language that are most often thought of relative to user friendliness, but there are others as well. These include the following:

Capability: It doesn't matter how simple a language is if it doesn't provide the author with the tools necessary to do what is required. An instruction set must be complete enough to provide flexibility.

Adaptability: Closely tied to capability, adaptability implies that a language can be used for diverse applications. For example, a language developed only for interactive videodisc applications could not be used by an author in applications requiring interaction with a simulator.

Tolerance for Faults/Diagnostics: Anyone who has done any programming knows that programs rarely run correctly the first time. A useful feature of any language is toleration for such faults as typographical errors. Where errors exceed the limits of reason, diagnostics indicating what sort of error has been made (and where) are a great help in identifying what needs to be changed to make the program run correctly.

Editing

As was the case with language considerations, simplicity is the most obvious characteristic that will make an editor user friendly. The simpler the editor is in function, the easier it will be to learn and use it. However, there are some additional, and perhaps less obvious, features that can be useful:

Internal Helps: Closely associated with simplicity, internal helps provide the user with assistance when he doesn't know what to do next.

Speed: How fast can source code be entered on a sustained basis?

Documentation: To what degree can comments be added to the source code to provide information on program logic? This is a very important feature when the author must go back into the program to correct errors or change it for some reason.

JUDGMENT CRITERIA

From the foregoing discussion, it is obvious that there are at least seven factors that can be used to judge the user friendliness of a given system:

- o Simplicity
- o Capability
- o Adaptability
- o Tolerance for faults/diagnostics
- o Internal helps when editing
- o Editing speed
- o Documentation.

These criteria provide the basis for the discussion that follows.

HISTORICAL SYSTEM DESIGN

The most common system design for a user friendly authoring language actually obscures the language being used. The author deals exclusively with an editor that provides menus and templates to extract the required program information. As the author responds, the editor composes and formats the requisite commands, and inserts them at the required places in the program. In this way, the authoring language is totally transparent to the author. This approach can be evaluated as follows:

Simplicity

A template system is very simple to learn. Typically, a new author can be on the system and working within a few hours. Authoring vocabulary and syntax are not problems, since the author is isolated from the actual language base.

As simple as this approach seems, however, there are problems with it. While it is true that the new author can begin to work quickly, total proficiency comes much more slowly. A flexible language, with extensive capabilities, requires a great many menus and templates, and the sheer numbers may be overwhelming at first.

As proficiency is gainea, a new problem develops. With experience, the author outgrows the need for many of the prompts the system gives. The speed with which the author can create reaches a terminal point, and frustration with the system sets in.

Capability

As discussed above, the capabilities of this type of system may be quite extensive. The nature of the approach, however, limits the ability to extend those capabilities. Each new feature requires not only that new commands and programming routines be prepared, but also that new code be written for the editor that allows authors to use the feature. This is a time consuming and expensive proposition, since the updated editor must be thoroughly tested to ensure that the new features do not interfere with previously existing features.

Adaptability

This approach makes it very difficult to adapt to new applications for the same reasons listed for increasing capability. The problems are of the same nature, but are more extensive.

Tolerance for Faults/Diagnostics

This approach scores very high for this criterion for one potential error situation, since the system does not allow the author to enter an unrecognizable command. Problems can result, however, if an entry is made that is syntactically correct, but logically incorrect. The recognition and solution of this type of error will be extremely difficult and time consuming

Internal Helps

This is the strongest suit of the traditional system. Using an editor of this type provides excellent internal helps for the author. The next required entry is always displayed on the screen.

Speed

As noted earlier, the new author can begin to create very rapidly, and the time it takes will probably be faster than would be possible with other systems at first. However, as proficiency is gained, the prompts become a hindrance. Templates require that each prompt be addressed, whether the feature it represents is required or not. This creates the first bottleneck. A second problem is that it takes a finite amount of time to perceive the prompt and respond to it.

Documentation

The ability to document the source code varies from one system to another. Generally speaking, however, this approach does not provide for the extensive internal documentation required for a sophisticated program. This lack of documentation severely curtails the usefulness of the training system. Programs need to be changed from time to time, and changes are not always made by the same person who originally wrote the program. A new author may not be able to perceive the original author's logic if it is not well documented, and may be forced to recreate a lesson from scratch as a result.

THE OMEGA DESIGN

The OMEGA authoring system has been designed to incorporate as many of the strengths of the traditional system as possible, while overcoming its weaknesses. It consists of three elements: the OMEGA language itself, an editor used to create OMEGA source code files, and a set of procedures developed for using the editor effectively.

The OMEGA system is designed to support diverse instructional applications, including operation and maintenance of complex equipment. Unlike other authoring systems, OMEGA can control students as they acquire both cognitive skills using two dimensional (2D) media and psychomotor skills using three dimensional (3D) media. A typical hardware for these training applications could consist of:

- A microprocessor for system control
- Mass memory in the form of either floppy or hard disks
- Mass video memory in the form of laser videodiscs
- A color television monitor to display stored video and/or digital materials
- A touch sensitive bezel, mounted on the front of the monitor, to allow student inputs
- A voice recognition unit to allow for student inputs when both hands are occupied with performing a manual task
- A three dimensional (3D) simulator to allow the student to manipulate equipment as required by the training task.

Lesson design and authoring for 3D applications can be extremely complex. Experience has shown that it is sometimes necessary to anticipate 15 to 20 responses at one time while teaching the troubleshooting of a complex piece of electronic equipment. Sometimes, half of these are anticipated incorrect responses that require remediation. The other half in that situation are logically correct responses. Each correct response requires a separate branch path in the lesson that would accomodate the actions that follow.

The system can also be used for more traditional applications. There are times when the system is used to present standard interactive videodisc instruction, even when dealing with very sophisticated equipment. This instruction can consist of a basic series of instructional frames, or "pages," to be presented to the student. They are "turned" when the student indicates that he is ready for the next page, usually either by touching a designated spot on the screen or by giving a verbal command using the voice recognition unit. A student's understanding is tested from time to time by presenting questions on the screen. Incorrect responses are remediated, while correct responses take the student along the main path of the lesson.

The Language

The OMEGA language consists of approximately 50 commands, but only a dozen or so are required for most lesson authoring. These commands are divided into six categories, according to function:

- Lesson exeeution
- Instruction
- Student interaction
- Lesson variables
- Simulator communication
- Instructor communication.

Lesson Execution: The lesson execution commands serve two functions: they divide lessons into logical units called EVENTs, and they provide branching within a lesson that is not student-initiated. These commands are totally transparent to the student at lesson run time, but it is primarily these commands that give flexibility and power to the language.

Instruction: The commands that present instruction to the student at run time either display video images and/or audio messages from the videodisc, or they present computer generated graphics that can be overlaid on video graphics. As is the case with all computer based instructional systems, each instructional message is determined during lesson design. The OMEGA instructional delivery commands simply sequence the messages properly.

Student Interaction: Student interaction commands allow the student to communicate with the system. This communication can take the form of "go ahead" indications, responses to direct questions, or 3D manipulations, as discussed above. Student responses are judged as either correct, anticipated incorrect, or unanticipated. The system reacts differently to each category of response. For both correct and anticipated incorrect responses, it proceeds to an place in the program that has been specified in the command. At that place, the system either advances the student on through the lesson or provides remediation specific to the action taken.

Unanticipated actions are incorrect by definition. Since they have not been anticipated, it is not possible to provide specific remediation for them. In such situations, the OMEGA software provides a system generated message that tells the student what control was moved, what position it was moved to, and what position it was moved from. This allows the student to correct the error before attempting to continue through the lesson.

Lesson Variables: The author can define and manipulate variables using OMEGA commands. These variables can be used for a number of purposes. They can be used to keep track of student errors, including number and type. They can count the number of times a student exercises a procedure; this could be used in a situation where there are three different versions of the same help message. By keeping track of how many times the student has asked for help, the lesson can provide a different message each time. The variables can also be used as the basis for branching within a program.

Simulator Communication: When dealing with a 3D simulator, it is frequently necessary for the lesson programs to communicate with the simulator programs. Much of this communication is done automatically using the student interaction commands discussed above. There are times, however, when additional communication is required, either to manipulate variables in the simulator's programs or to determine the value of those variables. The simulator communication commands allow for this additional interaction between the lesson and the simulator.

Instructor Communication: The OMEGA system allows an instructor to monitor what the student is doing on a separate cathode ray tube (CRT). Alerts and/or informative messages can be incorporated into the OMEGA lessons to ensure that the instructor always knows what is happening.

All of the OMEGA commands are straightforward, regardless of the category they are in. Each command consists of a meaningful mnemonic followed by parameters. Most of the commands have three parameters or less, and the most commonly used typically have only one. The most common values of the parameters are set as defaults to simplify their entry at edit time.

The syntax for organizing a lesson program is also quite simple. A lesson is organized as a series of EVENTs, which are logical groupings of OMEGA commands. The group of commands in an EVENT specify what can happen at one particular time in a lesson. Generally speaking, the elements of an EVENT include what the student will see and/ or hear, as well as acceptable student responses. Other information, such s instructor prompts, historical remarks, or documentation notations, can also be specified as required.

The Editor

The OMEGA system uses a sophisticated off-the-shelf word processing text editor, because of its power and its simplicity. It provides extensive edit time help in the form of menus, and the author can easily set (and reset) the amount of help desired while editing. The following capabilities are provided:

- Inserting text (characters, complete files)
- Deleting text (characters, words, lines, groups of lines)
- Moving text (from single character to large blocks of text)
- Global corrections
- Saving text (blocks, complete files).

The Procedures

Each OMEGA lesson is constructed by putting a series of commands into a computer file using the editor. Four different methods can be used to enter this code, depending on the instructional requirements and the programming capabilities of the author:

Command: The author can enter individual commands simply by using the computer keyboard as a typewriter. This option provides maximum flexibility, as the author can group and sequence commands in any way desired.

Template: Here the OMEGA system begins to resemble the more traditional systems, but this resemblance is only superficial. Since certain groupings of commands tend to occur more often than others in any programming language, they can be grouped together to form a template. Specific details may vary from one specific grouping to another of the same type, but the command structure itself changes very little. For convenience in editing, common OMEGA command groupings have been put into individual files. Any of these files can be inserted into any source code file as an intact unit simply by using the "READ" option available in the editor.

The standard groupings can be considered as templates because they provide a predetermined structure to an individual EVENT. However, they are *flexible* templates since they can be tailored to individual situations by adding or deleting commands as necessary. The commands provided in the templates already have their most frequently used parameters filled in; parameters that change frequently are left blank to be completed at edit time.

Theoretically, any number of templates can be stored in the the system's mass memory, but we usually limit the number stored at any one time for the sake of simplicity. If the author sees that the same command structure will be required frequently, he can create a new template that can be saved, used, modified, and deleted without ever leaving the lesson file being edited.

Extended Template: As the name implies, an extended template is a special case of the template. Extended templates include more than one EVENT, and can include several hundred. They usually involve rather sophisticated logic, and so are normally prepared and saved by authors with extensive programming capabilities. These templates are used for instructional formats whose logic always remains constant, but whose details may change, e.g., interactive games used for drill and practice. Completing an extended template requires only a small amount of editing relative to the amount of lesson code generated.

Module: A module is distinguished from an extended template in that it is a totally intact unit. It requires no modification by the author. Neither the logic nor the details change in a module. It is always used for the same purpose, and it always presents the same instruction. Modules are normally used for hands on, interactive instruction, where the same set of actions is performed a number of times in different lessons. This feature represents a tremendous savings of time and labor, since the code for any module can be included in any lesson once it has been produced.

EVALUATING OMEGA

Simplicity

OMEGA is a rather simple system, since both the language and the editor are easy to learn and use. Though new authors totally unfamiliar with programming cannot begin productive work as fast as they could on a traditional "user friendly" system , they are able to do so within a period of about two weeks. Total proficiency can be gained as quickly as with the traditional approach.

Capability

OMEGA has a broad range of capabilities. Source code can be infinitely tailored to the requirements of any particular instructional circumstance.

Adaptability

The OMEGA system was designed from the beginning for the most sophisticated applications. These include not only traditional computer assisted instruction and interactive videodisc, but also interaction with a three dimensional simulator. For this reason, the system can be used to teach any cognitive or hands on objective.

Tolerance for Faults/Diagnostics

As is the case for any system, errors in command syntax (such as entering an alphanumeric character where a number is required) will cause problems with OMEGA. These errors are trapped when source code is compiled, however, and a complete set of diagnostics helps the author identify and locate errors quickly. The extensive capabilities for internal lesson documentation also make lesson maintenance a relatively simple matter.

Internal Helps:

The editor provides selectable levels of help to the author at edit time. A new author can have help displayed constantly, and can gradually reduce the amount available as experience is gained.

Editing Speed

This is a major advantage of OMEGA. The use of adaptable templates, extended templates, and modules allows the author to enter large amounts of source code very quickly and efficiently. Experience with the system has shown that editing is considerably faster than with comparable menu-based systems. The most outstanding feature of this approach is that there is no loss of flexibility in using the templates since they are invoked and modified only as required.

Documentation

OMEGA source code can be thoroughly documented by inserting comments at any point deemed necessary by the author. Internal policy toward documentation is that virtually every command is commented, and that additional comments are inserted as required.

SUMMARY

The OMEGA approach to authoring lessons for computer based instructional systems is a significant improvement over traditional approaches. It is a simple system to learn and use, yet it has all the capabilities required for the most sophisticated applications. It can be used for a wide range of applications, including the teaching of both cognitive and hands on tasks. Editing proceeds quickly and efficiently, and various levels of help are available to any author at any time. The system provides for extensive internal lesson documentation, and extensive diagnostics are available to help the author identify, locate, and correct errors in lesson source code.

ABOUT THE AUTHORS

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EFFECTIVENESS OF MULTI-YEAR AND ADVANCE PROCUREMENT CONTRACTS

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ABSTRACT

Experience gained from the use of these types of contracts under the new regulations has proven that, within some restrictions, they have been beneficial to industry as well as cost effective for the Government. In a typical example, over 30% cost benefit over an annual procurement has been realized in acquisition and early delivery of training devices. The experience demonstrates the utility and adaptability of these regulations that can be attained through aggressive and innovative use. Additional changes and use of the regulations and uniform policies implementing the regulations would provide more frequent use of these procurement types.

INTRODUCTION

Multi-year and advance procurement contracts have been available to acquisition and financial managers for a long time. They have been infrequently used because of a reluctance by industry to accept the risks these contracts imposed. The major obstacles have been:

1) The restriction on recovery of the non-recurring costs in the case of cancellation of the out-year quantities to a limit of $5.0 million.

2) The equal pricing of the unit costs did not permit reasonable recovery of the total expended non-recurring cost until the final year deliveries.

3) The restriction that the cancellation ceiling include only non-recurring cost.

In addition to creating financial risk, these features failed to provide incentives for improvements in capital investments which increase productivity and establish future economical production bases.

Within the past few years the Department of Defense has revised the procurement directives in an attempt to relieve these restrictions. Through the Acquisition Improvement Program, the acquisition and financial managers have been encouraged to implement the initiatives and provide industry with the incentives to invest in capital improvements and to assume more risks than previously dictated by good business sense.

The Defense Department Authorization Act of 1982 went a long way in liberalizing the use of advance procurement. It authorized multi-year contracts for use in advance procurement and extended the scope of advance procurement to include not only material and parts, but also components and economic order quantities of subassemblies and assemblies for out-year end requirements. With these changes, the advance procurement can, to some degree, replace or supplement the use of multi-year contracts, thus providing a means for increasing productivity and lowering cost. As a minimum, these changes provide the acquisition manager with a greater variety of contracting and funding modes to reach a procurement objective.

Although many articles, conferences, and seminars have addressed the multi-year and advance procurement contracts on major programs, few have addressed smaller programs (those not identified by a separate budget line item). This paper provides an example of the effectiveness achieved by the use of these types of contracts on smaller programs, specifically as applied to a simulator procurement.

I will not identify the program or the actual dollar figures in this paper; however, the example provided is representative of one small program. It illustrates the teamwork required of Government and industry and demonstrates an aggressive pursuit of innovation in the use of contracting modes to provide end items in a timely fashion within budget constraints.

STATEMENT OF PROBLEM

A procurement problem was created because the price in the program years exceeded the constraints of the fiscal year's budgets for an annual contract. Table 1 depicts the problem after months of teamwork and risk consideration. It can be seen that the total price still did not fall within the total budget. In addition, the first and second years were major problems. Coincidentally, the shortfall was approximately the amount of the start-up and non-recurring costs.

ANNUAL CONTRACTING

$ x 1M

F.Y.	1	2	3	TOTAL
Item Qty	1	2	2	5
Price	24	26	28	78
Budget (Est.)	16	26	28	77
Problem/ShortFall	(8)	0	0	(8)

Table 1

SUMMARY OF APPROACH

An analysis was conducted to determine whether this program fit within the multi-year and advance procurement contract guidelines. Subcontractors and vendors were contacted and informed of our plan of action, and their cooperation was solicited in reducing costs to fit within the budget profile. The results were encouraging and, with the assumption of some risk, provided the comparative summary shown in Table 2.

	Annual Contracts	Multi-Year And Advance Procurement
Units	5	5
Price	$78M	$70M
Cancellation Ceiling	-	$12M
$ Cost Avoidance Over Annual	-	$ 8M
% Cost Avoidance Over Annual	-	10%
RISK RELATED FACTORS		RISK
Requirement Stability		Low
Funding Stability		Low
Configuration Stability		Low
Cost Avoidance		Low

Table 2

ANALYSIS OF RESULTS

The price reduction was for the most part accomplished through the use of economic order quantities. Although this did not get us to our goal, the use of EPA clauses, negotiations, and the stability of the program as evidenced by the risk factors convinced all parties that additional cost risks could be accepted. The resulting program profile, illustrated in Table 3, closely matched the budget profile.

MULTI-YEAR AND ADVANCE PROCUREMENT

$ x 1M

F.Y.	1	2	3	TOTAL
Item Qty	1	2	2	5
Price	14	28	28	70
Budget	16	26	28	70
Problem/Short Fall	2	(2)	0	0

Table 3

The cost avoidance shown in Table 2 is a pure subtraction of MYP price from the annual price. This figure does not represent the total potential cost avoidance benefits realized by the Government. The use of the MYP, and in particular the advance procurement, permits the simulators to be fielded much sooner than possible utilizing the annual contracting approach. This early fielding results in cost avoidances attributable to the significantly lower costs of aviator training utilizing simulators as compared to an "aircraft only" approach. The amount of these cost avoidances is substantially dependent upon how much the delivery schedule can be improved. In this case history, the overall schedule improvement provided 72 months of earlier simulator delivery with respect to annual procurement for all 5 devices (see Figure 1).

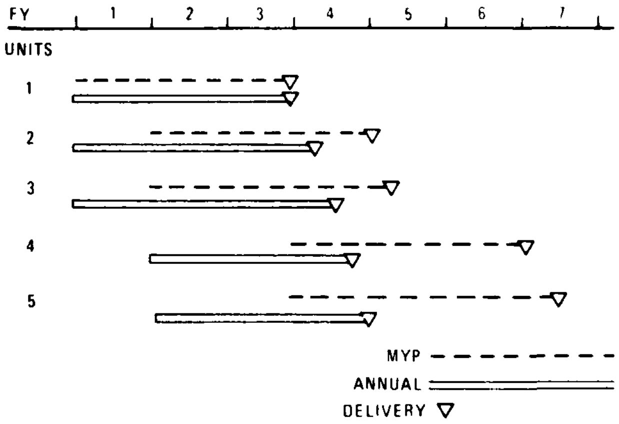

Figure 1 SCHEDULE ADVANTAGE OF MULTI-YEAR PROCUREMENT

The average cost of aircraft operation in 1982 dollars for the example simulator above is $2,300/hr. This figure compares to an average simulator operating cost of $290/hr. Simulator operation may be conservatively estimated at 2,000 hours per year.

On the basis of these figures, an additional cost avoidance of approximately $24.0 million was achieved. This cost avoidance amount is 30.7% of the annual contract program price! Results of this magnitude merit serious consideration and are well worth the earlier starts provided by the mixture of contracting modes.

CONCLUSION

To the contractor and subcontractors/vendors, this method of contracting provided a more competitive procurement, enabled consideration for additional capital equipment, smoothing of the workload, and better application of learning. The result of the use of these contracting modes was a program that fit within the budget profile and produced a significant cost avoidance.

This program illustrates the possible benefits that can be attained by innovative use of contracting modes. The teamwork involved in solving a funding problem heightens the awareness of all parties with regard to the amount of work and the acceptable risks associated with providing military end items at a more affordable cost. More can probably be done in the use of the DAR 1-322 changes, such as including some recurring costs in the cancellation ceiling. There are advantages to the Government and industry in the use of these types of contracting modes. As has been touched on, while MYP has come a long way, there are still problems and constraints on its use which preclude both Government and industry from receiving full benefits. Under current rules, MYP cannot be used for commercial items. The budgeting, appropriation, and funding process is complex and unwieldy. The need to provide up-front funding of recurring cost items purchased for future year requirements pits a MYP against other urgent and needed defense procurements. The practice of requiring two full cost proposals, for comparison purposes, one for a MYP and one for an annual buy, adds significantly to contractor expenses, is completely at odds with indirect cost cutting efforts and is unnecessary once a program is judged to fit an MYP profile.

In general, only procurement costs are looked at to judge MYP savings, but as shown above, earlier availability, at least in the case of simulation equipment, has a dramatic impact on these savings and should be considered.

President Reagan commissioned a Private Sector Survey on Cost Control on June 30, 1982 (The Grace Commisson). Thirty-six task forces were appointed by the Commission, one of which covered Procurement/Contracts/Inventory Management. In its report dated June 13, 1983, this task force made 57 recommendations, five of which specifically dealt with Multi-Year Contracting (Recommendations PROC 4-1 through 4-5). It is the contention of this task force that the use of multi-year contractings would save almost 3.5 billion dollars in just a three-year period and this is only based on estimates of initial procurement expense.

The challenge is there and it is up to all of us to accept the challenge and improve on cost and productivity and to continue to pursue mutually acceptable techniques for providing needed items at an affordable cost.

ABOUT THE AUTHOR

Mr. Belyea is currently Director of Helicopter Simulation Programs at Link Flight Simulation Division of The Singer Company. He is a graduate of the Electronics Institute of Detroit, Michigan, and has nearly 30 years of experience in the simulator industry. Since joining Link in 1954, he has held positions of increasing responsibility in Field Service, Design Engineering, Test Engineering, and Program Management. Mr. Belyea is exceptionally well qualified to write on the subject of multi-year and advance procurement practices, having been involved in them in the past and present.

MANAGING AIRCRAFT SIMULATOR CONCURRENCY

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ABSTRACT

"Concurrency" is the word being used to describe the situation when a simulator or other aircrew training devices are required for delivery at the same time as the new aircraft it will support. If traditional acquisition approaches are applied to concurrent aircraft and simulation programs, it is practically impossible, in many cases, to deliver a fully capable aircrew training device anywhere near the Initial Operational Capability (IOC) of the aircraft. This is especially true when dealing with aircrew trainers for a complex tactical or strategic weapon system. Using the B-1B Simulator System program as an example, this paper discusses the risks and management challenges involved with concurrency and an innovative acquisition strategy designed to ensure the availability of aircrew training devices at or before the aircraft IOC. Included in this strategy are: 1) a new approach to preparation of the request for proposals documentation, 2) a competitive preliminary design effort, 3) methods for dealing with the acquisition of simulator design data, 4) the concept of providing the user a limited (interim) training capability early in the program, 5) management of a configuration baseline which evolves along with the simulator design, and 6) retrofit/update of all delivered devices to the final aircraft configuration.

INTRODUCTION

The simulator acquisition process is changing. The changes have come about for several different reasons. One reason is the fact that simulators have steadily grown in complexity along with the technology that supports them. Another reason is that simulator users have demanded a higher level of simulator performance in order to support training programs with fewer actual aircraft flight hours. However, the biggest changes in simulator acquisition strategies have come about because of aircraft/simulator concurrency. "Concurrency" is the term being used to describe the situation when simulators or other aircrew training devices are required for delivery at the same time as the new aircraft it will support.

Concurrency has brought with it new challenges for the simulator procurer. No longer can one wait until flight test or even the initial aircraft production run is complete before committing to a simulator acquisition program. The complexity of most of the full mission simulators being acquired by the Air Force today has resulted in simulator development programs which are not much shorter than the aircraft development programs themselves. Therefore simulator development programs, in order to produce and deliver trainers at or before the aircraft IOC, must be started very early in the aircraft development process. Starting a simulator program this early, relative to the aircraft program, carries with it some amount of risk. Most, if not all, of the risk is related to the immaturity of design data and the uncertainty regarding the evolving aircraft configuration. In order to control these risks, new acquisition strategies are required. The B-1B Simulator System program is one example of a concurrent simulator development program. This program is applying several new concepts to the Air Force simulator acquisition process; a new approach to constructing the Request for Proposals (RFP), a competitive preliminary design effort, an integral retrofit (update process) and providing the user a limited early training capability are the key elements of the B-1B Simulator System acqusition strategy.

BACKGROUND

The design, performance and test criteria for simulators is based on aircraft data (test reports, drawings, technical orders, technical reports, etc.). This data defines the design, performance, and operating characteristics of the aircraft and aircraft systems. The degree to which the simulator will be representative of the aircraft depends upon how well the data package describes the aircraft. The data's description of the aircraft depends upon the point in the aircraft development program that the data is baselined and how much the data base is updated to represent the aircraft's production baseline.

The aircraft design is dynamic during the development process. There are, typically, three points in the aircraft program where the design becomes baselined. These points are: the Full Scale Development (FSD) Critical Design Review (CDR), the start of flight test, and the production configuration baseline. In most current simulator programs, the data baseline occurs between the start of flight test and production (Figure 1). The aircraft definition of the simulator is usually the start of flight test with some updating to the production configuration. As a result, the Engineering Change Order (ECO) budget for simulator programs is normally structured to update the simulators to the eventual production configuration.

This typical simulator development approach in which the data baseline depends upon the flight test data baseline of the aircraft (with some updating to the production baseline) minimizes cost risk associated with the simulator updates, but delays simulator availability until late in the aircraft program (usually well after initial aircraft availability and the aircraft Initial Operational Capability (IOC)). The more optimal or mature the data package, in terms of

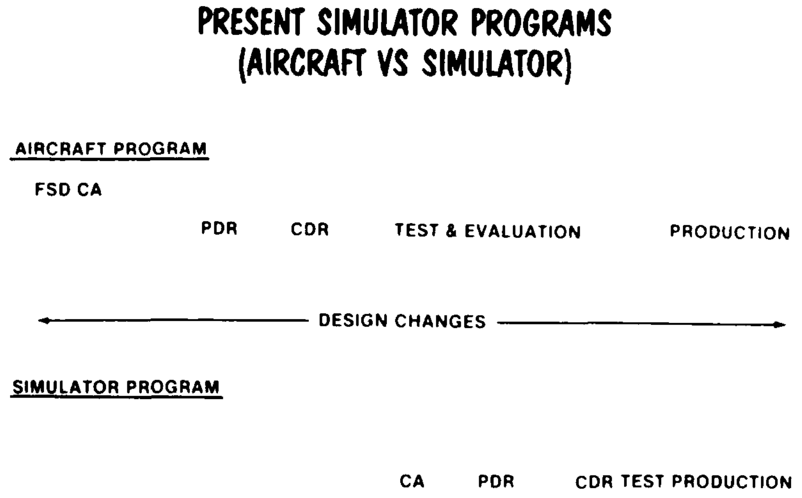

FIGURE 1

completeness and currency, the later it becomes available and the later the simulator will be delivered in relationship to the aircraft. The B-1 simulator program has been structured to gain concurrency with the aircraft program (to the degree possible) but with acceptable risk associated with the changing aircraft baseline and concurrent aircraft and simulator developments. The B-1B simulator program will have the design data freeze dates tentatively established based upon the aircraft software Physical Configuration Audit (PCA) baseline (for Prototype and Lot 1 production simulators) and completion of flight test (for Lot 2 production simulators) (Figure 2). These baseline or freeze dates seem most appropriate when viewed from the perspective of the simulator program not being initiated until almost a full year after the aircraft contract go-ahead and the fact that the B-1B aircraft program itself has concurrent development and production activities.

B-1B SIMULATOR SYSTEM

Program Overview

The B-1B simulator acquisition strategy is based upon a two-phase program intended to provide a training capability as close to the aircraft IOC as possible. Phase 1 is a competitive effort by two contractors to complete the system definition and the FSD effort through the Preliminary Design Review (PDR) milestone. The Phase 1 contractor activities include:

a. Writing detailed performance specifications.

b. Writing vendor and subcontractor work packages.

c. Formulating contractual agreements covering data, parts, and services with each of the B-1B weapon system associate contractors.

d. Conducting trade studies in design and logistics (to identify and reduce cost drivers).

e. Completing the simulator system design to the PDR level.

f. Conducting detailed cost, schedule and technical planning for Phase 11.

Phase 11 of the program will include completion of FSD and production of the simulators. During Phase 11, five Weapon System Trainers (WST), two Mission Trainers (MT) and a Software Support Center (SSC) will be developed, fabricated and delivered to the Strategic Air Command.

The Request for Proposals

Given concurrency and the initiation of the B-1B Simulator System program nearly a full year after the B-1B aircraft go-ahead, it was necessary to find a way to condense the front end of the acquisition process referred to as the RFP generation phase.

The Requests for Proposals (RFPs) for Air Force simulator acquisitions are typically comprised of a Statement of Work (SOW), a Contract Data Requirements List (CDRL), the model contract and one or more Prime Item Development Specifications (PIDS).

Specifications. The PIDS typically define the detailed performance of the simulator or major simulator subsystem being acquired. When the simulation device being acquired is to represent an aircraft or aircraft subsystem (e.g., radar) which has been in the inventory for some time or at least has completed developmental flight test, the writing of the PIDS is relatively straightforward; actual performance of the "to be simulated" system is documented by both design and performance specifications and some flight test data is normally available. In the concurrent aircraft/simulator design situation, actual system performance data is, at best, speculative when the simulator RFP needs to be written. For the B-1B Simulator System program, the solution was to write a system level specification which relates the major system components to be acquired and their basic functional characteristics. The prime item development specifications will be written by the competing contractors during Phase 1 of the program. The competing contractors will develop separate prime item specifications for the WSTs, the MTs, and the Software Support Center. These

B-1 SIMULATOR PROGRAM SCHEDULE
AIRCRAFT/AVIONICS CONTRACTOR INTERFACES

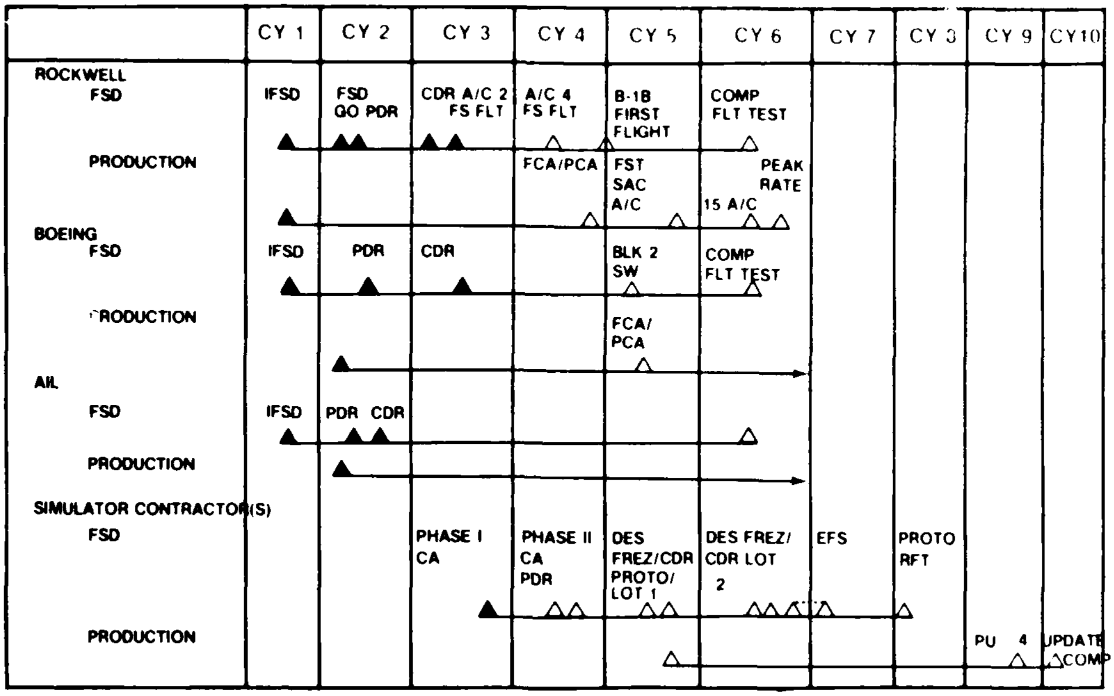

FIGURE 2

specifications will be written based not only on the system specification issued with the Phase 1 RFP, but also on the user's (Strategic Air Command) stated training concepts and concept of employment of the trainers within the overall B-1B training curriculum.

The advantages of having the contractor write the prime item specifications are three-fold: 1) It normally takes the Air Force engineers six to nine months to generate prime item specifications for simulators as complex as the B-1B Simulator System. This presupposes that the essential aircraft or subsystem performance data is available at the time the task is undertaken. Hence, by having the contractors generate the detailed specifications after the contract is underway, several months of front-end lead time can be eliminated. In addition, the Air Force's specification writing team is normally rather small. The contractor can usually devote more manpower to the task and, therefore, complete it in a shorter period of time. 2) Data on the various aircraft subsystems usually becomes available in a sequential fashion as the aircraft development proceeds. Therefore, the simulator contractor can acquire aircraft design specifications and performance data, write the PIDS and create the preliminary design for the simulator on a piecewise basis. The complete prime item specifications, then, can be assembled as the contract (and the preliminary design effort) progresses. 3) When a new weapon system is in its early stages of development, the user is not able to provide details of exactly how the simulator will be used in the training curriculum. Based on experience, the user is capable of describing the general types of devices that will be needed to train the aircrews, but specific training device characteristics cannot be provided until the design of the weapon system and its subsystems reaches some level of maturity. When the weapon system design matures sufficiently to allow the user to identify the various specific aircrew tasks, the user can then make some definitive statements regarding how the training devices will be employed. In the B-1B Simulator System program, the training concept and training task analysis data have been provided to the contractors shortly after Phase 1 contract award. At that time, all of the airframe and major subsystem critical design reviews were completed and the majority of the aircrew training tasks were identifiable.

In the two-phased B-1B Simulator System acquisition program, the Prime Item Development Specifications generated by the contractors during Phase 1 will become the focal point of their proposals for Phase II. During the preliminary design review, which essentially completes Phase I activity, the simulator designs will be evaluated in light of the prime item specifications. These specifications will then become the contractual basis for simulator performance in Phase II.

Statement of Work. Another advantage of using the two-phased approach for a concurrent simulator development program is that the Statement of Work (SOW) can be written in two parts. The first part of the SOW covers only those tasks to be accomplished during Phase 1. Since part of the contractors' Phase 1 effort is to plan the optimal development and production approach for Phase 11, it was necessary to give the Phase 1 offerors some insight into the work envisioned for Phase 11. Accordingly, an annex to the Phase 1 SOW outlines the major tasks planned for Phase 11. While written in SOW language and format, this annex is provided "for information only" and is not contractually binding during Phase 1. In addition to the Phase 11 insights this annex afforded the offerors, it also provides the procuring agency a certain amount of flexibility and additional time to define the detailed Phase 11 work requirements. Given the concurrent evaluation of the weapon system to be simulated, the simulator procuring agency is afforded more time to finalize development and production details. In fact, it allows the Air Force to factor information gained during Phase 1 source selection and the initial part of Phase 1 contractual activity into the Phase 11 SOW. It is believed that the result will be a much more accurate and definitive document. Also, since the contractors are encouraged to refine the government's overall program planning schedules during Phase 1, the realism of the Phase 11 SOW can be enhanced by incorporating the contractor's relevant comments.

The Competitive Design Effort

As outlined earlier, Phase 1 of the B-1B Simulator System program is a competitive design effort by two contractors. The competitive Phase 1 design effort will ensure that the simulators to be delivered during Phase 11 will provide an optimal mix of performance, fidelity and instructional features. Equally as important is the fact that the cost of the development and production of the simulators (Phase 11) will be bid on a competitive basis. Hence, the delivered simulators should provide the best possible training capability at the lowest possible cost.

Design Data Acquisition

The topic of who is or should be responsible for obtaining the simulator design data is always sharply debated. The sides are usually clearly drawn. It appears that the simulator manufacturers think the Air Force should collect and provide the data to the contractor, yet the Air Force many times structures contracts to handle design data or design criteria by having the simulator contractor obtain the data directly from the airframe and avionics contractors. The reasoning on both sides of the debate is sound; the contractor would like to avoid the acquisition cost of the data and the Air Force would like to "stay out of the data business". Also, it is generally held that the organization which collects the data is ultimately responsible for its completeness and accuracy. Hence, one more reason to shun the role of data collector.

In reality, the responsibility for obtaining simulator design criteria best lies with the simulator developer. The developer knows first-hand exactly what amount and types of data are required to fully and accurately design the simulator. Dealing directly with the airframe and avionics contractor, the simulator contractor can usually obtain the required data more quickly without the Air Force "middleman". The contractor can also usually specify to the airframe and avionics contractors his most preferable format for the data.

In the concurrent aircraft/simulator development situation of the B-1B, having the simulator contractor be responsible for obtaining the design criteria is the only practical approach. Speed in obtaining the basic design data and timely updates thereto is of paramount importance. In the concurrent development scenario, the simulator contractor must be capable of obtaining preliminary engineering data concerning potential aircraft Engineering Change Proposals (ECP) before the aircraft ECPs are formally submitted to the Air Force. This will allow the simulator contractor to prepare simulator design change impact studies in parallel with the generation of the aircraft ECP. Hence, when the aircraft ECP is considered for incorporation into the aircraft, the potential impact of the change on the simulator can be thoroughly evaluated by the Air Force at the same time. If the change data were not available to the simulator contractor until after the ECP was formally approved, the associated change to the simulator would most often occur well after the aircraft change.

Configuration Management and Update

The non-concurrent simulator program normally has a single design criteria freeze date and a single CDR. All changes to design criteria occurring after the freeze date, whether representing more mature data or aircraft design changes, result in "cost" ECPs. In a concurrent simulator development program, many changes in design criteria can be expected throughout the program. Processing a cost ECP for every design criteria change would present a configuration nightmare and an unacceptable cost risk. In the B-1B Simulator System program, multiple freeze dates and incremental CDRs are planned. An initial freeze date and CDR will cover the prototype WST and the first production lot (two WSTs, an MT and the Software Support Center). A second freeze date and a delta CDR will cover the second production lot (2 WSTs and an MT). All configuration update activity required to bring the prototype WST and the Lot 1 devices up to the production aircraft design baseline will be part of the initial Phase 11 contract cost. This integral update approach reduces the cost risk associated with attempting to maintain aircraft/simulator concurrency.

An Early Training Capability

Every attempt was made to structure a program to deliver B-1B simulators at or before the aircraft IOC. Due to a late start of the simulator program relative to the aircraft program as well as limited early availability of offensive and defensive avionics data, delivery of the first WST is not possible until approximately one year after the aircraft IOC. In order to provide an earlier training capability, a concept called the "early flight station" was developed. Since a large portion of the B-1B aircraft development is in the avionics area, the design data for the WST avionics stations (offensive systems officer and defensive systems officer positions) is the pacing item in the WST design, development and delivery schedules. However, due to extensive flight testing of the existing B-1A aircraft, relatively mature B-1B flight performance (aerodynamics and propulsion) data will be available early in the simulator program and the development and availability of a simulator flight station (pilot and copilot positions) is possible at or slightly before the aircraft IOC. The early flight station is expected to be essentially the same as the flight station portion of the WSTs. The early flight station will be made available for SAC aircrew training until the prototype WST becomes ready for training. At that time, the early flight station will be deactivated and its residual hardware assets applied to one of the production WSTs.

CONCLUSIONS

Applying traditional acquisition strategies to the problem of aircraft/simulator concurrency results in excessive cost and performance risks. New acquisition strategies such as those being applied to the B-1B Simulator System program are required in order to control risks and assure the timely delivery of training devices to the user.

ABOUT THE AUTHORS

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MANAGING A LOW QUANTITY, HIGH TECHNOLOGY TRAINER DEVELOPMENT PROGRAM

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ABSTRACT

To effectively manage a low quantity, high technology trainer development program, the program management team must consider a variety of trade-offs during the development cycle. These trade-offs stem from the fact that a limited production trainer is neither a prototype nor a production line unit. This paper presents the issues and trade-offs which should be addressed by the program management team prior to and during the trainer development program.

INTRODUCTION

We in the trainer development community are generally faced with developing a high technology trainer that has a small number of follow-on production units. This situation presents an interesting management problem. The quantity of follow-on units is not large enough to justify setting up the program and running it like a full scale production job, but the quantity of follow-on units and the requirement to produce production quality end items prohibits the full use of prototyping techniques.

A successful trainer development program must draw upon the processes and management techniques of both production and prototyping. This paper presents the issues and trade-offs which should be addressed by the program management team prior to and during the trainer development program. The main items addressed are:

1. Configuration Control - Maintaining configuration control throughout the development and production cycles.

2. Design - Designing to cost with the balance of non-recurring and recurring costs.

3. Production - Deciding on what to build yourself, what to subcontract and when to place procurement orders.

4. Testing - Deciding on the level (board, sub-system, system) of testing to be performed and whether engineering or manufacturing should perform this testing.

5. Support - Developing a good long term support program within the commercial grade trainer budget and schedule.

CONFIGURATION CONTROL

Configuration control is important regardless of the number of trainer units that are to be built. Even when a prototype device is being developed, it is important to document the configuration of the device for several reasons. First and foremost is the fact that it is necessary to maintain enough configuration control in order to know what you have done. Second, it is important to maintain enough configuration control in order to keep the prototype device working during its life cycle.

For a full scale production program, configuration control is even more important because it has a significant impact on the life cycle cost. A good configuration control program will keep all the production units as identical as possible and maintain an accurate file of all differences. The benefit of this program will be that common spares, training, updates, etc. can be used to support all the trainers, rather than having a separate life cycle support program for each trainer. Special attention to the configuration control program must be paid to the first development unit. During the development phase where the designers are implementing many changes to make their conceptual design a reality, it is easy for the actual configuration of the development unit to be lost. This has proven to be very costly to many contractors when they release to build the follow-on production units and end up making another batch of prototype units which must be made to work.

A special problem that we in the training community have with our limited production, design to cost, trainers is the use of commercially supplied equipment, i.e. computers, power supplies, etc. It is difficult to maintain configuration control during a long production schedule in which only a few trainers are produced every year. Commercial equipment configuration changes at a very rapid rate. What a contractor can purchase for one production lot may not be the same for the next production lot. This topic and how to deal with it is a paper all in itself. Let it suffice to say that we do the best we can.

Configuration control objectives differ depending on whether a contractor is building a prototype, full production or limited production trainer. Table 1 presents a comparison of these objectives.

TABLE 1. CONFIGURATION CONTROL OBJECTIVES

PROTOTYPE OBJECTIVES	FULL PRODUCTION OBJECTIVES	LIMITED PRODUCTION OBJECTIVES
1. Maintain enough control in order to know what you have done.	1. Maintain enough control in order to have all devices as identical as possible.	1. Same as "full production" objectives with the exception of commercially supplied equipment (i.e. computers, etc.) which we do the best we can.
2. Maintain enough control in order to keep the device working with an engineering staff.	2. Maintain enough control so that one set of documentation, spares and training courses will suffice to support all devices during their life cycle.	

DESIGN

The major objective for the design of a limited production trainer is designing to cost with a balance of non-recurring and recurring costs. This objective is a compromise between the design objectives of a prototype device and a full production device. Prototype or one of a kind devices generally make use of what is readily available in order to demonstrate a capability quickly and reduce non-recurring costs. The tendency is to buy hardware or software rather than develop new software. On a full production program, it is generally more advantageous to design new hardware and software in order to reduce the recurring costs. The key to a successful limited production trainer program is to identify the components of the trainer which may satisfy the requirements of a full production program or a prototype program. Once these components are identified, the appropriate design objectives can be applied to provide an overall lower program cost. Table 2 provides a comparison of the design objectives of a prototype, full production and limited production trainer.

TABLE 2. DESIGN OBJECTIVE

PROTOTYPE OBJECTIVES	FULL PRODUCTION OBJECTIVES	LIMITED PRODUCTION OBJECTIVES
1. Minimize non-recurring costs.	1. Minimize recurring costs.	1. Balance of non-recurring and recurring costs.
2. Use available hardware.	2. Develop less expensive hardware.	2. Attempt to use common hardware and software across many different types of trainers.
3. Emphasize purchased hardware/software vs. software development.	3. Emphasize software development vs. purchased hardware/software.	

PRODUCTION

During the production phase of a limited production trainer, the program team must decide on what to build in-house, what to subcontract, and when to place procurement orders. In addition, the level of the documentation to be developed must be determined.

The production of a prototype or a one of a kind device usually involves taking many production short cuts. The documentation effort is usually limited to engineering drawings and, in some cases, engineering sketches. Manufacturing drawings are seldom required due to the fact that most items are built in the engineering laboratories or model shops. Formal make or buy decisions are not common place. The contractor will generally build what he can and buy what he cannot build himself. Procured items are placed on order when they are identified and some are ordered in anticipation of need.

A full production program will have different objectives than a prototype program. Complete engineering and manufacturing drawings are required for a production program. A pilot production effort is also required in order to get the "bugs" out of the manufacturing processes. Make or buy decisions receive formal attention and are made at the detail level. Finally, extensive use of material requirements planning (MRP) is used to efficiently manage inventories and cash flow.

A limited production trainer program uses the techniques from both prototype and full production programs. Complete engineering and limited manufacturing drawings are developed. Manufacturing drawings are only developed for the relatively large quantity items. (On a limited production trainer program, one must look to the subsystem and detail level in order to identify what is applicable to full production techniques.) Pilot production programs are not conducted at the trainer system or subsystem level. Make or buy decisions are performed for major cost items only, and material requirements planning is also only used on major cost items. A summary of the production objectives for prototype, full production and limited production programs is shown in Table 3.

TABLE 3. PRODUCTION OBJECTIVES

PROTOTYPE OBJECTIVES	FULL PRODUCTION OBJECTIVES	LIMITED PRODUCTION OBJECTIVES
1. Limited engineering drawings.	1. Complete engineering and manufacturing drawings.	1. Complete engineering and limited manufacturing drawings.
2. Build what you can in the engineering laboratory or model shop.	2. Pilot production to get the "bugs" out of the process.	2. No pilot production program.
3. Few formal make or buy decisions.	3. Make or buy decisions.	3. Make or buy decisions for major cost items only.
4. Buy most items when they are identified and some in anticipation of need.	4. Extensive use of material requirements planning.	4. Use of material requirements planning on major cost items.

TESTING

The testing process of a trainer system can perform a needed functional quality and functional configuration checking. In addition, testing early in the production process can identify problems at the level where they can be efficiently remedied.

On a prototype program, almost all the testing is performed by the design engineer or programmer. The designer will normally start his testing at a higher level than on a production program because he is more intimate with the design and can quickly identify and solve problems. Formal test specifications are not required because the designer knows what the performance of the device should be.

Full production testing programs are entirely different from prototype testing programs. Formal test specifications and manufacturing test tools are required because people other than the original designer are going to perform the testing. Testing is also performed at the bareboard, board, subsystem and system level in order to identify and remedy problems at a level where people other than the original designer can perform this function. Finally, the testing at the lower levels can provide an electrical configuration audit to verify that all components of the device are functionally identical, including follow-on spares at a later date.

The testing objectives for a limited production trainer closely follow the full production program testing objectives. Testing is a means of verifying a conceptual design and/or verifying that the assembly process was performed correctly and that all the components are functional. During the development phase of a limited production program in which the first training device is produced, the testing process is more important for verifying a conceptual design. Once the first unit is working, the testing process becomes more of a check on the assembly process, including verifying that all the components are functional. If test specifications and manufacturing test tools are developed during the development phase, an electrical configuration audit can be performed on the final configuration of the development unit prior to starting the follow-on production units. An electrical configuration audit is the re-testing of the known working system boards and subsystems on the manufacturing test tools. This is done to verify that the test specifications and test tools are to the latest functional configuration prior to being used for a limited production run (see Figure 1.) A comparison of the testing objectives of prototype, full production and limited production programs are presented in Table 4.

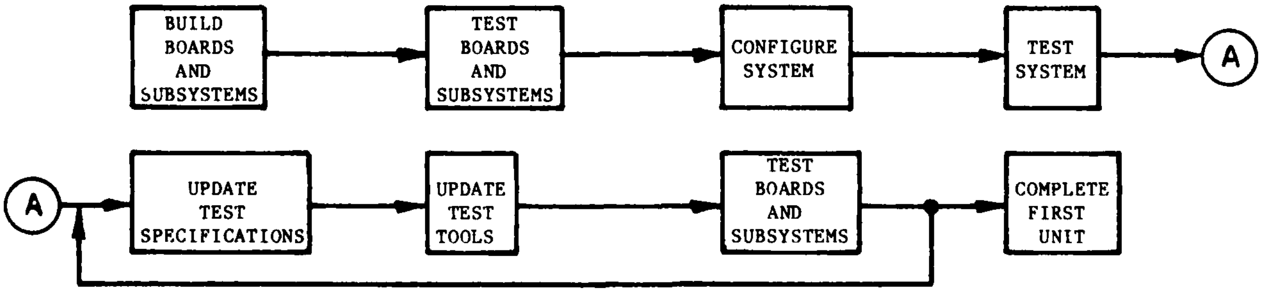

FIGURE 1. ELECTRICAL CONFIGURATION AUDIT ON FIRST UNIT

TABLE 4. TESTING OBJECTIVES

PROTOTYPE OBJECTIVES	FULL PRODUCTION OBJECTIVES	LIMITED PRODUCTION OBJECTIVES
1. No test specifications.	1. Test specifications are required.	1. Test specifications are required for most items.
2. No manufacturing test tools.	2. Manufacturing test tools are required.	2. Manufacturing test tools are required for most items.
3. Design engineer or programmer will test out all levels of system.	3. Manufacturing test performs testing functions.	3. Manufacturing test performs the lower levels of testing. Engineering performs the system testing.
4. Most testing will be performed at system level.	4. Testing is performed at bareboard, board, sub-system and system levels.	4. Board and sub-system testing can be used as an electrical configuration audit.
	5. Board and sub-system testing can be used as an electrical configuration audit.	

SUPPORT OBJECTIVES

Developing a good long term support program within the commercial grade trainer budget and schedule is no simple matter. In order to meet the budget requirements of a program, extensive use of commercial equipment, especially computers which go out of production in three to five years, is required. This requires an agreement with the Original Equipment Manufacturer (O.E.M.) that they will support their equipment for the life cycle of the trainer. Documentation, training and maintenance for limited production trainers usually follow the requirements for a full production program with the exception of commercial equipment. Commercial grade documentation and contractor maintenance are acceptable alternatives to full military documentation and support for trainers because trainers are usually located with the United States and within easy access to most support requirements. Table 5 shows a support objective comparison of prototype, full production and limited production programs.

TABLE 5. SUPPORT OBJECTIVES

PROTOTYPE OBJECTIVES	FULL PRODUCTION OBJECTIVES	LIMITED PRODUCTION OBJECTIVES
1. Minimum documentation.	1. Full military documentation.	1. Commercial or full military documentation.
2. Use developer for maintenance function.	2. User to perform maintenance function.	2. User or contractor to perform maintenance function.
	3. Training courses.	3. Training courses.
	4. Full spares put into military supply system.	4. Depot at developer's factory and vendor services for O.E.M. equipment.

CONCLUSION

Management of a low quantity, high technology trainer development program requires that the program management team be familiar with prototype and full production techniques. It is only by the careful selection and application of these techniques that a limited production program can be fully successful.

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MARINE CORPS GROUND SIMULATOR TRAINING NEEDS IN THE 1985-1995 TIME FRAME

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ABSTRACT

This study was initiated to develop a document to be used for the planning and programming of simulation acquisition in support of Marine Corps training.

Generic training task requirements in the ground combat (C), combat support (CS) and combat service support (CSS) fields which can be enhanced through the use of simulation were identified. Tradeoff analyses were performed to develop prioritized lists of the tasks for which simulators should be developed and of recommended generic-type simulation devices.

The extent of the need for simulation was assessed by determining which of the training task requirements would be improved by the use of simulation, taking into account the technology state-of-the-art (SOA). Measures of quality of training used included: performance, time to train, training cost, personnel support, technological risk, integratability with other training, and special assets requirements.

This paper describes the methodology applied and the results obtained. Special emphasis is put on the criteria utilized and the planned future use of the results.

The purpose of the study reported here was to develop a prioritized list of ground combat, combat support and combat service support tasks for which simulation would economically improve training. This prioritization is critical because the number of tasks whose effective training can be supported through simulation cannot be fully supported by available resources. The study resulted in a baseline of tasks and simulation technology for Marine Corps efforts to define and incorporate simulator training during the 1985-1995 timeframe.

To fulfill such a purpose, the objectives of the study were to:

- Determine those training requirements in the ground combat (C), combat support (CS), and combat service support (CSS) fields which could be enhanced through the use of simulation, and
- Develop a prioritized listing of recommended generic-type simulation devices, based on current and emerging technology, which would be capable of satisfying those requirements.

For purposes of meeting the objectives of the study, a simulator was defined as a device which provides a functional replication of hardware or operational system in an environmental context and which requires interaction between it and the trainee(s).

APPROACH

The approach started with a review of extant system front-end analyses results, followed by the determination of tasks to be trained, the development of training objectives, the determination and evaluation of training approach alternatives, the tentative selection of device needs, and a cost/benefit analysis. This study contains the basic elements of this approach at a depth of detail consistent with the broad scope of interest entailed when addressing all the tasks which are encompassed by the C, CS and CSS fields.

In deciding on the depth of detail that would be consistent with the study's purpose, consideration was given to the stated need to provide a structure within which programmers could identify where funds for simulation would provide the best returns. In this context two parameters were of most concern. The first dealt with the ability to identify validated training requirements. Performance of detailed task analyses for each military occupational specialty (MOS) in each of the three fields of interest would have resulted in a study of much longer duration and thus be inconsistent with the immediate need. The solution was to utilize existing documentation, supplemented by discussions with Marine Corps' personnel responsible for training. When combined with the methodology developed as part of the study, this would provide action officers with a valuable tool that would mature as further analyses were conducted.

The second concern dealt with the level of definition of simulation concepts. It was felt that creation of a catalog of devices would be time consuming, would produce an unmanageable document and wouldn't be what was really needed. Taking the above concerns and others into consideration, the approach to the study was defined by bounding the scope with the following guidelines:

- Definition of training requirements was based on a comprehensive review of the combat, combat support, and combat service support fields (including maintenance requirements).
- Training requirements were defined in generic terms as opposed to specific hardware. Accordingly, concepts were defined in terms of generic types of simulation, as opposed to specific training devices.
- Training requirements described tasks to be performed.
- A detailed task analysis of each MOS to determine task training requirements was beyond the scope of the study. The requirements data base was compiled from existing documentation and discussions with Marine Corps personnel responsible for training.
- Life cycle cost (LCC) evaluation was conducted based on order-of-magnitude information, since generic equipment is involved. Major factors affecting LCC were identified.
- The study took into account increasing costs of fuel and ammunition, decreasing availability of ranges and training areas, environmental impacts on training, and expected levels of learning for future user populations.

The general approach used in performing the study consisted of four parts: (1) development of the study framework, (2) assessment of the need for simulation, (3) prioritization of the simulation alternatives, and (4) development of a baseline for future efforts to define and incorporate simulator training in the Marine Corps.

STUDY FRAMEWORK

The framework within which the study was to be performed was established by the conduct of a comprehensive review of Marine Corps needs in order to define current and projected training requirements and to develop a training requirements data base. Also, the state-of-the-art (SOA) in simulation technology was determined and a technology data base was developed.

The output of the review of training requirements was a generalized task list. This list was basic to the study in that it represented the scope of training requirements for which the applications of simulation were to be evaluated. Both equipment-oriented and mission-oriented tasks were considered.

The product of the technology survey task consisted of a summary of the technology base that will be available in the 1985-1995 period which could meet the requirements of Marine Corps training. The survey encompassed simulation technology currently available, in the development stage and proposed. Emerging technology was identified.

TASK 1 - Review of General Training Requirements

The success of the data collection and review effort, it was recognized, would be dependent on acquiring, early, a clear understanding of the Marine Corps[1] training philosophy, training system, and internal responsibilities at all echelons involved in training. From this training framework, the data sources (documentary, institutional, and field unit) could be identified and the data collection effort structured. Accordingly, following an initial coordination meeting with the Contract Officer's Technical Representative (COTR) and selected Marine Corps representatives, the Falcon/XMCO team visited the Marine Corps Development and Education Command (MCDEC) and Headquarters, U.S. Marine Corps (HQMC). The primary thrust of these meetings was to explore the training situation within the Marine Corps. The visits proved to be especially valuable in view of the on-going initiatives to restructure the training system. The information gained, through briefings and documentation, covered the in-house studies which resulted in the changes which are occurring, the organizational and responsibility realignments made, the procedural changes being instituted which affect the methods used in training development, and a perspective of the direction and objectives of the training system.

With regard to this task, the information of overall interest (both current and projected) included: the composition of the C, CS, and CSS fields; their associated weapons/hardware systems; task analysis or other data reflecting general training requirements; critical tasks; training deficiencies and problem areas; and the impact of NBC defense requirements on training. The sources used to acquire this information included: HQMC, MCDEC, and field visits to agencies and units at Camp Lejeune, North Carolina; Camp Pendleton, California; Marine Corps Air Ground Combat Center, Twenty-Nine Palms; the Landing Force Training Center, Norfolk; and the Naval Training Equipment Center (NTEC), Orlando, Florida.

Task training requirements were grouped into two general categories: those associated with the operation and maintenance of equipment (i.e., tanks, trucks, radios, etc.), and those which derive from the mission requirements of a C, CS, or CSS unit (i.e., operational functions). The former are primarily individual tasks whereas the latter are primarily collective tasks.

The source data for the MOS/equipment-oriented tasks consisted of the Marine Corps' Military Occupational Specialties Manual (MCO P12000.7D with Changes 1, 2, and 4), a machine printout of tasks extracted from U.S. Army Soldier's Manuals and extracts of Computerized Occupational Data (CODAP) for selected MOSs, obtained from Headquarters, Marine Corps. The Marine Corps' Combat Readiness Evaluation System (MCCRES) volumes were the main source for mission-oriented task data. Also, personnel directly responsible and involved in training provided inputs in developing the mission-oriented task list.

The overall task list contained 198 mission-oriented tasks and 1564 MOS/equipment-oriented tasks contained in 123 MOSs for 22 occupational fields (OF). The combat, combat support, and combat service support occupational fields of interest are listed in Table 1. Table 2 presents the first ten (out of 24) tasks of the 0311 Rifleman MOS as an example of the type of MOS-oriented tasks contained in the list. These tasks will be utilized later in the paper to demonstrate the methodology that was followed in defining tasks whose training would be enhanced by simulation. Table 3 presents a sample set of mission-oriented tasks for the amphibious raid mission.

Table 1

Combat, Combat Support and Combat Service Support Occupational Fields

OF 01 - Personnel and Administration
OF 02 - Intelligence
OF 03 - Infantry
OF 04 - Logistics
OF 08 - Field Artillery
OF 11 - Utilities
OF 13 - Engineer, Construction, Equipment, and Shore Party
OF 14 - Drafting, Surveying, and Mapping
OF 18 - Tank and Amphibian Tractor
OF 21 - Ordnance
OF 23 - Ammunition and Explosives Ordnance Disposal
OF 25 - Operational Communications
OF 26 - Signals Intelligence/Ground Electronic Warfare
OF 28 - Data/Communications Maintenance
OF 30 - Supply Administration and Operations
OF 31 - Transportation
OF 33 - Food Service
OF 34 - Auditing, Finance, and Accounting
OF 35 - Motor Transport
OF 40 - Data Systems
OF 57 - Nuclear, Biological, Chemical
OF 58 - Military Police
OF 99 - Officers

Table 2

Sample MOS-Oriented Tasks

<u>OF 03 Infantry</u>

<u>MOS 0311 Rifleman</u>

1. Cleans and maintains service rifle, grenade launcher, and intracompany communications equipment.
2. Engages targets with the service rifle, grenade launcher, light antitank weapons, hand grenades, and command detonated anti-personnel mines.
3. Controls/performs fire team, squad and platoon movements.
4. Camouflages and conceals self and individual equipment.
5. Navigates using a map and compass.
6. Applies first-aid.
7. Transmits and receives messages using intracompany communications equipment.
8. Reports information on the enemy, using "salute" report.
9. Handles prisoners of war.
10. Executes embarkation and debarkation from helicopters and amphibious ships.

Table 3

Sample Mission-Oriented Tasks

15. Amphibious Raid
    a. Conduct Planning
    b. Performs Preparations
    c. Develop a Concept of Operations
    d. Task Organize
    e. Develop a Scheme of Maneuver
    f. Conduct Ship to Shore Movement
    g. Move to Raid Objective
    h. Assault the Raid Objective
    i. Retire to the Extraction Point
    j. Conduct Reembarkation
    k. Conduct Debriefing

TASK 2 - Technology Survey

The technology data base survey encompassed simulation technology currently in existence, in the development stage and proposed. Emerging simulator technology that may be responsive to specific mission area/weapon system general training requirements was identified.

As a result of discussions with personnel cognizant of the USMC training programs/facilities at both the support and operating force levels, a USMC training device/simulation source data base of current and desired items was developed. Information on developmental items together with emerging technology within the simulation field was added through contact with NTEC personnel/USMC Liaison Officers and PM TRADE representatives.

Since training devices/simulators are not service peculiar, a survey of U.S. Army training devices/simulators for those items of equipment, systems and functions common to both USMC and Army training requirements was made. Much of this information was supplied by the U.S. Army Training Support Center at Ft. Eustis, Virginia. Information on foreign and other existing technology was also gathered through a survey of published material and discussions with a number of industry representatives.

Although many of the technological areas are unique, most are used in support of one another to achieve a desired simulation effect. Therefore, they can be consolidated into the following disciplines of simulation technology that are at the forefront of the indicated emerging trends:

- Data Processing
  - Reduced Componentry/Environmental Requirements
  - High Speed Micro-Micro Electronics
  - Transferability/Flexibility of Software/Courseware Modules
- Visual Simulation
  - Hi-Resolution/Hi-Density Realtime Video/Digital Discs/Computer Generated Imagery (CGI)
- Engagement Simulation
  - Eye-Safe Lasers/Area Lasers
  - Imbedded Sensors
  - "Safe" Ammunition
  - Holographic/Liquid Crystal "Terrain" Displays
  - Robotics
  - Games
- Environment Simulation
  - Thermal Signature Generators
  - Gas Producers
- Equipment Simulation
  - Operable Mockups
  - Part-Task Trainers
- Surrogate Learning
  - Automatic User-oriented Software/Courseware with Voice Synthesis
  - Video Games
  - Embedded Training Systems
  - Measures of Effectiveness

Development of this technology could have any of the following effects on training effectiveness:

- Real-time/better resolution
- Increased functionality (more power for the same size or same power for a smaller size)/shipboard applicability
- Increased direct fire ranging (safe focusing) allowing force-on-force with combined arms operations
- More detailed visuals with greater fidelity
- Reduced componentry/storage requirements for visual resolution/fidelity
- 3-D visual displays
- Low cost simple displays (speed not critical)
- Allowance for "missing person" response in war games
- Realistic gunnery training target/identification using night vision devices
- Reduced range/environmental constraints
- Improved weapon environmental effects (obscuration)
- Added incentive to train with low cost
- Situation scoring response (realism)
- Allows indirect fire applications in force-on-force operations
- Increased realism to built-up area operations

Using the results of the technology survey, generic technology categories were established and are presented in Table 4. Candidates for simulation training of the tasks previously identified were chosen from this list.

Table 4

Generic Technology Categories

CODE	GENERIC TECHNOLOGY	EXAMPLE
EMM	Electromechanical/microprocessor	Panel board trainer
VDM	Video-disc/microprocessor	Video-disc COFT - firing trainer
CGI	Computer-generated imagery/computer	M1 tank gunnery trainer
TG	Tactical game (manual or computerized)	TACWAR, TWSEAS - war gaming trainers
OM	Operable mockup	Satellite communications repair trainer
SED	Signal emitter/detector	Radiac training device
IDM	Interactive display/microprocessor	Noncommunication intercept/EW trainer
IR	Infrared transmitter/detector	REDEYE trainer
L	Laser transmitter/detector	MILES - laser gun fire trainer
TB	Terrain board	Amphibious assault trainer
BS	Ballistic simulation	Pneumatic mortar trainer
MO	Mechanical-optical/microprocessor	Observed fire trainer
NAT	No applicable technology identified	

NEEDS ASSESSMENT

Once the framework for the study was established, the extent of the need for simulation was assessed by determining which of the training requirements would be improved by use of simulation, taking into account the technology SOA. For those requirements, an evaluative data base was developed.

The output of the first task in the needs assessment phase of the study (quality-of-training assessment) was a requirements/concepts matrix which was developed by: (1) matching simulation alternatives with training requirements, (2) applying the quality-of-training criteria and (3) identifying those requirements that would be improved by the use of simulators. The measures of quality-of-training employed four criteria:

- *Higher performance*
- Decreased time to train
- Decreased training cost
- Decreased personnel support costs

In the second task during this phase of the study (evaluation of requirements/concepts) further evaluation of the requirements/concepts matrix was performed to establish a data base for the prioritization of the concepts. Criteria that were applied included:

- Cost and risk factors
- Integratability with other training
- Special assets requirements

TASK 3 - Quality of Training Assessment

An overview of the methodology used in the performance of this task is shown in Figure 1. Essentially, the methodology represents a series of "gates" through which each task must pass successfully in order to remain a candidate for the Marine Corps program to enhance training *through the use of simulation.*

The first gate in the process applied five (5) criteria to the generalized task list in order to identify those tasks that need to be or could be improved and thus should be given priority and emphasis in the simulation analysis. Those tasks which met one or more of the criterion were retained for further analysis. The criteria retained tasks which: (1) presently require facilities/resources limited in availability or expendable, (2) were identified as experiencing training problems or inability to train, (3) have demonstrated weaknesses or shortfalls in unit performance, (4) are mission-critical, and/or (5) are mobilization/reserve forces oriented.

Application of criteria (1) and (2) was based on survey/interview data gathered during visits to Marine Corps facilities. Criterion (3) was based on Marine Corps Combat Readiness Evaluation Systems (MCCRESS) reports and the tactical exercise evaluations at 29 Palms. Criteria (4) and (5) were based on analysis of task requirements by the study team. Out of the original 1762 tasks, 394 were deleted through this step.

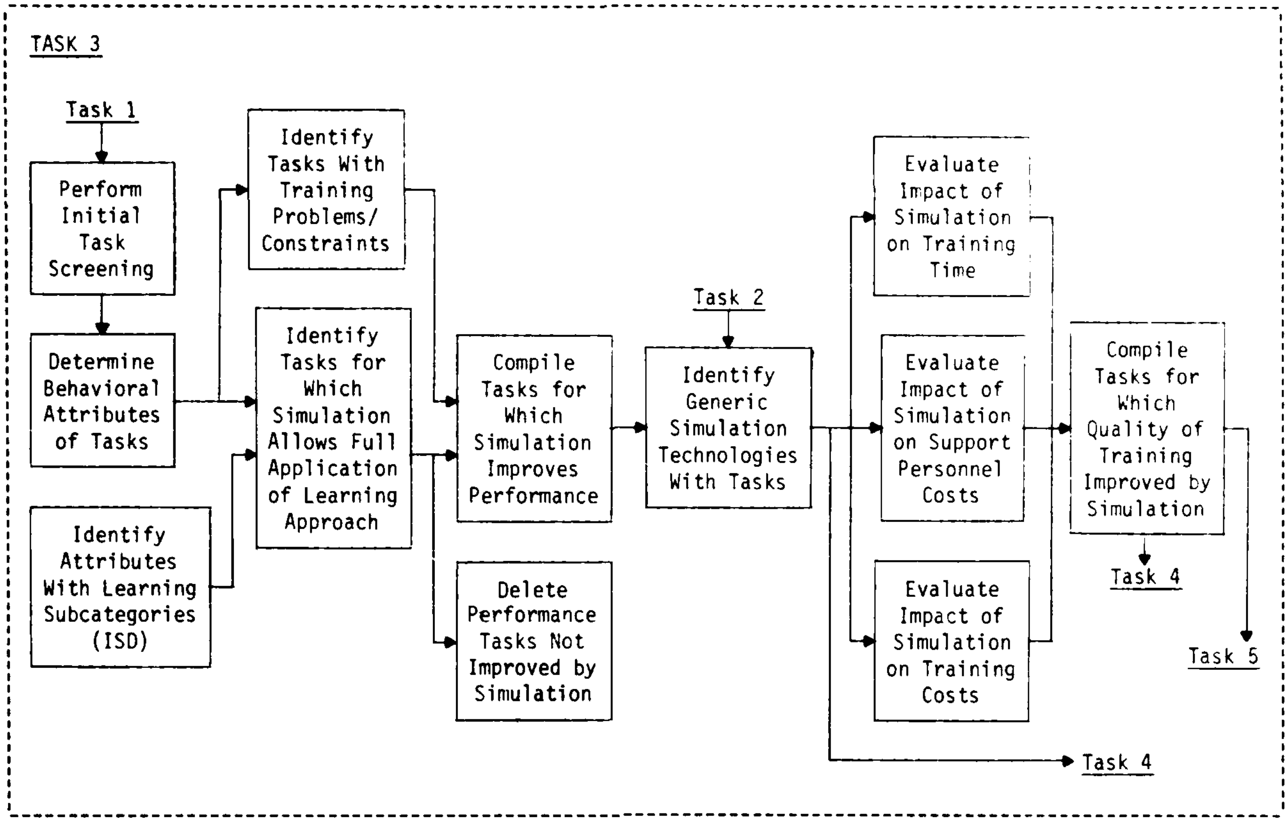

Figure 1

Task 3 Methodology Overview

The second gate applied the first of four criteria used to identify those training tasks that would be improved by the use of simulation. This "higher performance" criterion was applied using a methodology which did not require identifying the specific simulation technologies applicable to each task. The methodology employs, as a guide, the procedures defined in the Instructional Systems Development (ISD)[2] model for selecting the training delivery approach which best permits the application of learning guidelines established by the model. In this process, training tasks are addressed in terms of their behavioral attributes (mental, physical and attitudinal) essential for task performance. The ISD model associates the behavioral attributes for a task with a learning subcategory and provides learning guidelines to be used in developing effective training. For each learning subcategory, ISD also identifies the alternative delivery approaches (e.g., simulator, operational equipment, computer aided instruction, etc.) which will/will not permit complete application of the learning guidelines, considering task stimulus criteria.

In applying the above methodology, the following procedure was employed. If the task met one or more of the first three of the five criteria applied at the first gate, it was concluded that simulation would result in higher performance and the task was retained for further evaluation. If the task had been retained after having met only the fourth or fifth criterion, the methodology was applied. The results of a behavioral-attributes analysis, along with application of the guidance which relates the associated learning subcategories with alternative delivery approaches (e.g., simulator, operational equipment, etc.), were used to predict higher performance. Those tasks for which the prediction of higher performance through the use of simulation was negative were deleted from further analysis; 452 tasks were deleted, leaving 916 out of the original 1762 tasks.

For each training task identified in which the use of simulation would improve the quality of training, a determination was made as to what type of generic technology categories (as defined in Task 2 and listed in Table 4) would be applicable to produce an envisioned benefit in training quality. An applicable simulation technology could not be identified for 174 tasks. These were removed from further consideration, but a list of these tasks was included in the report for periodic review.

The three remaining quality-of-training criteria addressed whether the use of simulation will, for the same level of proficiency, decrease: (1) training time, (2) training costs, and (3) support personnel costs. They were applied to the training task/technology matrix. Those tasks for which at least one of the three criteria would be improved by simulation were retained (84 out of 742 were dropped from further consideration at this gate).

Performance of the quality of training evaluation resulted in the assessment that 658 (505 MOS/equipment-oriented and 153 mission-oriented) tasks out of the original list of 1762 would be enhanced by the use of simulation. The data developed for this part of the effort, including the simulation alternatives identified with each task, provide an audit trail for arriving at the list of tasks.

Table 5 summarizes the results of the quality-of-training assessment for the ten tasks of the Rifleman MOS (Table 2) being used to demonstrate the methodology. From the results we see that one (No. 6) did not make it through the initial screening (five criteria). Two more (Nos. 1 and 9) did not pass through the higher performance (P) criterion. When the generic technology categories were matched with the remaining tasks, no concepts were found which could satisfy the requirements for two of them (Nos. 5 and 8). These two tasks were removed from further consideration in the study, but were compiled into a separate list for future review. Of the remaining five

Table 5

Quality-of-Training Summary Data

OF: 03 - INFANTRY	INITIAL SCREENING					QUALITY OF TRAINING SCREENING				SIMULATION TECHNOLOGY ALTERNATIVES**		
0311 RIFLEMAN	FR	PB	PF	MC	MB	P	T	TC	SC			
1. Cleans and Maintains Service Rifle, Grenade Launcher, and Intra-Company Communications Equipment	N	N	N	Y	Y	N	-	-	-	-		
2. Engages Targets With the Service Rifle, Grenade Launcher, Light Antitank Weapons, Hand Grenades, and Command Detonated Antipersonnel Mines	Y	Y	N	Y	Y	Y	Y	Y	YNN*	VDM	IR/L	L
3. Controls/Performs Fire Team, Squad and Platoon Movements	Y	N	Y	Y	Y	Y	Y	YN	YN	TB	L	
4. Camouflages and Conceals Self and Individual Equipment	Y	Y	N	Y	Y	Y	N	N	N	L		
5. Navigates Using a Map and Compass	Y	Y	N	Y	Y	Y	-	-	-	NAT		
6. Applies First-Aid	N	N	N	N	N	-	-	-	-	-		
7. Transmits and Receives Messages Using Intra-Company Communications Equipment	N	Y	Y	Y	Y	Y	N	Y	N	OM		
8. Reports Information on the Enemy, Using "Salute" Report	Y	N	N	Y	Y	Y	-	-	-	NAT		
9. Handles Prisoners of War	N	N	N	Y	N	N	-	-	-	-		
10. Executes Embarkation and Debarkation From Helicopters and Amphibious Ships	Y	Y	N	Y	Y	Y	Y	Y	Y	OM		

KEY: FR - Facilities or Resources Required to Conduct Training
PB - Training Problem Identified During Field Data Collection Effort
PF - Performance Deficiency Identified During Field Data Collection Effort
MC - Mission Critical Task
MB - Mobilization Training Task (IRR)
P - Simulation Will Result in Improved Task Performance
T - Simulation Will Decrease Training Time Required
TC - Simulation Will Decrease Training Cost
SC - Simulation Will Decrease Support Personnel Requirement Cost
N - No
Y - Yes

* Where Multiple Entries Occur, they Refer to the Technologies Alternatives in the Order Listed.
** See Table 4 for Definitions.

tasks, one more (No. 4) did not pass any of the remaining quality-of-training criteria and was dropped from further consideration. Tasks 2, 3, 7, and 10 remained from this sample group.

TASK 4 - Evaluation of Requirements/Concepts

For the surviving combinations of training task/concepts, the basis for the prioritization of alternatives was established by evaluation in terms of: (1) cost/risk involved in using the simulation, (2) integratability of the simulation with other training and (3) special requirements imposed by the use of simulation, such as host structure(s), ancillary equipment, range facilities, etc.

Essentially, the methodology consisted of the assessment of the candidate task/concepts combinations in terms of the evaluative criteria using data available on current devices and estimates for developmental and proposed systems. In this context, the list of current, developing and proposed simulators/training devices was evaluated to determine which ones could be applied to a specific MOS or mission training task requirements. The resulting matrix of task requirements and specific simulation devices was used in developing qualitative estimates for the evaluative criteria.

CONCEPTS PRIORITIZATION (TASK 5)

Using the matrix of training requirements and appropriate training concepts in conjunction with the evaluative criteria and results of the requirements/concepts evaluation, tradeoff analyses were performed to develop a prioritized list of recommended generic-type simulators. This resulted in an integration and analysis of the data developed in the previous tasks into:

- A prioritized list of generalized task training requirements, to include a prioritization of the generic technology approaches applicable to each requirement, and
- An overall prioritized list of generic simulation technology approaches.

Taken collectively, these results provide the Marine Corps with a baseline for training simulation development along either of two paths. One is on the basis of task training requirements which should be given emphasis in utilizing simulation; the other is on the basis of the applicable scope of generic simulation approaches.

The generalized task requirements and associated simulation technologies considered in the prioritization process were those for which it had been determined, in Task 3, that the use of simulation would improve the quality of training. A flow diagram of the steps taken in completing this task is shown in Figure 2.

The first step in the process was to consolidate tasks, where appropriate, on the basis of training commonality. Through this effort, those task requirements which are common across an occupational field(s) (e.g., communicate using radio equipment or conduct planning) and those which, in fact, are elements of a larger task (e.g., establish and operate an intelligence

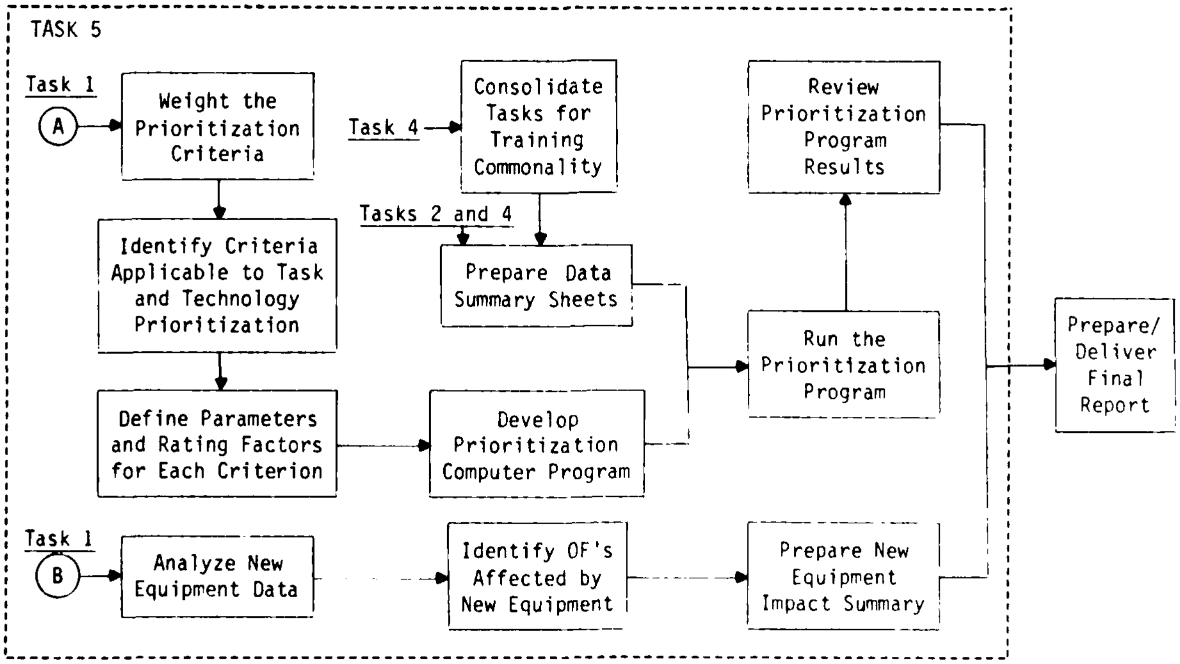

Figure 2

Task 5 Methodology Overview

section or a fire support coordination center) were combined.

The prioritization process required that 10 criteria be applied. A rank-ordered listing of the criteria and the basis used for rating them are summarized in Table 6. From a review of the criteria, it can be seen that they fall into two groups: those which affect the prioritization of generalized task training requirements (items 1, 2, and 3) and those which affect the prioritization of applicable generic technology concepts (items 2,

Table 6

Prioritization Criteria Rating

CRITERION	DESCRIPTION
1. Mission criticality of task trained (emphasis placed on combat-type tasks in anticipated combat environment).	For combat MOSs/units, those tasks essential to accomplishment of the combat mission; for noncombat MOSs/units, those tasks essential to support combat operations on a sustained basis.
2. The existence of training problems or deficiencies (due to cost of ammunition and fuel, range availability or other resource constraints).	Information collected during data collection/research effort. Type of resources required to conduct training further divided into three categories (live fire ranges, resources such as helicopters, field environment).
3. Commonality of type skills trained (type of tasks using a generic type simulator).	Combining of tasks based on training commonality; potential training population density for the task; frequency of generic technology usage identified with individual tasks.
4. Site adaptability (ship- and/or shore-based training).	Simulator concept, based on generic technology alternatives, with regard to size, resources required (e.g., environmental controls), and compatibility with amphibious shipping used by the Marine Corps.
5. Projected or estimated training effectiveness.	Experience with application of the generic technology in training the same or similar tasks; the portion of the task which can be trained (full or part); an assessment of the technology's ability to simulate the essential elements of a task.
6. Suitability for mobilization and reserve training.	For mobilization, the ability to reduce training time (i.e., train large numbers of people quickly) and task importance in mobilization training; for reserve use, the probable availability of facilities/area requirements associated with use of the generic technology.
7. Schedule (i.e., projected technology availability).	Status of current, developmental, or proposed use of the technology to train the same or similar type tasks.
8. Ability to modify the simulator to reflect changes in training requirements or the hardware/system being simulated.	For training changes, the ability of the user to modify/tailor the trainer to training needs; for hardware/system changes, whether modifications would likely involve simple hardware changes or complex hardware and/or software changes.
9. Relative cost of the simulator/facility.	Unit cost of similar existing devices, when possible; an assessment of the task elements and the complexity of simulation requirements; for laser engagement simulation, the cost of a "battalion set"; for games, the size of the group to be trained using manual or computerized versions.
10. Development risk (i.e., maturity of the technology).	Current, developmental, or proposed use of the technology application to the same or similar tasks.

and 4 through 10) with regard to each requirement. The criteria were applied accordingly.

To facilitate the process of integrating and applying the criteria and to ensure consistency, a computer program was developed to perform the prioritization function (Program for the Evaluation of Training Simulation, PETS). The program applies weights to each criterion and to the ratings given within each criterion to each task training requirement and the technology alternatives. It should be noted that the application of the technology is, for the most part, task dependent. Therefore, the values assigned for a particular technology may vary depending on the task requirement. Figure 3 presents the flow diagram for the prioritization methodology.

A modified Delphi technique was used to determine the weight to be given to each criterion and the possible values to be given within each criterion. Seven retired officers (one brigadier general, two colonels, three lieutenant-colonels, and one captain) comprised the Delphi panel. In arriving at the criteria weightings, two constraints were placed on the group: that the first criterion (mission criticality) would be rated 100, and that the weightings assigned to each criterion could not result in a reordering of the criteria.

Using the data previously collected and the established rating values, a data sheet was prepared for each combined task, the data was entered into the computer, and the program was run.

Note the shaded area in the flow diagram. Although not part of the study requirement, the training devices currently in being, under development, or proposed have been identified with the task requirements for which they have potential application. This information will ensure that those responsible for implementing the results of the study are aware of their availability. This will allow them to tailor their simulation decisions accordingly.

BASELINE FOR DEFINITION AND INCORPORATION OF SIMULATORS IN TRAINING

As stated earlier, the objectives of the study were to determine those training requirements in the combat, combat support and combat service support fields which could be enhanced through the use of simulation, and determine a prioritized listing of recommended generic-type simulation devices which would be capable of satisfying those requirements. To this end, a number of data lists, to be found in Reference 1, were developed which provide a basis for future

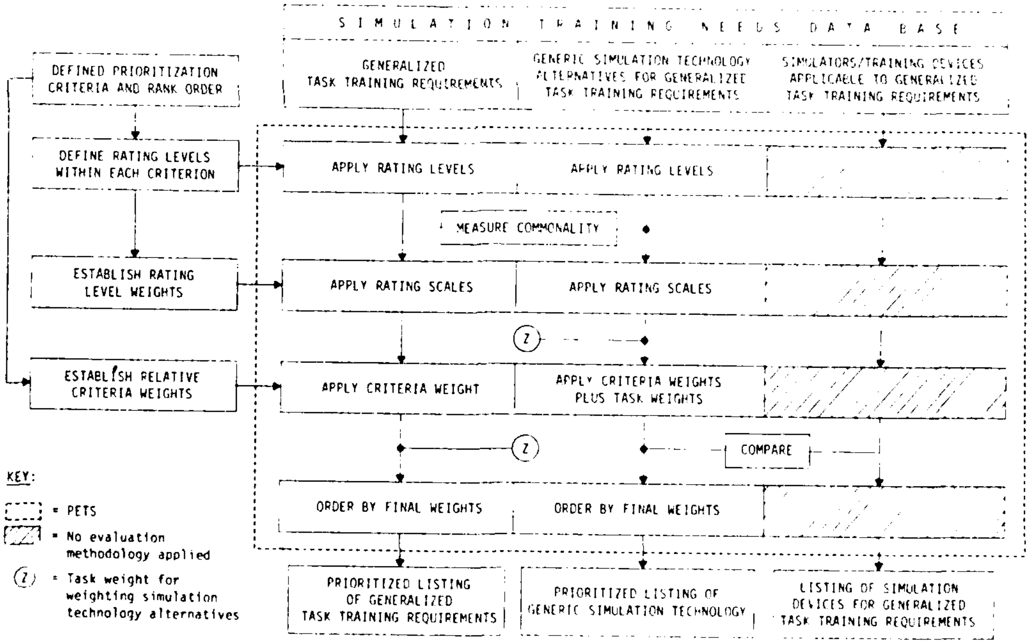

Figure 3

Overall Prioritization Methodology

Marine Corps efforts to define and incorporate simulation concepts in training. Of specific interest are:

- Inventory of simulator/training devices currently available, in development or planned.
- Overall task list and list of tasks assessed to be improvable by simulation.
- Results of needs assessment task and weighting factors applied to criteria used in prioritizing the requirements/concepts matrix.
- Prioritized list of task training requirements by field and corresponding prioritized list of generic simulation concepts for each task.
- Prioritized list of generic simulation concepts and corresponding prioritized list of task training requirements for each concept.

Table 7 presents a summary of the results in terms of the top ranked simulation concepts by mission area. The results are shown for both common- (applicable across all grade levels) and leader- (applicable to NCO/officer grade levels) oriented task training requirements. The fourth column of summary results shows the percentage of the generalized training requirements (the actual number is shown in parentheses) that would be satisfied by the simulation categories shown.

The fifth column shows the percentage of task requirements within the top 40 percentile of prioritized tasks which are satisfied by the simulation categories shown. The last column

Table 7

Prioritized Listing of Generic Simulation Technology

MISSION AREA	GENERIC SIMULATION TECHNOLOGY (SEE TABLE 4)	TECH. RANK	% GENERALIZED TRAINING REQUIREMENTS SATISFIED	% WEIGHTED GENERALIZED TRAINING REQUIREMENTS SATISFIED BY TOP 40 PERCENTILE	OCCUPATIONAL FIELD MOSs TRAINED (SEE TABLE 1)
(1) For Common Generalized Task Training Requirements by Mission Area					
Combat	L VDM OM IR	1 2 3 4	65 (87/131)	48 (29/60)	03, 08, 18
Combat Support	OM TGM/TGC	1 2	76 (64/85)	49 (19/39)	02, 13, 26
Combat Service Support	OM EMM VDM	1 2 3	72 (185, 256)	41 (52/125)	04, 11, 13, 21, 23, 25, 28, 34, 35, 40, 57, 58
(2) For Leader Oriented Generalized Task Training Requirements by Mission Area					
Combat	TGM/TGC TB	1 2	97 (90/103)	45 (19/42)	03, 08, 18, 99
Combat Support	TGM/TGC TB	1 2	100 (33/33)	44 (6/14)	13, 26, 99
Combat Service Support	TGM/TGC TB	1 2	88 (65/75)	52 (16/31)	04, 13, 25, 57, 99

shows the occupational fields within each mission area that can be trained with the simulation categories shown.

From the results shown and the data base developed, the following conclusions can be reached:

Technology

- Majority of simulation needs can be met by existing technology and/or improvements to existing technology.
- Trends are developing toward:
    - --"Families" of devices using common simulation technology (e.g., panel-type trainers).
    - --Games, both manual and computerized, for common- and staff-type task training functions.
    - --Shift in emphasis from few devices located in formal schools to multiple devices for sustainment training.
- NBC simulation technology is currently limited, but development/planned programs are progressing. NBC simulation is difficult to achieve by the nature of the task.

Quality-of-Training

- The quality-of-training of 37% of all tasks in the combat, combat support, and combat service support fields can be improved by the use of simulation.
- No technology concepts could be identified for a number of tasks which, otherwise, would have been improved by simulation. These tasks should be reviewed at regular intervals.

Evaluation of Requirements/Concepts

- No constraints were found for the generic simulation concepts of interest that would preclude or hinder integratability with training.

Prioritization of Requirements/Concepts

- Results obtained are based on the established criteria and the weight/rating level assigned. As these are refined, reevaluation of the prioritization may be required.
- The prioritization of generalized task training requirements ordered by decreasing importance relative to training needs shows that.
    - --the occupational fields of Infantry (03), Field Artillery (08) and Land and Amphibian Tractor (18) predominate in both the common- and leader-oriented combat mission area tasks.
    - --the occupational field of Engineer, Construction, Equipment and Shore Party (13) is predominant in both the common- and leader-oriented combat support and combat service support mission area tasks.
    - --mission-oriented tasks have the most shortfall of all leader-oriented task training.

FUTURE USE

In order to provide an explanation of how this study will be used by the Marine Corps it is necessary to introduce two on-going efforts of considerable impact.

The first of these efforts is in the realm of front end analysis. The Marine Corps has recently begun an effort to develop documented training standards for individuals. That effort is now underway and as portions of it are completed they will be subject to this study's findings.

The second effort is a program titled the Training Resource Initiative Program (TRIP). TRIP was developed to solicit input from trainers, training managers and commanders at all levels. That input is requested in the form of deficiencies or areas in which training is not conducted. Respondents have been directed not to consider resources, environmental or political restraints as they develop their input. They have been further directed to prioritize their submissions in terms of the stated deficiencies' impact on mission accomplishment.

Therefore, the first of these efforts will produce training standards which will be used to refine the evaluation of simulation support needs in training. In addition, the task analyses that are conducted in order to develop training standards will be used to refine what is now a generic effort and give it specificity necessary for the most effective identification of appropriate training medium. There is a third value to the identification of training standards and that is a form of feedback not now available. With a standard for performance we can document the now generically approved technology to a degree not presently possible. With that documentation, reordering of the recommended technologies or further substantiation of their present order will be possible.

The interface with the second effort, TRIP, is expected to provide a more immediate return. With documented evidence of the value and cost benefit various technologies can afford identified training requirement, the results of the study can be applied directly by resource managers in developing plans to respond to identified deficiencies.

In summary, the Marine Corps will use this effort as a dynamic tool of particular value to the resource manager as he seeks to provide the most effective, efficient media for training, and to the trainer as he seeks to identify the most definitive means to measure training program effectiveness.

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CHANGING ARTILLERY TRAINING REQUIREMENTS

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ABSTRACT

The modern battlefield has created a need for new artillery tactics and equipment. The need to fight a sustained battle in a nuclear, biological and/or chemical (NBC) environment while maintaining high mobility is a substantial challenge. New HELP and DSWS Self Propelled Howitzer (SPH) configurations, combined with laser rangefinders and computers promise significant increases in artillery effectiveness and efficiency. Revised tactics and equipment dictate new artillery training requirements. Digital data, on-board navigation and automatic fire control systems are now included in the primary operating modes. The responsibilities and technical capabilities of personnel are changing. The challenge is to provide effective training from individualized classroom instruction through integrated live fire exercises.

INTRODUCTION

In the past, live-fire training was the primary training method for the howitzer crew. The reasonable cost and availability of ammunition, fuel and other resources and the comparative simplicity of the SPH systems provided a strong argument for this method of training. A number of changes have occurred and are occurring which alter this situation. The modern battlefield has become more hostile and complex than in the past. Inflation and the high turnover of skilled personnel have combined to make live fire training far less cost effective than in the past. Also, the Army is developing new equipment and methods. Some advanced prototype systems have already been fielded.

Now that some of the specialized and diverse training requirements for these new systems are understood, the emphasis on alternate training and simulation techniques has grown. As more and more of the advanced artillery systems are fielded, training will be accomplished with a combination of live fire exercises and specialized trainers and simulators. "Closed loop," integrated system training as well as individual unit training will use these special devices. Trainers and simulators will not eliminate live fire training but will make overall training more thorough as well as cost effective.

Following a discussion of changing requirements, new training considerations will be addressed using howitzer crew training as an example.

CHANGING REQUIREMENTS

As evident in the recent Middle East conflicts, battlelines and battlefield positions have become increasingly dynamic. In future conflicts, the artillery mobility will be of the utmost importance. The potential for a warfare environment requiring NBC protection adds yet another layer of complexity to the problem through the possible contamination of both the firing batteries and supply systems. The requirements of the modern battlefield and the resultant new equipment under development are placing different requirements upon artillery personnel.

Modern Battlefield Environment

- o NBC (Nuclear, Bio., Chem. Contamination)
- o HIGH MOBILITY
- o EARLY ROUND ACCURACY

Operations in an NBC environment require protective shelters, sealed vehicles, and/or protective clothing. Routine tasks become difficult and often exhausting when performed in protective clothing. Tasks such as artillery ammunition handling are extremely difficult when significant fire rates are involved. Much of the new equipment under development will incorporate features designed to improve operation in the NBC environment. For example, the Human Engineering Laboratory is developing an experimental Command Post Vehicle which is secure against contaminants, thereby permitting the crew to operate inside the vehicle without individual protective clothing. While equipment of this type enhances the crew's ability to function in an NBC environment, it may introduce additional stress factors associated with confined living spaces. It is not difficult to see that these new operating conditions will influence the type and extent of training.

For generations, mobility has been a steadily increasing parameter of the battlefield environment. High mobility for artillery units creates many new problems in terms of coordination of command and control, setup of secure communication networks, reconnaissance, selection of position, and development of reliable ammunition resupply techniques. Establishing rendezvous points for resupply vehicles is but one element of the mobility problem for which training will be necessary.

Accurate early round fire will become essential if our artillery units are to avoid counterattack resulting from enemy fire-finder radars. Accuracy and quick response are generally conflicting requirements implying a need for special training.

New Equipment

- o MULE/PTL (Laser Ranging and Designation)
- o BCS/TACFIRE (Computerized Fire Control)
- o DMD (Digital Message Device)
- o HELP (Howitzer Extended Life Prog)
- o DSWS (Div. Support Weapon Sys.)
- o SINCGARS (Comm. Equipment)

As a result of the requirements of the modern battlefield, the Army is producing and developing many new equipments and systems. Advances in materials and microelectronics have made possible the Battery Computer System (BCS), on-board navigation and many other tactical equipments. Even more advanced concepts and prototype equipment have been evaluated in the recent HELBAT tests.

The next generation of howitzer systems, now in the development stages, will include many ordnance-related and computer based improvements. The M109 HELP howitzer, which will soon be in production, incorporates on-board navigation and electronic fire control displays for the first time. An integral part of the HELP howitzer system is the Field Artillery Ammunition Supply Vehicle (FAASV) which provides armored ammunition resupply in the forward areas. The DSWS howitzer configuration is expected to extend the improvements of the HELP configuration with the incorporation of automatic loading and a fully automated fire control system with on-board ballistic calculations. New cannon launched guided projectiles, rocket assisted projectiles, and nuclear projectiles are enhancing the artillery's accuracy, range, and destructive power. Jam-resistant communication equipment, such as SINCGARS, will interconnect the various units.

The development of the many new equipments creates a number of opportunities for new tactics and strategies for artillery fire. In general, artillery units will be much more mobile than in the past. Also, the on-board capabilities of the howitzer create a potential for more autonomous operations by individual units. Tying all of the new equipments and tactics together will be C^3 strategies designed to increase the responsiveness of artillery in the total battlefield situation.

The improvements cited above are specifically designed to increase the accuracy and reduce the time required to place artillery fire on specified targets. In many cases, there is also a large emphasis on computer based digital system operations.

NEW TRAINING CONSIDERATIONS

There are a number of aspects of new training considerations:

- o PERSONNEL
  - Capabilities
  - Turnover
- o FACILITIES
  - Ranges
  - Training Devices
- o MATERIEL
  - Equipment
  - Ammunition
  - Fuel
- o TIME
  - Training Intervals
  - Time Limitations
- o INTEGRATION
  - Unit Elements
  - Closed Loop
  - Combined Arms

Effective artillery fire depends upon the coordinated efforts of a number of different elements within an artillery division. Forward observer, Fire Support Team (FIST), fire direction center, ammunition supply system and howitzers must function as a team while maximizing individuals skills. This is analogous to a baseball team where each separate play depends on the indivdual skills of a few, but the overall effectiveness depends upon the entire team. Therefore, artillery training must first address the skills of individual elements and then provide for integrating more and more of the entire team in closed loop and combined arms training.

Training for the next generation howitzer crew element is used as an example to illustrate new considerations necessary for artillery training. Operators and crews for other elements, such as the FIST units and fire direction centers, will require similarly revised individual training. Some of the training considerations which arise when an individual howitzer is integrated into battery closed loop training are addressed later in this paper.

Howitzer Crew Training

- o CREW MEMBERS KNOW MULTIPLE TASKS
- o IMPROVED CLASSROOM AND DRY FIRE TRAINING

- CLOSED LOOP TRAINING
- TRAIN ON OWN EQUIPMENT
- MORE EFFICIENT LIVE FIRE TRAINING
- REFRESHER TRAINING

To establish the framework in which crew training must be considered, we first look at the specific aspects of individual crew operations. It is desirable, if not a requirement, that more than one crew member know how to perform a given task. Hence, individual training must be repeated several times to achieve proficiency in the entire crew. At the same time, the costs of live fire training are significant and many of the ranges have distance restrictions which, in turn, force propellent charge zone restrictions. These factors all point toward increasing the effectiveness of classroom and dry fire training in order to maximize the usefulness of range time and minimize costs. It should be recognized that while improved classroom and dry fire training will reduce requirements for live fire training, it will never eliminate live fire training entirely.

Another factor affecting methodology is the level of proficiency which each crew member must have before closed loop battery training can be conducted efficiently. Here, by closed loop we mean, for example, integrating a forward observer, FIST, battery computer system, and howitzer crew into an operational loop which delivers fire onto a target area and adjusts fire according to forward observer inputs. A recent demonstration at Ft. Sill has shown that training devices developed for individual unit elements can be combined to accomplish closed loop training, including the firing of full caliber training rounds. Efforts are currently underway to establish detailed training goals, including assessment and scoring methods for this type of training.

There are two other factors which must be evaluated in considering training methodology. One has to do with the equipment itself, the other with any ancillary training equipment. First, it is desirable for a crew to train with its own equipment. The peculiarities of operation are then thoroughly understood by the crew and do not present surprises should they need to use the equipment in either evaluation or combat. Second, crew training equipment should be designed so that it can be removed from the host equipment or is embedded in the host. Embedded training equipment, especially in the case of embedded training software, can be made completely transparent to the user. In either case, the training realism is enhanced by using the crew's actual combat equipment.

A number of trade-offs will exist as to how and where training is conducted. The extent of training in the classroom vs. dry fire or live fire training will depend very much on the equipment for which the training is required. For example, classroom training can accomplish much of the training required to teach personnel to use keyboards and displays, as well as some elements of navigation and map reading. However, there will never be a complete substitute for the actual use of the navigation system and maps to navigate a howitzer from one location to another. A special feeling exists when a crew is put into it's howitzer for the first time to navigate to a distant point. Emerging from the vehicle they will be happy or shocked depending upon where they find themselves.

Training methodologies must also take into account training for proficiency through refresher courses at schools and in field exercises. Training for some specific howitzer subsystems illustrate training needs.

Training for Specific Howitzer Subsystems

- FIRE CONTROL & NAVIGATION
  - Automatic Modes
  - Monitoring and Malfunction Identification
  - Recalibration
  - Map Reading
  - Back-up Modes
- RESUPPLY
- TRAINING ROUNDS
- NBC TRAINING
  - Decontamination
  - Individual & Collective Protection

Fire control systems for howitzers are rapidly progressing from fully manual to fully automatic systems. The HELP howitzer configuration represents an intermediate stage of automation. The gun tube orientation in space is determined electronically, but the drive system for gun tube pointing is controlled manually. Except for back-up mode operation, the manual inputs to the onboard fire control system have been replaced by automatic digital data inputs. The DSWS configuration, in concept development, is expected to have a fully automatic fire control system where digital data from a remote location may initiate loading, gun tube pointing and firing of the howitzer.

As fire control functions are transfered from manual to automatic operation, the responsibilities of the crew members also change from one of performing the weapon-laying operation to system monitoring and malfunction identification. New training courses will therefore emphasize these latter monitoring and recognition tasks as opposed to manual dexterity and pointing accuracy tasks. Proper use of BITE and diagnostic routines are among those new subjects to be included in training. Identification of malfunctions and selection of proper back-up modes (with knowledge of the associated amount of system degradation) will be a major part of the new training. Because some kind of manual back-up fire control will exist at least for the foreseeable future, training for manual operation will not disappear from the curriculum. Training for the new automated fire control systems is expected to be accomplished by a combination of embedded and stand-alone trainers. The assessment parameters and scoring for these new tasks must be developed if training is to be truly effective.

On-board navigation will appear first in artillery systems in the HELP howitzer. The on-board navigation systems will be largely transparent to the crew and will automate the majority of the navigation task. Among the new training tasks will be field re-calibration at known survey points, coordination of map readings and visual observations with navigation system data, interpretation of diagnostic routines and selection of firing locations. It should be noted that the more independent or autonomous the operation of the given howitzer, the greater will be the responsibility for navigation. Depending upon the organization of artillery batteries with this new equipment, both fire control and navigation tasks may create higher levels of authority and responsibility for the Chief of Section, as compared to current operating methods. As with the new automated fire control systems, training for the on-board navigation systems will require a combination of embedded training capability and stand-alone driver/section chief trainers.

Both the HELP and DSWS configurations anticipate a one-on-one operation between a resupply vehicle and the self-propelled howitzer. Operating in this one-on-one mode, much of the ammunition handling will be performed inside the resupply vehicle including fuzing, removing propellent from containers and selection of projectile types. While refinements such as the introduction of stick propellents will modify the tasks somewhat, they will not be largely different from the tasks presently performed by the ammunition handlers in the howitzer crew. A significant difference will be that tasks are performed in a limited space inside the resupply vehicle. Quick response to mission changes may be more difficult inside the vehicle where previously prepared rounds may be in the way.

It has always been difficult to incorporate ammunition handling into crew training because the howitzer could not be fired. The flow of ammunition through a howitzer is normally only one way, and training which introduces any return flow of projectiles and propellent is not entirely effective, especially when trying to simulate rapid fire missions. The Field Artillery Shootable Practice Round (FASPR), now under development, showed great promise in the recent demonstration at Ft. Sill. It is full size, yet requires minimum range facilities. Further, the projectile is reuseable and needs very little propellant. Combined with a recoil simulator, also under development, most of the training requirements can now be met. Training for shoot and scoot type missions will require such a shootable practice round to facilitate thorough training.

Other types of training rounds, such as the copperhead and nuclear training rounds, require the crew to unpack, inspect, initialize and load a full size mock-up of the actual round.

Among the new training considerations relevant to operations in an NBC environment are the following: familiarization with individual protective clothing, performance of mission tasks in confined spaces over long periods of time, clean-up of contaminated equipment and material, field maintenance of equipment without incurring contamination, understanding of nuclear blast induced equipment damage and special tactics for the NBC battlefield.

Integration of a Howitzer Crew With Other Battery and Division Level Elements

- BATTERY COMMUNICATION
- RECIPROCAL LAYING
- RESUPPLY RENDEZVOUS
- COORDINATED FIRE
    - Forward Observer
    - Fire Direction Center
    - C^3 Strategies
- CLOSED LOOP OPERATION
- COORDINATED SUPPORT
    - Infantry/Armor
    - Coordinated Battle Plan

Once a howitzer crew is capable of operating effectively as a unit unto itself, it is appropriate to consider the training needed to integrate the howitzer crew element into the total team. This integration will be both horizontal and vertical in nature. Horizontally, in that a given howitzer must be integrated with the other howitzers of its battery. Vertically, the howitzers of a battery must be integrated through the command and control structure with the Fire Direction Center, TACFIRE, forward observers and finally in combined arms configurations. Spread formations and high mobility complicate these integrations. For example, when all the howitzers in a battery are located close together they can all fire on the same bearing to attack a single, small area target. In contrast, when they are wide spread, each howitzer will have its own bearing in order to bring the combined fire onto a single target. Direct, personal communication between all the guns in the battery may not be possible.

Integration of howitzers in new spread battery formations will first require training in communication. If the howitzers are operated in pairs, this will mean establishing communication among the various pairs, which may not be possible with line-of-sight communications or land lines. This will depend upon the extent to which the battery is spread, and whether or not there are NBC environmental constraints. Each howitzer in the battery must be linked to the appropriate Fire Direction Center (FDC), but direct communication among the howitzers is highly desirable. Horizontal integration must also provide for operation when the enemy uses jamming to interrupt radio communications, or damages a howitzer's electronics. In the latter situation, reciprocal laying techniques may be necessary to maintain the firing capability of a damaged howitzer. Horizontal integration also requires interfaces and coordination between the howitzers and ammunition resupply vehicles. Depending on the battlefield, an armored, resupply vehicle, may service one or more howitzers. During shoot and scoot tactics rendezvous points and timing for resupply will become critical considerations in battery operation.

In terms of vertical integration, the howitzer crew is currently tied through the FDC to the Tactical Fire Direction (TACFIRE) System. Recent field tests showed that the time required from an initial call for fire until rounds impact the target can be reduced substantially if the forward observer is in direct communication with the Fire Direction Center. Current studies are evaluating a number of optional paths of command and control to improve the effectiveness of an artillery battalion in its overall operation. One can readily imagine that no single arrangement will be the best for all possible artillery support roles. Consequently, training methods at this level will need to incorporate lessons or simulations which train personnel to use the most appropriate command and control strategy. Coordinate transformation, reference point recognition, accurate message transmission and geographical barriers all have implications in terms of successful integration of the complete artillery unit. There is also a very clear connection between the factors which affect artillery integration and the corresponding training methods and equipment.

As an example of vertically integrated training, consider the closed loop training concept mentioned earlier. Forward observers (FO), gun crews and FDC operators are trained individually with the Training Set Forward Observer (TSFO), Artillery Firing Battery Trainer (AFBT) and BCS training software, respectively. Then, these trainers are interfaced to one another via appropriate communication and data links to form a loop. The FO observes a target on his TSFO and calls for fire support. FDC personnel receive the request and transmit orders to each gun crew. The gun crews lay their operational howitzers, load and fire FASPR ammunition while the AFBT monitors each crew and transmits actual results back to the TSFO. "Would hit" coordinates are used to locate burst signatures in real time on the TSFO screen. The FO can then initiate corrections as necessary and then fire for effect. The closed loop concept can be applied to any of the command and control loops found in artillery operations. Current efforts are directed to field trials of the concept with existing equipment and an evaluation of the effectiveness of this type of training as compared to classroom and live fire exercises.

Combined arms training is also necessary. This is yet a higher level of integrated training in which the artillery unit is cooperating with infantry and armor units to learn complete battlefield strategies. The effectiveness of combined arms training will depend heavily upon the effectiveness of the training which individual units receive prior to joining a combined exercise. At this level there is a need to simulate artillery fire without danger to the troops involved. When the artillery is supporting the infantry it must place cannon fire over and just in front of the advancing troops. Consequently, the safety requirements for training are especially difficult. As a minimum, some form of training round which allows the howitzers to be fired and the apparent fall of shot to be computed is a requirement. (Whether it is possible to create a training round with adequate safety to be fired over the troops, and simulate the burst of artillery fire in the forward area remains a challenge.) Laying errors committed by the SPH crew can be measured and used to compute the expected impact coordinates. This information can be used to increase the realism of combined arms training by providing a real-time indication of actual artillery fire impact which can then be used to provide more realistic casualty/damage assessment. Coordination of the battle maneuver plan, including the use of effective artillery, will be the primary training at this level.

CONCLUSIONS

This examination of new artillery battlefield environments, equipment and specific new tasks for a howitzer crew leads to several conclusions:

1. The new battlefield environments and equipment imply new training needs.
2. Personnel and cost considerations point to a greater emphasis on classroom and dry fire training to make live fire training more efficient.
3. Crew training with the units' equipment has special benefits to readiness.
4. Trainers designed for individual unit elements can be interconnected to provide closed loop integrated training.
5. Thorough individual element (e.g., howitzer crew) training prior to integrated training will yield more efficient training overall.
6. Keyboard and visual display useage, map reading and malfunction analysis will all be key training elements.
7. Backup modes will require continued training in manual operating methods.

Changing artillery training requirements will mean revised training methods supported by correspondingly revised training facilities.

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COST ANALYSIS OF PROPOSED TRAINING DEVICES FOR DSWS OPERATOR COURSE

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ABSTRACT

This paper reports on a preliminary training development study (TDS) of the proposed training devices for the operator course of the Division Support Weapon System. Training device requirements for this system are being determined during the earliest stages of the Life Cycle System Management Model (LCSMM). The study overcame the lack of data needed for training device decision-making by building upon the comparability analysis techniques embodied in previous applications of the HARDMAN methodology to the Division Support Weapon System. The results of this study suggested that device-based courses would be substantially less costly than equipment-based courses.

INTRODUCTION

The basic thrust of the training device effort for the Division Support Weapon System (DSWS) (now called the 155mm Self-Propelled Howitzer Improvement Program) is to identify system training devices early enough so that actual equipment and training devices can be developed and fielded concurrently. Additionally, under the DARCOM/TRADOC Letter of Agreement (LOA), the training for the first Operational Test (OT I) of the weapon system will provide for the inclusion of brassboard training devices. In order to meet this schedule, training device requirements are being determined during the earliest stages of the Life Cycle System Management Model (LCSMM) - earlier than most other major Army systems acquisition programs.

The purpose of this paper is to describe a cost analysis of the training devices proposed for use in the entry level DSWS operator course. The study extended analyses of this course and utilized pertinent data and results obtained during previous applications of the HARDMAN methodology to DSWS.

THE HARDMAN METHODOLOGY

The HARDMAN methodology is designed primarily for front-end analysis; it determines human resource requirements, identifies high resource drivers, and provides the necessary information to conduct human resource/equipment design tradeoffs during the early phases of the Weapon System Acquisition Process (WSAP). As in DSWS, where several competing configurations are proposed, it permits comparisons of the relative human resource demands of each.

The methodology, shown in Figure 1, is a six-step process. It is triggered with the establishment of a consolidated data base (CDB); the next three steps determine the demand of a systems design, generally following the precepts of comparability analysis. Comparability analysis derives systematic estimates of human resource requirements of a proposed weapon system by extrapolating from the known requirements of similar, operational systems and subsystems.

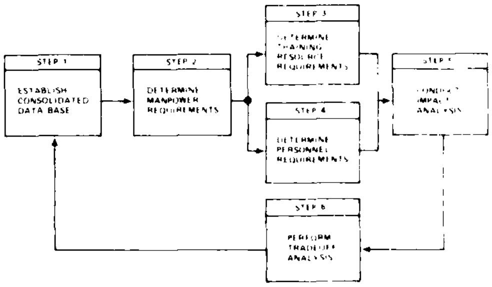

Figure 1. Steps in Methodology

One of the major constructs of this analysis is the development of a Baseline Comparison System (BCS) as described in MIL-STD 1388-1A, Logistic Support Analysis.(1) The BCS is a current operational system, or more likely, a composite of current operational subsystems, which also closely represents the design, operational and support characteristics required for the system proposed for development. In summary, comparability analysis forms a bridge between a new system's mission requirements and its people and cost requirements. Further descriptions and explanations of the methodology can be found in other sources.(2, 3, 4)

THE DSWS PROGRAM

The Division Support Weapon System is envisioned as a replacement for the current M109-series of 155mm self-propelled howitzers and the fire support system associated with it. The concept is intended to be applicable to all levels of conflict in the 1990-2010 time frame.

The program is presently in the concept formulation phase with Army Systems Acquisition Review Council I (ASARC I) scheduled in January 1984. At this stage in the acquisition process, a number of contractor designs and one foreign system are under consideration. The HARDMAN application focused on three proposed design configurations, one each from Norden Systems, Inc., FMC Corp., and Pacific Car and Foundry, Inc. (PACCAR). In addition, a near-term Product Improvement Program (PIP) alternative was evaluated. The Norden design represented a maximum product improvement and was chosen as the equipment configuration for study. This concept represented a theoretical "midpoint" between the existing self-propelled howitzer (SPH) and its ammunition resupply vehicle (ARV) and a totally new design. Without going into any specific design detail, suffice it to say that the battlefield of the future envisioned for this weapon system will require capabilities that are profoundly different from the existing system. The improvements in rates of fire, mobility, communications, fire control, resupply, navigation, and its ability to survive in future battlefield conditions will have dramatic impacts on the tasks performed by the operators and maintainers of the existing weapon system and, hence, on their training programs.

OPERATOR INSTITUTIONAL TRAINING DEVICES

The training device concepts evaluated in the study were those included in the DSWS Training Device Concept Formulation Plan (CFP), which was prepared under the direction of the Program Manager for Training Devices (PM TRADE). This plan represented a major departure from the usual pattern, in that is was prepared during the concept definition phase with, as previously described, several candidate concepts under consideration. As such, the plan was justifiably general in scope to accomodate all of the proposed designs.

Two devices included in the CFP were intended for use in entry level institutional training of the DSWS operator. These devices were the DSWS Institutional Fire Mission Trainer (IFMT) and the DSWS Institutional Driver Trainer (IDT). Because of the "first-cut" nature of the CFP, the operational strategy of how the devices were to be used in the course of instruction was expanded in the study.

Figure 2 shows the Institutional Fire Mission Trainer (IFMT) which consists of five (5) trainee stations and one instructor station. Each trainee station consists of a mock-up of the DSWS SPH crew compartment. The IFMT would be used to train SPH crew members individually or as a team in the tasks required to conduct a direct or indirect fire mission, including performance under degraded conditions.

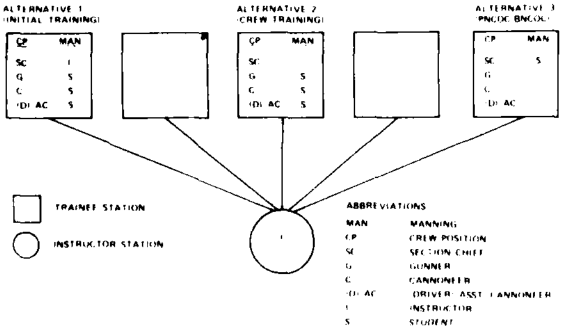

Figure 2. Institutional Fire Mission Trainer

Figure 3 depicts the Institutional Driver Trainer (IDT) which consists of six (6) trainee stations and one instructor station. Three of the trainee stations consist of a mock-up of the DSWS SPH driver compartment, and three would represent the ARV driver compartment. The IDT will be used primarily to train DSWS SPH and ARV crew members in the tasks needed to drive the respective vehicles.

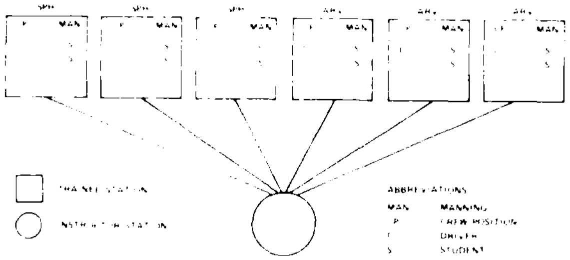

Figure 3. Institutional Driver Trainer

DESCRIPTION OF STUDY AND METHODOLOGY

The major objective of the cost analysis was to determine the training and resource impacts of using equipment versus training devices in the proposed DSWS operator course. The trend in weapon system acquisition is in the direction of acquiring a smaller number of more capable (and more expensive) weapons that will be less available for training. The DSWS Outline Individual and Collective Training Plan (OICTP) assumed that training strategies making extensive use of table of organization and equipment (TOE) hardware would not be cost effective; hence, an increased use of training devices would be required. The study was aimed at testing this assumption. Several resources that are typically affected by the use of equipment versus training devices for operator training were included as follows: (1) fuel, (2) ammunition, (3) maintenance facilities, (4) maintenance and other support personnel, (5) spare parts, (6) live-firing ranges, and (7) driver training areas. Key training issues that affected this study included:
(1) safety restrictions due to the operation of the automatic loader, (2) need for more extensive crew training, (3) space available within the DSWS turret/cab for training, (4) increased capability of some training devices to facilitate fault isolation and scenario programming, and
(5) student to instructor and student to equipment ratios.

An analysis of the resource impacts of these alternative training concepts raised the following two questions: (1) Can training devices be used to lower the number of DSWS self-propelled howitzers (SPH) and ammunition resupply vehicles (ARV) required for training in the 13B Cannon Crewman Course? and (2) Are the training devices proposed for the 13B course in the DSWS Training Device Concept Formulation Plan less costly over a twenty year training life cycle than the operational equipment (assuming fixed training effectiveness between equipment and training devices)?

The study was conducted in five steps:

- Updated Operator Course and Tasks
- Identified Equipment Requirements
- Identified Training Device Requirements
- Conducted Cost Analysis
- Presented Results

Given the objective of the study and DSWS as a developing system, the study constituted a preliminary Training Development Study (TDS) as described in TRADOC Reg 350-4,(5) TRADOC Cir 70-1(6), and the TRADOC Training Effectiveness Analysis (TEA) Handbook.(7)

DSWS OPERATOR TASKS

The DSWS operator tasks were initially analyzed in the HARDMAN application and updated in the study. The first step in analyzing the DSWS task requirements was to identify the sources of system-specific task and course information. The Operator Training Source Index was used for this purpose and provided a system functional context in which to analyze the effects of equipment design differences on the operation of the total system.

Functional focus for the study was provided by using the operational scenario for the SPH and ARV developed in the HARDMAN Functional Requirements Analysis. This scenario is shown in Figure 4 as a mission event profile. Five of the functions are performed in series, i.e., no two of these functions can be performed simultaneously. However, other functions, such as command and control, can be performed in parallel, i.e., simultaneously with any other function.

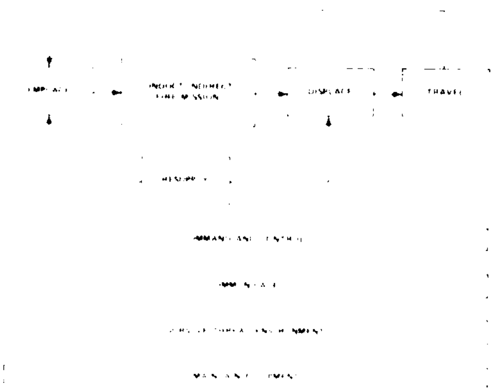

Figure 4. Mission Event Profile

Tasks identified in the first step from the existing M109 system were then analyzed. The analysis of the existing tasks identified (1) which tasks had to be deleted, and (2) which tasks had to be modified to reflect the proposed system design. The resulting system-specific task changes were then documented by code on Existing Task Deletion/Modification Worksheets. Deletion of a task may be indicated for reasons of subsystem elimination, task automation, reduced task frequency, change in maintenance concept, or change in operational concept. Task modifications include minor change in equipment/procedure, skill level change, frequency change, or major change in skills and knowledges.

Inputs to this analysis from the HARDMAN application included equipment descriptions/manuals, engineering functional flow diagrams, engineering design difference indexes, equipment lists, engineering equipment configurations, results from the reliability/maintainability analysis, and the results of the functional and manpower requirements analyses. Of key importance to this analysis is the interdisciplinary interaction of manpower, personnel, training, engineering and systems analysts involved in defining the various system designs and their impacts.

Existing tasks requiring major modification and additional tasks identified on the Operator Training Source Index were analyzed further on the Task Characteristic Worksheet. During this step, further descriptive information about the comparable tasks is added and the characteristics of the new tasks are estimated. Estimates of task difficulty, importance, and frequency (DIF) are possible in this analysis, but due to uncertainties associated with the criteria for selecting tasks for training and training settings, and difficulties involved in getting proper data for the comparable tasks, this analysis was not conducted. The approach used in this iteration was to consider all tasks identified at this point to be selected for training and to assign the training setting and skill level of the comparable task to the new task.

A total of 70 skill level 1 tasks were identified. Of these, 15 tasks were determined to be affected by changes in frequency that may, after further analysis, result in the deletion of these tasks from the course. While identifying tasks that would be trained in the entry level operator course, 21 additional skill level 2 tasks were identified. These tasks represent a substantial amount of advanced technical training that will have to be assigned to a training setting. This future assignment may drastically affect the entry level course.

DSWS OPERATOR COURSE

Once the operator tasks had been identified, an entry level course of instruction was developed that incorporated training for the skill level one tasks. This initial course was equipment-based and incorporated the training philosophy found in the existing M109 operator (13B10-OSUT) program of instruction. Using this course as a basis, a device-based course was then developed. The development of the device-based course involved replacing the SPH with the appropriate training devices, changing equipment to student and instructor to student ratios, removing vehicle-specific resource requirements, and reducing commander's time previously needed to cover such field training contingencies as weather, and range and vehicle availability.

In order to capture the vehicle and instructor resources that are consumed during the conduct of training, Course Resource Worksheets were developed. These worksheets graphically showed the use of the following resources:

(1) Hours of Instruction
(2) Vehicles Used
(3) Types of Instruction
(4) Equipment to Student Ratios
(5) Instructor to Student Ratios
(6) Instructor to Equipment Ratios
(7) Miles Traveled
(8) Ammunition Fired

COST ANALYSIS

Once the resource parameters were established, the equipment and device requirements were determined. Courses were overlapped, where possible, in order to optimize resource requirements. If courses are overlapped, the number of days between the starting time of successive class sessions decrease and, therefore, the number of sessions per year increase.

Research and development (R&D) costs, investment costs, and operations and support (O&S) costs were then determined for the equipment and device-based courses. These costs were obtained from a large number of different sources and methods. The most important sources were the DSWS Baseline Cost Estimates (BCE) for the equipment and the PM TRADE cost estimates for the training devices.

As tradeoffs, two alternatives for the equipment and training device courses were evaluated:

(1) 30% Driver's Training - Only 30% of the trainees are required to complete driver's training.

(2) Double Shift - In addition to 30% driver's training, two shifts of classes are held.

RESULTS

A summary of the significant resource requirements are shown in Table 1.

Over a twenty year life cycle, the equipment-based course was 28% higher in cost than the device-based course. In the 30% driver's training alternative, the equipment-based course cost was 31% more than the device-based course, while in the double shift alternative, the equipment-based course cost was 40% more.

These results, however, are very sensitive and are dependent upon a number of assumptions in the following areas which must be precisely defined in order to make a sound investment decision:

	EQUIPMENT COURSE		[illegible]		
	BASELINE	ALTERNATIVE	BASELINE	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CLASS LENGTH DAYS	[illegible]	[illegible]			
ANNUAL SESSIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CLASS SIZE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPH REQUIRED	[illegible]	[illegible]	[illegible]	4	4
ARV REQUIRED	206	206	[illegible]	[illegible]	[illegible]
[illegible] REQUIRED			[illegible]	[illegible]	[illegible]
[illegible] REQUIRED			[illegible]	[illegible]	[illegible]
20-YEAR LCC $M	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 1. Summary of Resource Requirements

- Student to Equipment/Device Ratios
- Class Lengths
- Staggered Usage of Equipment/Devices
- Sequencing of Course Modules
- Number of Different Equipment Devices Available for Training

The cost accounting categories and procedures employed at the training center level, post level, and TRADOC level do not coincide. Cost factors identified at the course level are undistinguishable by the time they reach TRADOC. This negated the usefulness of the TRADOC course cost analysis program as a tool for modeling the costs of training devices within courses of instruction.

CONCLUSION

The cost analysis conducted in this study took place prior to ASARC/DSARC I. Most existing techniques for conducting Cost and Training Effectiveness Analyses (CTEA) are designed for use later in the Weapon System Acquisition Process when more specific and larger amounts of design data are available. The present analysis overcame this lack of data and met the requirements for conducting preliminary training development studies by building upon the comparability analysis techniques and data base embodied in previous applications of the HARDMAN methodology to the Division Support Weapon System.

The previous HARDMAN training requirements analysis and existing consolidated data base facilitated a timely study. A study which on the average takes 120 days[8] to complete, was completed in approximately 80 days.

The multidisciplinary nature of the HARDMAN approach insured that the overall analysis focused on the mission requirements of the weapon system and that it was cohesive and comprehensive in nature. This multidisciplinary team of hardware and training analysts coupled with data base management techniques and analytic models was able to bridge the gap between the needs of the DARCOM developer and the training development community.

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Low-Altitude Database Development Evaluation and Research (LADDER)

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ABSTRACT

Singer-Link and the Air Force Human Resources Laboratory (AFHRL), Williams Air Force Base, combined efforts to investigate specific visual requirements during low-level, high-speed flight. Visual information requirements were hypothesized, and an experiment was designed to systematically test the effects of various visual cues upon flight performance. The experiment tested the effects of visual scene elements in supporting simulator flight tasks of experienced Air Force fighter pilots. Specific visual factors studied were: 1.) the importance of surface texture, 2.) the importance of 3-D objects and object type, and 3.) the effect of turning and bank angle upon flight performance. Pilot subjects were able to control flight at a mean altitude of 198 feet and at an airspeed of 480 knots. Test results indicate that both 3-D objects and 2-D terrain surface texture aid controlled low-altitude flight.

INTRODUCTION

Effective air defense systems require tactical and strategic aircraft to fly at very low altitudes and high airspeeds. These altitudes and airspeeds enable the aircraft and crew to use terrain masking and the element of surprise to evade hostile threats. The crew of today's tactical and strategic aircraft must balance the probability of destruction from hostile air defense systems with the probability of destruction from the terrain. A segment of a combat mission route that has a high air defense threat level will cause the aircrew to fly closer to the terrain and to accept a greater hazard from impact with the ground.

Experienced pilots have little difficulty flying at low altitudes. Unfortunately, during a combat mission the pilot must also navigate, monitor the aircraft systems, manage the weapon systems, evade the hostile threats, and perform many other critical tasks. The pilot must practice continually until these tasks can be performed almost automatically.

The amount of aircraft low-altitude, high-speed flight training necessary to attain this performance level is difficult to obtain because of cost, safety, noise, and pollution. Simulators equipped with Computer Image Generation (CIG) visual systems could safely provide the needed training at much lower cost with no environmental impact. The potential of this type of training has been demonstrated and the savings in aircraft and pilots can be predicted (3, 4). However, low-altitude, high-speed combat mission training in simulators is not presently being conducted on a large scale.

A key factor inhibiting the large-scale development of Combat Mission Simulator (CMS) facilities is visual scene content. Present terminology is not adequate to describe scenes, and there is little agreement on the relevant characteristics of a scene (10). In addition, data concerning scene content requirements is scarce (9).

The Low-Altitude Database Development Evaluation and Research (LADDER) study was initiated to examine visual scene content for low-altitude, high-speed flight training, and to gather experimental data that relates experienced pilot performance to visual scene content. To obtain this data, a generic cockpit trainer equipped with a CIG visual system was developed, and a visual database was produced to manipulate several scene content variables throughout a high-speed, low-altitude flight route. The performance of experienced military pilots was recorded during simulated flight and subjected to statistical analysis.

APPARATUS

A special-purpose research simulator was designed and assembled at the Air Force Human Resources Laboratory (AFHRL). The simulator consisted of a modified T-38 instrument trainer cockpit, a modified F-111 Computer Image Generation (CIG) visual system, a special-purpose low-altitude database, and the Advanced Simulator for Pilot Training (ASPT) F-16 flight dynamics and performance measurement systems.

Cockpit

The cockpit was part of a surplus T-38 instrument trainer. Since the LADDER study was concerned only with pilot performance relative to visual imagery, only the airspeed and percent-RPM instruments were functional. All other instruments within the cockpit were static during the experiment.

The T-38 control stick was fixed in the center position, and the pilot's control inputs were sensed by strain gauges. This control system is a hybrid of the F-16 force stick controller and the T-38 center displacement stick. The pilot subjects controlled the simulated aircraft by varying the force applied to the nonmoving stick. The T-38 force stick inputs were directed to the ASPT F-16 flight dynamics simulation program. The program processed the control inputs and generated the appropriate visual system eyepoint movement to simulate an F-16 aircraft flight path.

Visual System

The LADDER visual system consisted of a Singer-Link F-111 Digital Image Generator (DIG) and Wide-Angle Collimated (WAC) displays.

The F-111 DIG is capable of generating three channels of day-dusk-night, full-color scenes. A few modifications were made to increase its scene generation capacity. Each channel presented a computed scene via an array of 875 by 1024 picture elements. The imagery was updated at a rate of 30 Hz.

The WAC displays consist of high-resolution color monitors matched to collimating optics. The displays present a near-infinity virtual image of the computed scene to the pilot. The three displays were oriented as they exist in the F-111 simulator: to the left, center, and right of the aircraft centerline. The total field of view is approximately 36 by 120 degrees.

Low-Altitude Database

The visual system database was specifically designed to evaluate the contribution of different levels of scene content. The basic database consisted of a valley corridor 3000 ft wide, which was bordered by 900- to 1100-ft mountains. Within the valley there were 200-ft transverse level and sloping ridges, and 500-ft hills. The corridor permitted pilots to fly a continuous 420-mile route. The corridor construction forced pilots to continually change their altitude and heading to avoid impact with the terrain.

The experimental database content was chosen for its anticipated importance to the low-level flight task. Previous research and experience of Singer-Link (5, 8), and HRL (1, 2, 6, 7) with CIG database features indicated that some features were expected to have a significant effect upon low-level flight performance. Scene content features were agreed upon by Singer-Link and HRL.

Visual database content was studied for flight at approximately 100-ft AGL and a true airspeed of 480 kt. The visual factors selected were:

1.) Importance of texture and texture size. Four texture conditions were studied: no texture, 150-ft, 300-ft, and 450-ft square texture patterns. Texture was placed only on the floor of the flight corridor.

2.) Importance of 3-D objects and their sizes and shapes. Five object conditions were studied: no 3-D objects; houses, warehouses, or trees alone; and a mixture of all three types of objects.

3.) 90-degree shallow-turn versus 180-degree steep-turn corridor sections. Previous research at [illegible] that there are significant differences between pilot performance in straight and turning (over 30-degree bank angle) flight. This experiment was designed with two types of corridor configuration to attempt to determine whether there is a difference in visual requirements between the two flight tasks. The 90-degree shallow-turn segment did not require a bank angle over 30 degrees, while the 180-degree steep-turn segment required at least a 50-degree bank turn for the entire segment.

All combinations of the 2-D and 3-D database features were placed in steep- and shallow-turning modular sections of a corridor (Table 1). The corridor sections were joined to form a continuous 420-mile flight test corridor (Figure 1). The placement of each section with its particular combination of database features was randomly assigned. Several sections of the corridor were repeated to permit checking the reliability of performance data. The corridor mountains were deleted in two sections to assess their contribution to pilot performance.

* * *

STEEP- and SHALLOW-
TURNING FLIGHT

3-D OBJECTS	2-D TEXTURE			
	NONE	150 ft	300 ft	450 ft
NONE	X	X	X	X
HOUSES	X	X	X	X
WARE HOUSES	X	X	X	X
TREES	X	X	X	X
MIXTURE	X	X	X	X

TABLE 1 - TEST CONDITION MATRIX

* * *

* * *

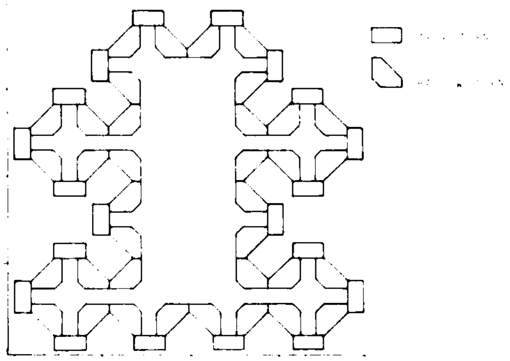

FIGURE 1 - LADDER TEST CORRIDOR

* * *

Subjects

Eighteen experienced fighter pilots with low-level flight experience participated in the experiment. Ten were pilots in F-16 training, and eight were training to be fighter test pilots. The mean age of the pilots was 34.6 years, their mean total flight time was 2,513 hours, and their mean time in fighter/attack aircraft was 1541 hours.

Performance Measurement

The performance sample and measurement capability of the ASPT simulator were used to measure and record flight path parameters. Performance parameters during flight following the practice period were sampled and recorded at a 30-Hz rate. At a prespecified distance in each segment, recording was stopped so that flight performance measurements would not reflect the effect of visual information seen by the pilot when the next corridor segment came into view.

When a crash occurred during flight through a segment, that condition was terminated. The display and cockpit were initialized to the beginning of the subsequent corridor segment, and flight was resumed.

The primary flight parameters recorded at 30 Hz included position, heading, airspeed, altitude, angle of attack, angle of bank, angle of pitch, and crash. Many other parameters were also recorded for possible use in analysis.

Experimental Procedure

Each pilot flew the entire corridor with the starting condition randomly selected. Pilots were instructed to attempt to maintain an altitude of 100 ft above the corridor floor. A few minutes of practice flight were given to each subject, enabling him to accustom himself to the controls and visual system. During the practice flight, altitude and airspeed were announced verbally to the pilot to enable him to visually determine an altitude of 100 ft in reference to the corridor.

Comments made by the pilots and significant flight events were noted by the experimenter throughout the experiment. Each pilot was interviewed following the data collection.

RESULTS

Terrain Crashes

There were a total of 33 crashes with the terrain. The distribution of crashes among the corridor segments are provided in Table 2; 58% of the crashes occurred in steep-turn sections and 42% occurred in shallow-turn sections. Most of the crashes (61%) occurred in sections without 2-D texture on the valley floor. The rest of the crashes were distributed throughout the remaining sections with 2-D texture.

A relatively large number of crashes occurred in two separate corridor sections that had 2-D texture and 3-D objects but no mountain borders.

****

STEEP-TURNING FLIGHT

TEXTURE

3-D OBJECTS	NONE	450	300	150	SUM	%
NONE	5	0	2	1	8	42
HOUSES	3	1	0	0	4	21
WARE-HOUSES	2	0	0	0	2	11
TREES	2	0	1	1	4	21
MIXTURE	1	0	0	0	1	5
SUM	13	1	3	2	19	
PERCENT	68	5	16	11		

SHALLOW-TURNING FLIGHT

TEXTURE

3-D OBJECTS	NONE	450	300	150	SUM	%
NONE	4	0	0	1	5	36
HOUSES	2	0 (3*)	0	0 (7*)	2	14
WARE-HOUSES	0	0	1	0	1	7
TREES	0	0	1	1	2	14
MIXTURE	1	0	2	1	4	29
SUM	7	0	4	3	14	
%	50	0	29	21		

* Section without mountain border

TABLE 2 - NUMBER OF TERRAIN CRASHES

****

Altitude Control

The average altitude the pilots maintained above the valley floor (i.e., altitude above flat earth only) for all conditions was 195 ft. The average altitude maintained for shallow-turn segments was 175 ft, and 221 ft for steep-turn segments. The average altitudes maintained for each condition of 2-D texture and 3-D objects are listed in Table 3.

2-D TEXTURE		3-D OBJECTS	
NONE	199.76	NONE	201.05
150 ft	202.69	HOUSE	201.57
300 ft	193.26	W/HOUSE	197.3
450 ft	197.06	TREE	197.93
		MIXTURE	192.89

STEEP-TURNING FLIGHT = 221.49
SHALLOW-TURNING FLIGHT = 175.12

TABLE 3 - MEAN ALTITUDE (feet)

The dependent variables of RMS error altitude, maximum altitude, and mean altitude above flat earth were included in a multivariate analysis (the SPSS MANOVA Procedure Release 9.0) to include univariate F-tests. An alpha level of 0.10 was chosen for the univariate tests. Scheffe's S-method was used to explicate the F-test results. The main effects of turn and object factors were significant on at least two of the three dependent measures. The F-tests on the interaction effects of Objects X Texture was significant. In addition, all subject effects were significant.

It should be noted at the outset that the data contain a high level of between- and within-subject variability, and that the variance is not always distributed heterogenously. The task structure allowed differences in individual flying technique, particularly in terms of lateral flight path (i.e., the pilot chose his path within the 3,000-ft wide corridor). For example, some pilots worked very hard to avoid going over the portions of elevated terrain, whereas other pilots attempted to fly the shortest distances regardless of terrain. In addition, many pilots attempted different strategies during the course. Much of this type of variability cannot be controlled with group-oriented statistical analyses. The nature of the variability may have concealed some effects that may be revealed in a more structured task. The data collection procedure used in this study did not lend itself to idiographic analysis techniques.

The steep-turn corridor section was clearly associated with poorer altitude control than the shallow-turn segment, presumably because of the difficulty of the greater bank angles required in the steep-turn section.

The main effect of texture was not reliable (p = .069). There were reliable effects of Object type on both RMS error (p = .035) and maximum altitude (p = .05). Post hoc tests (Scheffe's S-method) revealed that for RMS error, the Mixed Object condition was significantly better than either the No Object or Houses Only condition. On the maximum altitude variable, the Mixed Object condition was reliably better than the No Object, Houses, and Warehouse conditions. Additionally, the Trees were associated with significantly lower maximum values than Houses, Warehouses, or No Object. Warehouses were reliably better than No Objects.

There was a significant Objects X Texture interaction. The post hoc tests revealed that the condition of 300-ft square texture and Mixed objects was associated with significantly lower mean altitudes than no texture with Houses or Mixed objects, 150-ft square texture with either No objects or Houses, 300-ft square texture and No objects, or 450-ft square texture with Trees.

In summary, altitude control was significantly worse in the steep-turn sections; the Mixed Object condition was the best, with Trees second-best and No Objects worst. There was no reliable main effect of texture on altitude control, but there was a reliable interaction between objects and texture such that the combination of 300-ft square pattern with Mixed objects was the best condition.

Pilot Reports

The pilots' subjective comments concerning the effectiveness of the various combinations of scene content indicated that most of the test conditions were able to support low-altitude 480-kt flight. The comments contained no consistent preference for either texture size or object type. Many pilots commented that they had no idea of how high or low they were in the No Object or No Texture condition. The pilots' levels of comfort and confidence with the scenes increased as features were added to the corridor segments. The ranking from low to high resulting from additional corridor content was 3-D objects, 2-D surface texture, and both 3-D and 2-D features.

Experienced pilots felt they could follow the terrain at low altitudes in the LADDER database. After completing the experiment, which lasted over an hour, many pilots requested more simulator time to test their flight control capabilities beyond the task of maintaining an altitude of 100 ft. During these unrecorded sessions, pilots consistently flew at altitudes as low as 30 ft without crashing.

DISCUSSION

Considering the results of the terrain crash and altitude data along with pilot opinion, it is clear that a combination of 3-D objects and 2-D terrain surface texture best supports controlled low-altitude flight. The distribution of terrain crashes most clearly reflects the importance of both types of cues. The results of previous research had led us to expect a more systematic relationship of performance with respect to the size of surface texture squares. The present study did not reveal a reliable main effect of surface texture. The ordinal rankings suggest that the 300-ft square condition was the most effective and the No Texture condition the least effective. It is curious that the clear inferiority of the No Texture condition as reported by the pilots and reflected in the distribution of terrain crashes was not reflected in at least the RMS error measure. However, note that the visual database included modeling the effects of sun angle so that shading cues were almost always present to signal variations in terrain, and that the bordering mountains provided strong peripheral cues to changes in altitude. This suggests that even the most impoverished cue conditions contained sufficient information about surface orientation for some altitude control.

Another somewhat surprising finding is the effectiveness of the Mixed Object condition. The results of previous research had indicated the potential for abstract geometric shapes (pyramids and cones) to aid in altitude control and terrain avoidance. However, the Mixed Object condition did not differ significantly from the Tree condition on the Maximum altitude variable, and both were superior to the two building types and to no objects at all. On the RMS error measure only, the Mixed Object condition was found to be reliably superior to the Houses or No Object condition. It is possible that the differences in size and/or shape of the objects when found together in a section provided a significant enhancement of information that the pilot could use.

A much greater difference in performance attributable to objects and texture was desired. Even the results found to be statistically reliable were not large in terms of absolute magnitude (with the exception of the differences between steep and shallow turn). As noted earlier, problems with performance variability due to the task structure and differences in individual technique may have concealed some perceptual relationships. However, it is equally plausible that since the pilots did not have to simultaneously attend to navigation or tactical tasks, the visual environment provided sufficient information in even the No Object or No Texture condition to maintain relatively good low-level performance. The minimum scene content condition of a corridor with mountains, ridges, and hills (and sun shading) may have been nearly adequate for the pilots to maintain low-altitude flight. The relatively large number of crashes in the two segments without the bordering mountains suggests this might be true. The corridor without texture or objects in the valley is still more complex than most training simulator databases available today. The perceptual problem facing the pilots was also somewhat easy, since the valley floor was always flat and level, except for the obvious ridges and hills. This allowed pilots to make the valid perceptual assumptions that reduced their need for additional visual information to resolve ambiguities.

The pilots who participated in the experiment demonstrated that CIG scenes can support low-altitude, high-speed flight control. During the experiment, the pilots maintained an overall average altitude of 198 ft, which is higher than the 100 ft above the valley floor that the pilots were instructed to maintain. This result should be expected, since the 200-ft ridges within the corridor occasionally forced the pilots to fly higher than 100 ft. In addition, most of the pilots controlled their altitude to fly no lower than 100 ft instead of maintaining an average altitude of 100 ft. These two factors would cause the average altitude to be greater than 100 ft.

The LADDER experiment required the pilots to fly the corridor at low altitude for approximately one hour. Since pilots in the past have often expressed a distaste for flying simulators, it was surprising that many pilots requested more time to exercise both man and simulator to the limits of performance. Their requests and the extremely low flight maneuvers they accomplished during these periods attest to the effectivenes of the scene content in most of the LADDER database corridor sections.

The issue of scene content is far from being resolved. However, the LADDER database has demonstrated that it is possible to produce a CIG database that supports low-altitude, high-speed flight. In this sense, the results of the experiment are very encouraging. Clearly, more basic and applied research is needed to better understand the relationship between pilot performance and visual system database content.

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AN APPROACH TO A STANDARDIZED SIMULATOR DATA BASE

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ABSTRACT

The current trend in user requirements for data bases to support visual, sensor, and radar simulation for training is toward real-world data bases that cover large geographic areas. The production of these data bases is an expensive process and typically each new system develops new data base generation software, along with a data base itself, to meet its own specific needs. The result is a large amount of redundant effort, since the same geographic area may be modelled or transformed repeatedly for different applications. This paper will describe an approach to help the Department of Defense (DoD) control the escalating costs of generating and maintaining simulator digital data bases. This approach will be developed through Air Force Project 2851, Common DoD Simulator Digital Data Base/Transformation Program, a tri-service effort which was initiated at the direction of the Joint Logistics Commanders (JLC) DoD Joint Technical Coordinating Group on Simulators and Training Devices (JTCG-STD)

The objective of Project 2851 is to develop a DoD standard simulator data base and common transformation software to support all simulator training devices requiring the use of digital topographic data. The DoD standard simulator data base will provide a common source of digital data that will be specifically compiled to meet training objectives and which will minimize the need to enhance Defense Mapping Agency (DMA) data during the data base generation/transformation process for each individual simulator system. The goal of the common transformation program is to reduce the amount of system unique software for each simulator system. It will promote a greater degree of data base and software compatibility among the many DoD simulator systems. The results of the project should be improved simulator training capability at reduced development, acquisition, and life cycle cost to the Government.

INTRODUCTION

Project 2851 - Common Simulator Digital Data Base/Transformation Program - is a tri-service simulator software applications and data base development program assigned to the Aeronautical Systems Division (ASD) of the Air Force Systems Command (AFSC) by the Department of Defense (DoD) Joint Logistics Commanders. The purpose of the project is to develop a standard simulator topographic data base and to minimize the number of data base transformation programs for various DoD training simulators. The term "simulator data base" in this paper refers to a topographic data base containing a description of terrain relief, and natural and man-made features on the surface described by the terrain. It may contain cartographic, hydrographic and/or topographic features. This paper describes the background and problems associated with the current procedures for generating simulator digital data bases for training simulator applications, the major requirements that will be addressed by Project 2851, the program approach to be taken and related technical support.

BACKGROUND

Topographic data bases are required whenever the simulation involves a visual or sensor capability. Visual systems are required for training tasks such as take-off and landing for aircraft, harbor navigation for ships, and artillery practice for tanks. Sensor simulation systems are required for training tasks involving radar or electro-optical systems such as infrared sensors or low light level television. The data base provides the model from which the simulated image is generated. Data bases used in the past have included model boards built on either a stationary platform or on a moving belt for visual and optical glass plate transparencies for radar. However, the last ten years have seen a shift to computer based simulation systems using a digital topographic data base. Computer image generation (CIG) systems and digital radar landmass simulator (DRLMS) systems now permit realistic visual and radar simulation of real world areas over large geographic expanses.[1]

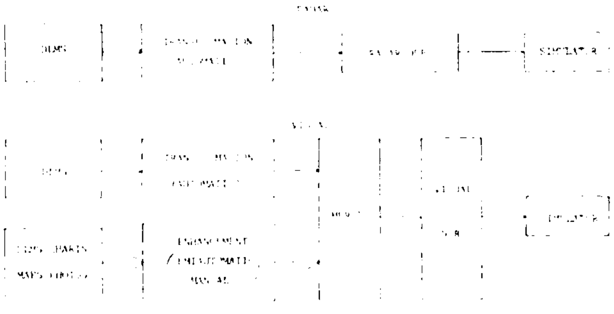
In an attempt to standardize cartographic and geodetic data base support throughout the DoD, the Defense Mapping Agency (DMA) was formed. The first prototype digital data base was developed by DMA in 1974,[2] primarily in support of radar simulation requirements. However, since that time, DMA data base applications have expanded to include tactical and strategic weapon systems. In 1977, a major revision to the DMA data base was accomplished to improve the detail and descriptive content. The 1977 data base, referred to as First Edition Digital Landmass System (DLMS) data[3], includes two files-terrain elevation and feature analysis. The terrain elevation file consists of a 3 arc-second by 3 arc-second matrix of elevation values which represent the elevation of the earth's surface. The feature analysis file is the more complex of the two and contains a description of all features on the earth's surface, both natural (lakes, rivers, forests, fields) and manmade (buildings, roads, towers, bridges). Descriptions within the feature analysis file include geographic location, feature identification (truss bridge, two lane highway, residential building, etc.), surface material category (metal, wood, soil, water, etc.), feature height, percent tree cover, and percent roof cover.

Use of the DMA DLMS is now required as the primary source of information for all DoD simulator data bases. The basic feature content, accuracy, and resolution of the DLMS data have proved adequate for the simulation of low to medium resolution radar systems. The DLMS data has also proved useful for visual and sensor simulation applications provided certain enhancements are added.

DATA BASE PROBLEMS TO BE SOLVED

Data Base Transformation Programs

As described in the previous section, the DLMS data is defined in terms of ground truth physical descriptors and is in a DMA standard format. CIG and DRLMS systems, however, require that the data base be in a format compatible with the particular system architecture. They also require certain descriptors in addition to those included in the DMA data for visual displays (color, texture patterns), and radar displays (feature reflectance codes). In order to convert from the DMA data base to one compatible with the specific simulator system, a conversion program, commonly referred to as a data base transformation program, must be developed. In the case of a visual data base, manual enhancement using additional data sources is usually required to supplement the transformation process. The transformation program development (and enhancement process for visual systems) is performed by the simulator contractor for each new simulator system. Figure 1 illustrates the transformation process for both radar and visual systems.



Unique transformation programs are required for each simulator system for several reasons. Due to the complexity of visual system design, only a limited number of edges or polygons can be used to represent a given scene (typically on the order of 4000 to 8000 edges). Therefore, visual system data base content must be restricted to those features necessary to meet the specific training task. For example, a visual data base used for low level navigation might require emphasis on roads, streams, vegetation patterns, and predominant terrain. On the other hand, a data base used for air-to-ground weapon delivery might require more emphasis on specific cultural objects or surface vehicles. The transformation program must therefore be designed to select those features of importance and use them to produce a visual data base compatible with the visual system architecture. Similarly, the radar data base transformation program must perform the same function to produce a data base compatible with the radar system architecture. Since each system has its own format and content requirements and therefore requires its own transformation capability, a transformed radar data base is not compatible with a visual system, nor can a radar system use a transformed visual data base. In fact, a visual system can seldom use a data base from a different visual system due to differing system capacities or capabilities and unique system or contractor designs. The same problem exists in the radar and sensor areas.

There are several consequences to the current practice of transformation program acquisition. The first is the large recurring cost of software development for every new simulator program involving a visual, radar, or sensor requirement. Visual transformation programs, typically 75,000 to 150,000 lines of code, are a significant part of the software development process. Second, the growth in the number of transformation programs places a burden on simulator computer facilities. Third, maintaining this proliferation of the transformation programs and keeping them current with the DMA data base is and will continue to be a problem. Finally, the effort to create data bases becomes highly redundant. This is especially true for a simulator with visual, radar, and sensor simulation systems, each with data base requirements covering the same geographic area, but in a different format.

As a result of the initial concept development of the data base transformation process and the development of several operational simulators, it has become evident that some additional control of this process is needed. It is highly desireable to reduce the redundant and complex, time consuming transformations and enhancements.

Simulator Data Base Adequacy

As previously explained, DLMS data has been adequate for some recent simulator acquisition programs, while it has required major enhancement for others. However, current DLMS data does not appear suitable for future simulator programs involving high resolution radar and sensors, or visual systems requiring large geographic areas. There are three reasons for this.

First, the resolution and content of the DLMS data base is not adequate for the simulation of new sensor systems such as synthetic aperture radar (SAR), which is capable of ten foot range and azimuth resolution. The current DMA DLMS data is not a one-for-one representation of features on the earth's surface. To be included in the DLMS data base, a feature must meet a set of criteria with regard to type, material, minimum size, and minimum adjacent feature separation, typically on the order of 100 to 500 feet; thus certain features may not be portrayed at all or may be included as part of a homogeneous grouping of similar objects. For example, a large feature may represent a combination of individual structures e.g., residential plat, factory complex, commercial buildings. In some cases, a small town may consist of only one, two or three features. On the other hand typical high resolution sensor systems are capable of displaying a one for one representation of individual buildings and landscape features. Therefore, a significant amount of additional detail would need to be added to the current DLMS data before it would meet the requirements for high resolution simulation applications.

The second data base problem deals with the lack of necessary feature descriptors. The DMA DLMS data was originally defined in support of radar simulation; as such, information unique to visual or sensor simulation applications such as color, surface patterns (runway stripes), and detailed three dimensional information are not contained within the data base. For current applications, the DLMS data requires enhancement which is usually accomplished manually. Although this approach may produce acceptable results over limited geographic areas, a high level enhancement is not practical for extended gaming areas that cover hundreds or thousands of square nautical miles.

The third data base problem is that of availability for specific geographic areas of interest. For any data base product requirement, DMA produces data for a specific area of geographic coverage based upon available allocated resources and assigned project priority. Therefore, a new simulator project or one with a low priority may have a difficult time obtaining the desired area of coverage unless that area coincides with existing data base production efforts. The competitive environment for obtaining DMA support includes not only simulator programs from all three services, but also strategic and tactical weapon system applications such as missile guidance systems, aircraft cockpit map displays, and aircraft navigation aids.

PROJECT 2851 OBJECTIVES AND REQUIREMENTS

Objectives

The problems described in the previous section were recently acknowledged by the Joint Logistics Commander's Joint Technical Coordinating Group on Simulators and Training Devices (JTCG-STD). As a result, in early 1982 the JTCG-STD named AFSC as the lead organization in a tri-service effort to develop a standard DoD simulator data base and common simulator transformation software. The program was designated Project 2851 under Air Force Program Element 64227F. One of the initial steps was to establish a working group consisting of ASD, Naval Training Equipment Center (NTEC) and Army Program Manager for Training Devices (PM-TRADE). The Defense Mapping Agency also serves as a supporting organization. Although funding began in FY84, the initial planning and some detailed in-house efforts started earlier. Project 2851 will address simulator data base requirements in the following three primary areas.

Technical Requirements.

The data base transformation software and standard simulator data base must be compatible with the technical requirements for all types of future training systems. This will include visual, high resolution radar such as SAR, and high resolution electro-optical systems such as infrared and low light level television. In addition, the training systems associated with each of the three services must also be considered i.e., air, ground, and naval simulation systems. The new data base structure and content, and the transformation software must be compatible with the basic architecture and data base processing capability of current state-of-the-art simulation devices, and must also be flexible to permit changes as simulation technology evolves.

Operational Requirements.

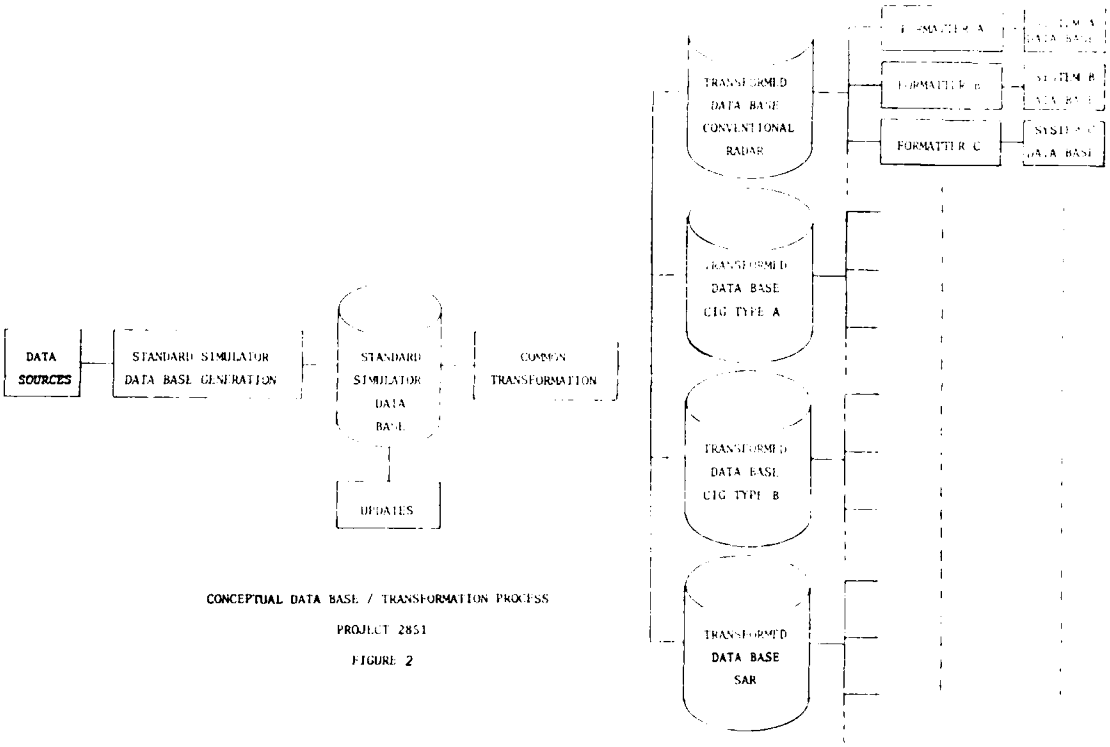
The standard simulator data base must meet the operational training needs of a wide variety of different requirements associated with Army, Navy, and Air Force simulator applications. Both cartographic and hydrographic data will need to be considered. The varied types of training place different kinds of requirements on the data base. These requirements range from very large areas (one million square nautical miles) with low to moderate detail to limited areas (hundreds of square nautical miles) with very high detail to some combination of these extremes. There are also requirements to support initial training, transition training, and continuation training, including mission rehearsal. Individual programs must be able to select and implement only what they need from the standard data base. Individual site updates or modifications will still be necessary in order to support individual mission needs, but these changes can be fed back to the central data base site so that all users can benefit.

The most significant data base requirements that need to be supported are world wide area of coverage and mission rehearsal. Mission rehearsal in particular will be a significant challenge since a ground truth, feature by feature representation of the earth's surface may be required for many simulator applications. Another major challenge will be the development and merging of highly detailed areas of real and synthetic data. The standard simulator data base must support enhancement of DLMS data, including manual enhancement, insertion of generic feature models, and addition of non-real world information using a process called synthetic breakup.[4]

Support Requirements.

Once a standard data base is created to meet the operational requirements, the need will exist to generate on-line simulator data bases i.e., develop data base transformation programs maintain configuration control, and update the data bases when new source information becomes available. Configuration management will be particularly important to insure data base availability for all simulator users and to avoid duplication of data base generation effort. Once a data base is generated for a particular geographic area, information on its availability, content and currency must be accessible to all simulator users.

A data base generation/transformation support



CONCEPTUAL DATA BASE / TRANSFORMATION PROCESS

PROJECT 2851

FIGURE 2

center will be needed to provide support for operational simulators and acquisition programs. Data bases for new areas will be generated and/or transformed in support of users and for test and deployment of new simulators. The magnitude of this task will vary continuously, depending on the numbers, types and sizes of areas needed. This center will have to modify and/or update previously generated areas based on revised source data and inputs from the field. There will be a continuing need to work with users and contractors developing new simulators to rapidly analyze and resolve problems as they arise. The center must support the test and evaluation activities of acquisition programs by supplying data, transforming data and resolving discrepancies in test results. Provisions for continuing research and development activities must be included to take advantage of new data base source materials and to maintain compatibility with new image generation techniques and transformation schemes. Finally it will be extremely important to keep the data base documentation current so that the data base content for any desired geographic area can immediately be determined.

PROJECT 2851 APPROACH

The data base generation/transformation process envisioned is illustrated in Figure 2. All applicable sources of topographic data will be utilized and converted to a common datum. The simulator data base will be generated by digitizing these cartographic, hydrographic, and photogrammetric sources and merging them with DLMS data. Generic models and synthetic data may also be used to enhance the DLMS. The final product of this process will be a standard simulator digital topographic data base. Provisions for updating this data base will be provided. At this stage the standard simulator data base shown in Figure 2 is not yet in a form ready to be directly loaded in a simulator. Because of the complexities of some of the transformation processes and the very lengthy time required for transformation, a goal has been established to identify the common transformation tasks and perform them once for all applications. It may be necessary to have individual transformation programs for a limited number of classes of applications e.g., conventional radar, synthetic aperture radar, CIG Type A, CIG Type B, etc. Ideally, transformed data bases will be in a format nearly ready for use by a particular simulator. In order to exactly match this transformed data base to a particular image generator, an adaptation/formatting program will be required for each simulator application. The goal is to maximize the common transformation processing and minimize the tasks remaining for the adaptation/formatting program. The feasibility and practicality of this approach remains a subject for further study.

This data base generation/transformation process is flexible enough to satisfy multiple purposes and many types of requirements. It permits a specific program to extract what is needed to satisfy its specific requirements. There are provisions for higher resolution data developed by a specific program to be added to the standard simulator data base and be available for subsequent users. Synthetic or non real world enhancements can be documented and separated from real world data. This scheme provides needed flexibility for individual programs but also forces individual data bases to be portable, thus reducing redundant modeling and generation efforts. By maintaining the standard simulator data base in a partially transformed form, the complex, time consuming transformation processing can be reduced for each application. It is essential that the partially transformed data base be independent of any particular image generator design yet contain all information that might be utilized for a particular application. This approach does involve knowledge of simulator subsystem design to some extent, but this is a reasonable tradeoff considering the benefits. If there is a significant advancement in the state-of-the-art, the initial (common) transformation process can be modified to maintain compatibility with newer simulator subsystem designs.

The implementation plan for Project 2851 will employ a combination of in-house Government resources and contracts with industry. By utilizing this combined expertise, an optimized solution to the data base/transformation problems can be attained. The Government has knowledge of the requirements and problems experienced with past simulator systems developed by several manufacturers and the objectivity to keep the solution generic and not favor any one design approach. Industry has knowledge of simulator subsystem design and first hand experience with simulator data base design and development. The following six tasks describe the development strategy to be followed. A schedule is provided in Figure 3.

Task 1 - Data Collection and Technology Baseline Definition.

A comprehensive list of existing and planned DoD training simulators that require the use of digital topographic data for visual, sensor and radar image generation will be developed. For each simulator system, the data base requirements, transformation program requirements, data base and transformation software acquisition costs, and training requirements will be collected. A detailed analysis will be conducted to determine which requirements are common among the simulators, which are common for a particular training category, and which requirements are anticipated for future applications. In addition the simulator industry will be surveyed to determine what advancements in the state-of-the-art can be expected that would impact the form of specific simulator data bases. This task will provide the basic data and will establish the baseline from which the project development effort will evolve. Task 1 will result in a technical summary describing DoD simulator systems utilizing digital topographic data and, for each system, a description of the data base and transformation program requirements. Task 1 will be an in-house Government activity requiring the involvement of each of the three services and is scheduled to be a 9-month effort.

Task 2. Evaluation of Data Base Sources.

An evaluation and analysis of existing data base sources will be accomplished in parallel with the Task 1 activities. Existing sources will include Level 1, Level 2, and Level V DMA data as well as other digital, photogrammetric, and chart sources. In addition to the analysis of real world data sources, an analysis of data base alternatives e.g., generic data base, synthetically generated data bases, etc. will be accomplished. Task 2 is intended to be a front end analysis which will provide information in support of the later tasks of requirements definition, program methodology, and software development. Task 2 will result in a technical summary describing the utility, strong points, and weak points of existing data base sources as well as the feasibility of generating data bases from non-real world sources or by combining real world with non-real world features. Task 2 will be an in-house Government activity and is scheduled to be a 15-month effort.

Task 3 - Program Requirements Definition

A training evaluation will be accomplished to determine data base and transformation program requirements as a function of training requirements. A composite set of simulator data base requirements will be developed, based upon results of the training utility evaluation data collected in Task 1, and the experience of the tri-service working group participants. A major goal will be to define a process that does not stifle future technological innovation nor severely limit the use of those innovations. It will then be necessary to develop a data base generation concept to identify which functions should be accomplished during the simulator data base creation process, which functions should be accomplished by a common transformation program for each application i.e., visual, radar, or sensor, and which functions should be accomplished in a system-unique environment, i.e., the adaptation/formatting process. The data base generation concept will serve as the basis for defining transformation program commonality requirements and alternatives. Task 3 will result in a technical evaluation of the requirements for the engineering development that will follow in Task 4, and will be accomplished primarily by the tri-service working group, although a limited amount of contract work will be considered. Industry inputs will also be solicited at this time. Task 3 is scheduled to be a 6-month effort.

Task 4 - Program Methodology

Once the data base generation concept and a set of requirements for both the data base and the transformation programs are established, the program development strategy will be defined. This strategy will pursue the primary objectives of developing a DoD standard simulator data base and common transformation software. The task will involve defining a set of engineering development activities that will be directed toward the program objectives and will determine the means by which each activity will be approached e.g., contract versus in-house Government work, which service or laboratory, etc. Task 4 will be accomplished by the tri-service working group and will result in a detailed program plan defining engineering development activities to be accomplished and technical specifications for the development activities. Task 4 is scheduled to be 6-month effort.

Task 5 - Data Base and Transformation Program Development.

During Task 5, the activities defined by Task 4 will actually be accomplished by both in-house and contract efforts. Specific work activities will include:

1. The development of simulator data base generation software.

2. The development of advanced, multi-application simulator transformation programs.

3. The generation of simulator prototype data base areas.

4. The evaluation of the prototype data base areas on various non-real time and real time simulator training devices.

5. The development of data base maintenance methods.

6. Detailed technical reports describing both the development activity itself and the actual test results.

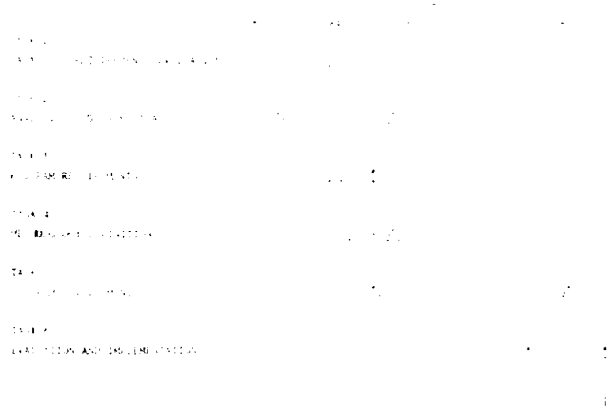
The development activity may be directed toward more than one specific approach and will permit government evaluation of several different alternatives. A wide variety of DoD agencies will play an active part throughout the development and follow-on testing. Testing of both the data base and transformation programs will include evaluations using both operational and in-house image processing systems i.e., DRLMS and CIG systems, reports describing both the development activity itself and the actual test results. Task 5 is scheduled to be a 30-month activity.

Task 6 - Final Evaluation and Implementation.

Once the data base and transformation program alternatives have been developed and testing completed, a final evaluation will be conducted by the tri-service working group from which an acceptable approach to data base generation and transformation will be selected. So that the selected approach can actually be utilized by each of the services, an implementation plan will be developed which will provide the means for an integrated DoD simulator data base generation capability. The final products of Task 6 will include a technical summary defining the approach selected for simulator data base generation, transformation, and maintenance, technical specifications defining the requirements for simulator transformation programs, a simulator data base generation capability including technical specifications defining the requirements for simulator data base content, and a final report with recommendations for DoD implementation. Task 6 is scheduled to be a 12-month effort.

SUPPORTING EFFORTS

Project 2851 will take advantage of a number of ongoing efforts to develop the standard data base and transformation software. These efforts have individually diverse goals, but all involve important considerations for data base standardization. Some of these efforts will be discussed in detail.



[illegible]

High Resolution Data Base

The High Resolution Data Base (HRDB)[5] also known as Level V, is an enhanced culture data base that is now available in prototype form from DMA. HRDB improvements over the earlier First Edition DLMS include the addition of roads, railroads, streams, airport lighting and buoys. Another major improvement is the addition of microdescriptors for some types of features. Microdescriptors provide additional information about the composition, or detailed makeup, of large homogenous DLMS features.

ASD is evaluating the HRDB prototype data to determine its ability to satisfy simulator data base requirements. The evaluation is making use of five small areas of prototype HRDB data which have been produced by DMA. The evaluation includes transformation of HRDB areas and generation of static CIG scenes. A dynamic demonstration of the CIG data bases on the C-130 visual system at Little Rock AFB is included along with a KC-135 radar evaluation at ASD. Results of the HRDB evaluation will be available by late 1983. HRDB or a derivative will likely be one of the major data sources for Project 2851.

Digital Multi-Use Feature File

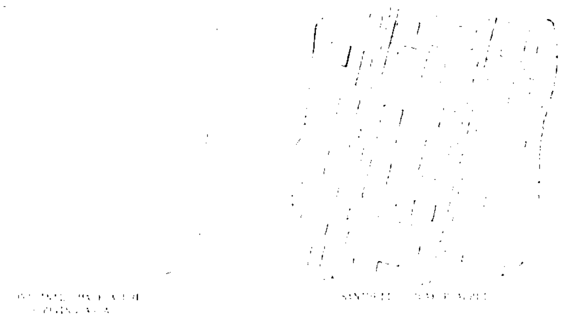
The Digital Multi-Use Feature File (DMUFF)[6] is another new prototype culture digital data base from DMA. While this new data base currently exists only in the form of a draft specification, it probably represents the next step beyond the HRDB data base. The DMUFF is intended to support a number of different DMA digital products and thus various levels of data detail may be contained in the data base. The structure of the DMUFF enables storage and retrieval of many products over the same geographical area using common data elements to describe features applicable to these various products. Much of the impact of the DMUFF will affect only DMA internal procedures, although some format changes will be required. However users will likely receive better support for a wider range of applications, with some changes in data format. A number of new features and new feature descriptors will likely also be provided.

Synthetic Breakup

Another effort being pursued at ASD involves the development of a comprehensive synthetic breakup algorithm. This is a technique to statistically break up large homogeneous features as provided by DMA into representative distributions of their component parts. This technique is initially being developed to use the microdescriptor information provided in the HRDB data.

Figure 4 depicts the concept of the synthetic breakup process. On the left is the outline of a DMA feature which defines the boundary of a housing area. Using HRDB microdescriptor information supplied with this feature, the predominant street pattern can be determined and generated. Then a representative set of buildings can be distributed throughout the feature areas. The result is shown on the right.

Synthetic breakup is currently being developed as a preprocessing step prior to transformation. It is scheduled to be demonstrated at ASD using the HRDB prototype data in December 1983. In the future, this capability could be integrated with other transformation processes, and will certainly be included in the standard data base and transformation process where exact real world ground truth is not a strict requirement. Although synthetic breakup does result in data that is not in one-to-one correspondence with the real world, it has great value in providing clutter information for high resolution simulator applications.



SYNTHETIC BREAKUP

FIGURE 4

Quality Control

Over the years a number of deficiencies or anomalies have been discovered in the DMA data. Until recently, little emphasis was placed on the systematic correction of these problems; however, ASD has developed software to automatically detect nearly all occurrences of many of the types of errors which are particularly bothersome to simulator applications.[7] The software also automatically corrects a high percentage of these errors, and provides an interactive means of analysis and correction for the remaining errors. This software has been used successfully by both ASD and DMA to correct problems with culture data for several simulator programs.

These concepts of quality control must be applied and extended for Project 2851 to provide a more comprehensive analysis of both terrain and culture data. Similar techniques must be designed and applied to any standard data base product produced by Project 2851.

Cartographic Applications for Tactical and Strategic Systems

The Cartographic Applications for Tactical and Strategic Systems (CATSS) is an effort by the Air Force Rome Air Development Center (RADC) to formulate a comprehensive list of Air Force requirements for digital cartographic data. This effort will attempt to identify common requirements and minimize redundant development of digital cartographic products. Project 2851 personnel will keep informed of the results of the CATSS analysis and recommendations in order to insure compatibility as much as possible with identified common needs. The Project 2851 team will also inform the CATSS program personnel of any new requirements which are needed to support Project 2851.

SUMMARY

The objective of Project 2851 is to develop a DoD standard simulator data base and common transformation software that will be used for simulator training devices requiring the use of digital topographic data. The DoD standard simulator data base will provide a common source of digital topographic data that will be specifically compiled to meet training objectives and which minimizes the need to enhance DLMS data during the data base generation/transformation process for each individual simulator system. The common transformation software will attempt to reduce the amount of system unique software that will need to be developed for each simulator system. It will promote a greater degree of data base and software compatibility among the many DoD simulator systems. The results of the Project 2851 promise to be improved simulator training capability at reduced development, acquisition, and life cycle cost to the government.

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DATA BASE GENERATION: IMPROVING THE STATE-OF-THE-ART

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Williams AFB, AZ 85224

ABSTRACT

The development of data bases for computer image generation systems is a time consuming, labor intensive process. While the last ten years have seen tremendous advances in the capabilities and capacities of computer image generation, comparable advances have not occurred in the area of data base management. As visual systems can output more scene detail, they require data bases which contain more information and so, take longer to build. If some effort is not made to develop methods to build data bases more efficiently, the limiting factor for the amount of detail contained in an environment will be the data base development time. This paper will discuss two projects currently underway at the Air Force Human Resource Laboratory (AFHRL), Williams Air Force Base, AZ, which enable data bases to be developed much quicker by allowing the modelers to utilize work which has been done in the past by AFHRL or other organizations. The first project is the development of software to convert data bases formatted for one visual system to the format required for another visual system. The intermediate steps of this process will utilize a "generic data base," which is simply a data base which contains the minimum information necessary to recreate the environment in any format. The preliminary test of this effort will be to convert data bases between the Advanced Simulator for Pilot Training (ASPT) and the F-111B Visual System Attachment. If successful, the effort will be extended to transform existing data bases from Defense Mapping Agency (DMA) and other visual simulation systems used by the Air Force, Army, and Navy. When completed, this will alleviate the necessity of completely regenerating the same data base by hand when it is to be used on multiple visual systems. The second project is the development of a library of models. This library is an on going effort to create a collection of pre-made models that are accurate, usable, and well documented. An effort is being made to predict which models will be required in the future and to create them before they are needed. The library will alleviate data base modelers having to make every model from scratch every time that model is used in a different data base. These projects and others also under development at AFHRL will allow data bases in the future to be generated much more efficiently and quickly than is currently possible for most visual systems.

INTRODUCTION

When Computer Image Generations (CIG) was introduced, the limiting factor was the processing power and speed of the hardware. Since then, much work has been done in the development of faster and more powerful hardware, and only limited work in the area of data base development. Due to hardware limitations, early data bases were small, covering only a limited area with relatively few visual cues. The increased edge processing capabilities of current systems permit missions to be more complex, requiring significantly larger data bases. It is not uncommon today for data bases to cover areas of several hundred thousand square miles. Although improvements have been made, these data bases still require a proportionally longer time to build and debug. A simpler, faster, and more automatic method of creating and modifying data bases must be found.

The goal of AFHRL/OT is the improvement of combat effectiveness through flying training related science and technology development. To help support this goal, several different computer image generators are used. When a different visual environment is required for a research study, it must be developed from scratch. In order to accomplisth this, it is very important to develop and manage CIG data bases. If two image generators are to display the same visual environment, it must be [illegible] separately for each system. [illegible], each image generator has its own [illegible] data base management system for creating visual environments. The data base modeler must learn all these systems and use them to build visual environments as required to support the mission.

There are two ways to speed up the process of data base development. One is to utilize work that has been done in the past. Another is to improve methods that will be used to build new data bases or modify existing data bases. This paper will discuss work currently being done at AFHRL/OT which enables us to save data base development time by using work done in the past.

There are two projects underway which will be detailed. The first project is a set of programs to convert data bases from one real-time visual system to another. The second project discussed is the library of standard models currently being developed.

Definitions

Before describing in detail the work being done at AFHRL/OT, definitions of key terms will be given.

A visual data base is defined as a collection of numerical data which represents a visual environment. This environment may be either an imaginary world or a portion of the real world.

The data base is built by using the following geometric concepts:

Vertex: A point located in 3-D space

Edge: A straight line segment between two vertices

Face: A closed convex planar polygon (includes a color)

2D Object: A set of coplanar faces

3D Object: A set of faces which form a closed convex polyhedron

2D Model: A set of 2D objects

3D Model: A set of 3D objects

Environment: A set of models that represents a visual scene

Level of Detail (LOD): Each model in an environment can be modeled in multiple levels of detail, each with a different amount of complexity. In real time, the visual system displays the appropriate LOD for each model in the environment. Proper use of feature results in the elimination from processing those edges, faces, and objects too small to be perceived.

ASPT Visual System

ASPT has a 2,500 edge monochrome visual system. It uses seven CRTs to display a 300° horizontal by 110° vertical field of view. The environment can be as large as 1256 x 1256 nautical miles. In a visual environment, there may be at most 300,000 edges, 40,000 objects, and 2,000 models. The real-time visual system can display at most 2,560 edges, 512 objects, and 200 models per frame. The ASPT visual system allows three levels of detail per model. The switching distance from one level to the next is a function of the aircraft altitude above ground, the distance to the center of the model, and the size of the model. ASPT uses shades of gray for painting the displayed faces. The scale goes from 0 (very black) to 63 (very white).

DIG Visual System

The F-111 DIG has an 8,000 edge color visual system. It uses three channels to display a 125° horizontal by 36° vertical field of view. The environment can be as large as 600 x 600 nautical miles. In a visual environment there may be at most 2,680 models. The DIG Visual System Attachment (VSA) allows 32 levels of detail per model. The switching distance from one level to the next is specified by the data base modeler. The DIG has 4,096 different colors available for real-time use.

Data Base Modeling

Modeling is the art/science of defining the visual environment which will become a data base. The data base modeler, in conjunction with the researcher, is responsible for identifying the important visual cues in the environment. The modeler then defines them in terms of a three-dimensional coordinate system and submits them to a set of modeling programs. These programs take this input data and generate a data base which can be used in computer image generation.

Until recently, the following procedure was used to build data bases: The modeler would manually digitize source information (such as maps, photographs, etc.) and then punch that information on to computer cards. The cards would be run through several offline programs, and the data base would be output to a disk file. The modeler would then have to use the real-time visual system to look at the data base and check for errors such as wrong colors, models placed in the wrong locations, or other mathematical errors. If any errors were found, the source data would be changed and the entire process repeated. Figure 1 illustrates this process. Although improvements have been made in most data base modeling systems, the same basic procedure is followed.

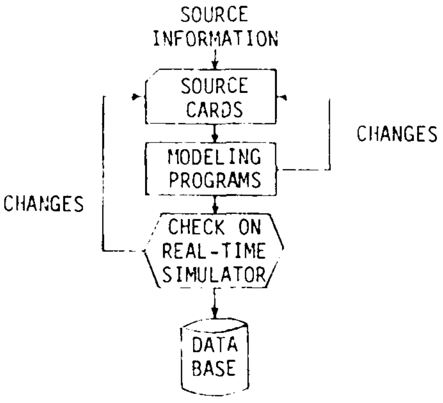

Figure 1 Typical Data Base Modeling Procedure

DATA BASE CONVERSION

Currently each real-time visual system uses a data base with a unique format. This is necessary to allow it to retrieve the information contained in the data base most efficiently. However, although different formats are used, the various system data bases contain the same basic information. This information includes the definition of the shape, location, and color of each object in the environment. Thus, it should be possible to use the information contained in the data base of one visual system to create a data base formatted for another visual system. This is the idea behind the data base conversion project; to utilize work done in the past.

Two different approaches to this conversion process were considered. The first was to develop software which would directly convert the data base of one visual system to that of another. This was rejected since the number of programs required to do this would grow almost exponentially as more visual systems were added. The second approach involves the use of a data base with a generic format as a kernel or core. Two programs would have to be written for each visual system that a data base is to be converted to or from. The first program would convert the data base from its native format to the format of the generic data base. The second program converts from the generic data base to one used by that visual system. The second approach was chosen since it has the flexibility built in to allow the number of visual systems to expand. Figure 2 illustrates this concept.

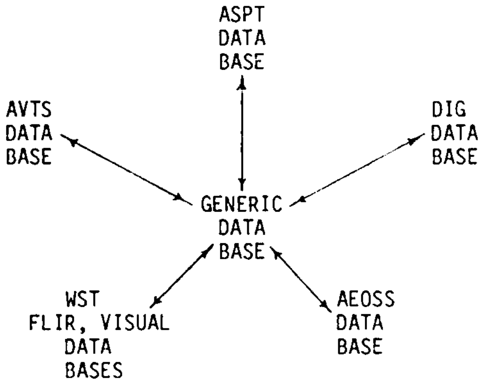

Figure 2 Data Base Conversion System

It was decided to use several phases in the development of this project. Phase 1 would allow the conversion of data bases between two specific visual systems. The visual systems selected were the General Electric Advanced Simulator for Pilot Training (ASPT) and the Singer-Link Digital Image Generator (DIG) for the F-111B Visual System Attachment. This is shown in Figure 3. These systems were chosen for two basic reasons. First, they were both on site at AFHRL which allowed for more convenient testing. Second, there were significant differences in the format of these data bases, so that a good test case could be provided. Details on these two visual systems can be found in the Introduction.

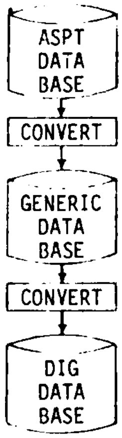

Figure 3 Phase 1 of Data Base Conversion

Phase 1

Phase 1 would be used to demonstrate the feasibility of the concept. It would also be used to explore different formats of the generic data base as well as different techniques to perform the conversion.

Phase 2 would take the lessons learned in Phase 1 and develop a more general format. This would allow the conversion of features not found in either the ASPT or DIG.

The first step of Phase 1 was the development of a generic data base format. What was required for this data base was enough geometric information to describe the visual environment exactly. This information was obtained by means of a thorough analysis of the two visual systems to be converted. The data base formats of several other visual systems were also reviewed at this time so that the generic format could be easily modifiable.

The generic data base contains enough information to allow the creation of a data base for either the ASPT or DIG visual systems. Basically, this data base can be thought of as having two parts. The first is a directory which contains the model name and disk location of its information. The second part is the geometric data of each model. This data is composed of general model data, general object data, face data, and vertex data. Examples of the type of data in the generic data base are given in Figure #4.

Model Data

Name
Level of Detail
Description
Geocenter
Switching Distance
Object Count
BIT Flags:
  Moving Model
  2D/3D
  Time of Day

Object Data

Name
Geocenter
Face Count
Vertex Count
Light Information
BIT Flags:
  2D/3D
  Time of Day
  Type of Light
  Sun Illumination
  Curved Surface Shading
  Type of Object

Face Data

Geocenter
Normal
Color
Edge Count
Vertex List

Vertex Data

Coordinate
Normal

Figure 4 Generic Data Base Information

The rest of Phase 1 is concerned with the development of a set of programs to perform the conversion of a data base between the two visual systems chosen. This consists of four programs which perform the following functions: convert an ASPT data base to the generic format; convert a DIG data base to the generic format; convert a generic data base to the ASPT format; and convert a generic data base to the DIG format.

Currently, two of the four programs have been written. The first allows the conversion of an ASPT data base to the generic format. The second allows the conversion of a generic data base to the DIG format.

The programs have been designed so that they will not have to be completely rewritten if the format of the generic data base is changed. When the programs were coded, an effort was made to insure that the programs were modularized. Also, each routine has been well documented to make any future changes easy to implement. The programs are written almost entirely in FORTRAN. The only assembly language routines perform tasks such as disk I/O. These programs are also relatively short, each being less than 1000 lines of code.

Once the data base has been converted, there is still work for the modeler to do. The differences between different computer image generators must be accounted for if the environment is to make maximum use of the capabilities of the visual system. The most common task to be performed is the addition or deletion of models. If the receiving system has a higher edge capacity than the originating system, then models should be added to the data base. However, if the receiving system has a lower edge capacity than the originating system, models should be deleted so the image generator is not overloaded constantly. Colors of faces may also have to be adjusted. This is most important when the originating system is monochrome and the receiving system has full color. However, some adjustment will also be necessary in the conversion between two color visual systems since their color tables will probably be different. In addition, some "tweaking" will need to be done on the real-time variables in the data base. These real-time variables include such things as the distances at which models appear and disappear in the visual scene. The conversion program computes default values for these and places them in the data base. However, the defaults will occasionally need to be adjusted.

A data base originally built for use on the ASPT has been successfully converted to run on the DIG. In spite of the work required to make maximum use of the DIG's capacity, the automatic conversion saved over 50% of the time required to rebuild the data base by hand. If one would be satisfied with seeing a 2500 edge, monochrome scene on the DIG, very little work need be done after the conversion is complete and much more time would be saved.

Currently, the last two programs of Phase 1 are being designed. Once these two programs are complete, a data base created on the DIG will be converted and flown on the ASPT. At this point, we will have the capability to transfer data bases between the ASPT and the DIG.

Phase 2

Once Phase 1 is completed, work can begin on Phase 2. This will be an expansion of Phase 1 to allow the conversion of data bases between any visual system at AFHRL. Phase 2 will use the same approach as Phase 1; the major difference will be in the format of the generic data base. The format of the generic data base will need to be expanded to include information not used by the ASPT or DIG but needed for the other systems. This information includes such things as DMA terrain and culture, texture, and circular features. One area which will require thorough investigation is the role that DMA terrain and culture will play in the generic data base. There are both pros and cons to including this information in the data base. Another area to be investigated is the possibility of converting between visual, FLIR, and radar systems to a limited extent.

MODEL LIBRARY

The second project to be discussed is the development of a model library. This library includes digitized models of various military vehicles and aircraft (mostly Soviet and U.S.). The digitized models are designed to be used on edge/face based aircraft simulation systems. The models are made as edge-efficient as possible while still retaining sufficient detail for vehicle and aircraft identification. Without this library, models were made only when they were required in an environment. When the same model was later required in another environment, the model was essentially remade from scratch. What is normally done is to accumulate models as they are generated for an environment. In addition to this, we are predicting what models will be needed in future visual environments and then developing these models into a readily accessible library. This library will allow data base modelers to generate visual environments more quickly and efficiently.

The models are being created on the ASPT visual system. Therefore, the models are designed and tested to the format and restrictions of the ASPT visual system. These were described in the Introduction.

When creating a visual environment, some models tend to be more of a modeling problem than others, and so, take longer to build. Unlike most models used in an environment, vehicles and aircraft require more modeler finesse to be efficiently and accurately represented. Source data in the form of photographs, blueprints, and dimensions is an absolute necessity. The identifying features for these models play an important role. Relative dimensions and angles require much more consideration than they would for models such as buildings. Since these models tend to be more complicated then others, significantly more development time is required. Assigning gray shades to faces can be tricky. For example, the top of an aircraft's wing should not be the same shade as the side or top of the fuselage. Separation planes required for object priority within the model tend to be a problem for vehicle and aircraft models. Since these vehicles and aircraft are likely candidates for "moving" models, real-time translation and rotation needs to be considered. Having such models premade and properly documented in a model library can decrease the amount of time required to build a visual environment.

The models in the library are designed with three levels of detail. An explanation of levels of detail can be found in the introduction. A typical vehicle modeled in its most detailed version is composed of five to ten objects with about 100 edges. Figure 5 shows a vehicle as it is typically modeled on ASPT, and Figure 6 is a photograph of the actual vehicle. A typical aircraft model in its highest level of detail has 13 to 15 objects composed of approximately 300 edges. Figure 7 shows an aircraft as it is typically modeled on ASPT, and Figure 8 shows the actual aircraft. The intermediate and least detailed levels tend to have respectively 60 and 30 percent of the number of objects and edges compared with the highest level. The lower two levels are designed independently of the highest level and so are not just a stripped down version of the highest level. All models are constructed along the X axis of a 3-D coordinate system with positive Z defined as "up." The center of rotation for modeled vehicles is at the middle of the vehicle on the ground. A modeled aircraft's center of rotation is at the aircraft's approximate geocenter. Aircraft are made in two versions, wheels up and wheels down. Variable geometry aircraft are modeled with the wings in two positions, the fully swept and fully unswept wing positions. The approach typically taken in modeling is to be more concerned with how "pretty" a model is and less concerned with how edge efficient it is. Since our goal is to create visual cues necessary to perform a specific task (and not to sell a visual system), the models are designed to be edge efficient yet easily identifiable. Instead of having one or two "pretty" models in a scene, we can have many less detailed but still useful models. It currently takes about two weeks to design, code, debug, visually test, and document a model.

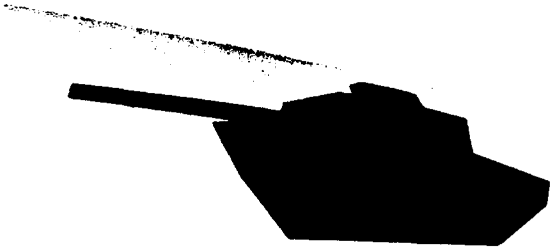

Figure 5 Vehicle Modeled on ASPT

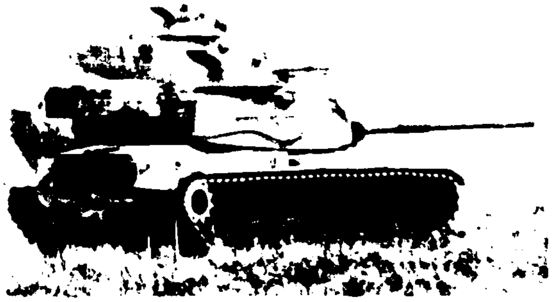

Figure 6 Actual Vehicle

Figure 7 Aircraft Modeled on ASPT

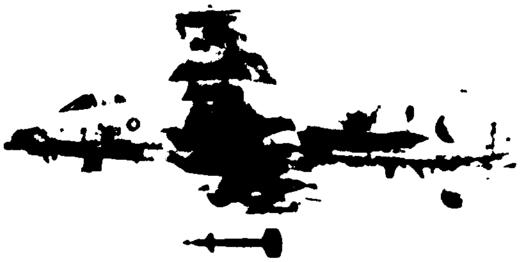

Figure 8 Actual Aircraft

Since it is intended that these models be used for multiple purposes, appropriate documentation is necessary. Documentation for models is available in the form of computer plots, formatted listings of the geometric information describing the model, and copies of the modeler's design sketches of the individual objects and the completed model. Figure 9 is a computer plot of a completed aircraft model. Figure 10 is a typical example of a modeler's design sketch of an object. The models are stored in ASPT modeling source format on a file saved on a computer disk and are easily listed on a line printer. This source data can be easily saved on magnetic tape for transport to other simulation systems. This would allow the vehicle or aircraft to be easily hand coded into the modeling source format of another visual system. In this way, the time consuming design phase of the modeling would be eliminated. When the conversion program is completed, the models could be converted automatically from ASPT format to the correct format of the receiving visual system. Using the same software, models could also be entered directly into the library from a donating simulator system.

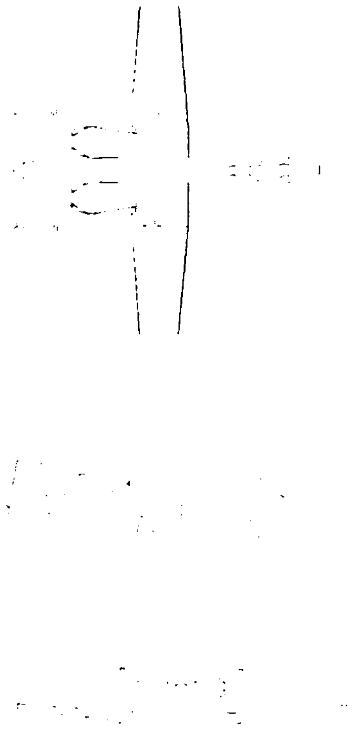

Figure 9 Computer Plot of a Modeled Aircraft

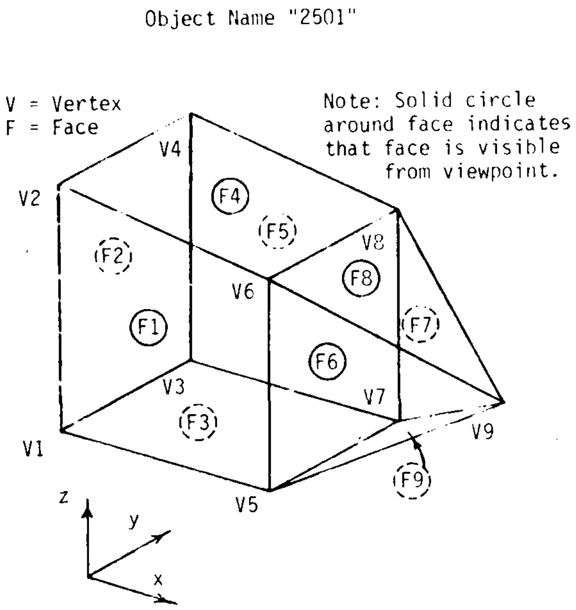

Figure 10 Design Sketch of an Object

The model library currently includes approxiamately 100 completed models. An earlier collection of ASPT formatted digitized models exists on computer cards. An effort is being made to transition these models into the model library. This means insuring that all of the card oriented models meet the standards of the model library (three levels of detail, documentation, etc.). The models in the library are a collection of work done by several modelers. Therefore the style (artistic license) the modeler used to represent the vehicle or aircraft may vary slightly from model to model. The models, when completed, are readily available for future study, test, and training applications.

The library of models is being expanded on a continuing basis.. Although the format of the library models is from the ASPT, the models can be transformed into the format of other CIG visual systems with relative ease. The thorough documentation available makes the models easy to be modified as needed. The library currently exists and is being used for on-going research and development. The models can be used for a variety of purposes. This model library will decrease database development time by about two weeks for each model used from the library.

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HUMAN ENGINEERING ANALYSIS FOR THE BATTLE GROUP TACTICAL TRAINER

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ABSTRACT

The U.S. Navy is currently developing a Battle Group Tactical Trainer (BGTT) which provides experiential war gaming exercises to Naval Officers engaged in tactical decision making and planning courses. A major design goal for the program is to simplify the man-computer interface such that players and controllers with little or no computer training can interact extensively with the BGTT data base. One step in the design process was to conduct a human engineering analysis of the BGTT's objectives, system functions, information flow, information processing requirements and user requirements, and make hardware and software recommendations that would assist in the achievement of this goal. This paper discusses the recommended hardware and software features required to simplify operator interface with the training system.

INTRODUCTION

The U.S. Navy is currently developing a Battle Group Tactical Trainer (BGTT) which provides experiential training through war gaming exercises to Naval Officers engaged in tactical decision making and planning courses. The trainer will afford the opportunity for officers (players) to make real-time tactical decisions and experience the impact of these decisions. This tactical operation performance will be extensively monitored and evaluated by a control group (controllers) for effectiveness and fulfillment of curricula objectives.

A major design goal for the program is to simplify the man-computer interface such that players and controllers with little or no computer training can interact extensively with the BGTT data base. One step in the design process was to conduct a human engineering analysis of the BGTT's objectives, system functions, information flow, information processing requirements and user requirements and to make hardware and software recommendations that would assist in the achievement of this goal.

The human engineering analysis followed the classical approach per MIL-H-46855. System functions were determined based on the mission of the training system. These functions were allocated to players, controllers and the trainer based on general human engineering principles. An extensive analysis was performed of the information input and output requirements for both players and controllers. Hardware and software were then recommended which would provide players and controllers the most efficient and cost-effective access to the required information. Detailed discussions of the human engineering analysis leading to the architecture recommendations are contained in Waldrop, McDonald, and Barry (1983).

SYSTEM MISSION

The BGTT system objectives will be accomplished in a unique environment which will allow experiential decision making training. This environment requires participation from players and controllers.

Mission for Players

The participants in BGTT will be senior Naval officers and their principal assistants participating in tactical training courses. The mission for the players is to improve their operational tactical decision making skills through practicing these skills in various tactical situations including simulated, high threat environments. This gaming environment requires participants to plan, execute and evaluate tactical operations.

Mission for Control Group

To support the BGTT objectives, a control group staff is required to instruct, monitor and assist the players. At times, designated control group personnel may also be required to participate in the war game as opposing forces to the players. The mission of the control group is to provide the players with a meaningful war game experience, monitor player performance, and provide feedback, both during and after the game, allowing players to profit from the experience and improve their operational performance.

CRITICAL TASK ANALYSIS

A task listing for the player group which outlined the duties of the warfare commander/coordinator during the planning and execution phases of their jobs was supplied by the sponsor. A Critical Task Analysis (CTA) was required for the control group because their duties had not yet been defined with reference to the BGTT. The tasks addressed in the CTA examined the functions required of the control group to support the training objectives for BGTT. This task analysis examined the duties to be performed by the staff, the information necessary, and the additional trainer support required for task completion.

The task analysis detailed control group information requirements for completion of each task. This was a direct input to the Human Engineering System Analysis which examined how to provide access to information in an easily retrievable manner.

Task Analysis Procedures

Data on the job requirements for the control group were systematically gathered from BGTT objectives, current duties of training personnel and other war gaming systems. In conjunction with obtaining current job specific data, the tasks of current training personnel were derived through interviews with subject matter experts (SMEs).

SYSTEM ANALYSIS

The informational requirements for both players and controllers were identified by gaming phase (Briefing, Planning, Execution, and Debriefing). The player tasks were prepared based on operational duties and were contained in a classified document. These tasks were modified and detailed for the gaming environment in an unclassified form. The controller tasks were obtained from the Control Group CTA. The System Analysis examined architecture configurations to fulfill task requirements.

Function Allocation

The purpose of the function allocation was to initially allocate functions to man (players and control group), machine (BGTT computer and peripherals) or both, such that the overall mission of the training system can be fulfilled in the most cost-effective manner. The functions to be allocated were obtained from the player and controller task analyses. The allocations were based on general man-machine capabilities and limitations and the mission of the BGTT Training System.

Two unique characteristics of the BGTT mission were important to the function allocation process. Since the primary mission is to allow warfare commanders/coordinators and their staffs the opportunity to make decisions, none of their decisions or actions would be allocated to the computer. However, Battle Group members above and below this level will not be included as players, and their decisions and actions must be performed by the BGTT training system (computer and control group).

A second unique characteristic concerned the fact that BGTT had been described as an experiential trainer; thus, player performance could not be evaluated based on pre-set rigid criteria. Consequently, evaluation of player performance was allocated entirely to the control group. However, the routine recording of game events, as well as provision of detailed information on student actions, was allocated to man and machine based on general human factors principles.

Allocation of Functions to Players

After review of the human factors principles, allocation of functions to players was straightforward. All functions normally performed by the Battle Group Commander/Composite Warfare Commanders (BGC/CWC) and their immediate staffs were allocated to the players.

Allocation of Functions to Trainer and Control Group

All functions involving the generation of information external to the BGC/CWC structure (mission, historical threat, geopolitical situation, rules of engagement, environment) were allocated to the BGTT Training System (computer and control group). All functions involving the decisions and actions normally executed (in accordance with Command Staff orders) by officers and enlisted personnel below the participating officers (platform movement, enemy engagement, logistics) were allocated to the BGTT Training System. All functions involving determination of engagement outcomes and assessment of player performance were allocated to the BGTT Training System.

Once the BGTT Training System functions were allocated based on mission, these functions were then allocated to man (control group) and machine based on human factors principles. Primary and support responsibilities for each task in the Control Group Critical Task Analysis were allocated based on the human factors principles.

Information Flow Requirements

The initial allocation of functions led to the examination of information flow requirements. The primary functions of a warfare commander are to gather information, assess its importance, make decisions and relay this new information to other members of the battle group. Likewise, the control group personnel must access and disseminate a great deal of information in order to perform their job. Consequently, understanding BGTT player and controller information input and output requirements is critical to equipment identifications. The information input and output requirements for players and controllers were detailed and defined.

Player Information Requirements

To perform Briefing, Planning, Execution and Debriefing Phase tasks, the players must receive and provide specific information. The BGTT Training System must provide this information in a readily usable form in order to complete its mission. Player information input and output requirements were listed for each task.

Player information requirements for each phase were presented in tabular format. Each phase had four tables associated with the information requirements for that phase, i.e., information input requirements by task, input definitions, information output requirements by task, and output definitions. Table I provides an excerpt from one set of information requirements. The player execution tasks are listed across the top (direct reference to classified task listing) and the information inputs required to complete these tasks on the left side. The X's in the table indicate what information is required to complete each separate task.

Equipment Identification

The next step in the analysis process was to provide a means to access and output the required information. The most efficient means of accessing and outputting information depended primarily on the information update rate and the form of the information. The information requirements previously detailed were analyzed for type and update rate.

This analysis led to the recommendation that each player station include the following hardware:

- o An Alphanumeric Display
- o A Standard ASCII Keyboard and Keypad
- o A Graphics Display with Touch Screen
- o An Alphanumeric Printer
- o A Game Book
- o A Secure Telephone
- o A Work Surface for Maps and Hardcopy
- o Facilities for Storing and Retrieving Hardcopy

The control group equipment identification was based on the same information access and output principles used in the player section. The analysis led to the recommendation that each station contain the same equipment as a student station plus the following hardware:

- o A Headset
- o A Graphics Printer
- o Access to a Word Processing System
- o Access to an Overhead Projector and Screen and Viewgraph Production Means

SOFTWARE REQUIREMENTS

Once the information requirements and hardware recommendations were completed, an extensive literature search was conducted on man-computer interaction. The software recommendations in this paper represent software features shown to be effective in recent research reports and design manuals and which will provide BGTT players and controllers the most efficient and cost-effective means of accessing and manipulating the required information. Software requirements for BGTT are discussed under the heading of Query Language, Dialogue, Menu Design, Screen Formats, and Error-Handling.

Query Language

There are a number of query languages available which could conceivably be utilized by BGTT. The first option is natural language entry of requests. Unfortunately, "human communication is characterized by ungrammatical utterances and syntactic and semantic ambiguities" (Ramsey, 1979). System performance can be improved by constraining the allowable syntax of the natural language. However, the naturalness of the language encourages the user to use syntax outside the constraints, causing errors that are hard to explain to the user. Natural language input is slow, error-prone and requires use of the keyboard. Natural language input of commands is not a viable alternative.

Another option is to use some of the simple computer query languages based on a relational data base (Shneiderman, 1980; Thomas & Gould, 1975; Zloof, 1975). These query languages were developed for the infrequent user and were intended primarily for management information systems. Simple and medium complexity requests in the Query by Example approach use tables to simplify categories, and links of interest are straightforward. More complex requests require the user to remember and use special characters and symbols. This approach does not apply to BGTT because information requests are not complex enough, and there are too many categories of information to present even a small fraction of the tables on a screen at one time.

Dialogue

One of the most important considerations is the type of dialogue between the user and the training system. The three types of dialogue are computer-initiated, user-initiated and mixed-initiative. In computer-initiated dialogue all interactions are initiated by the computer through prompts for the required input. Conversely, in user-initiated dialogue, the user enters commands from memory and the computer responds. In mixed-initiative, either the user or computer may initiate the dialogue. Computer-initiated dialogue is the most effective means of interaction for the untrained user (Parrish, Gates, & Munger 1981; Ramsey & Atwood, 1979; and Shneiderman, 1980). In addition to reducing errors and number of required key strokes, computer-initiated prompts implicitly convey to the user a mental model of the system's dialogue structure and remind the user of unused commands. Thus, as the users interact with the computer, they learn where the information is and the required pathway to reach it.

However, as the users become more proficient, their need for computer-initiated dialogue diminishes. Experienced users prefer to enter a single command from memory (user-initiated dialogue) and go directly to the required unit of information. Since the BGTT will be used by inexperienced players and control group personnel, as well as experienced operators, the system should be designed for

TABLE I

INFORMATION INPUT REQUIREMENTS FOR PLAYERS DURING EXECUTING PHASE (EXCERPT)

	COORDINATE OPERATIONS WITH TF/BG MEMBERS									COUNTER OWN FORCE THREATS					ISSUE/UPDATE REPORTS & TACTICAL ASSESSMENT					
	A	B	C	D	E	F	G	H	I	A	D	E	F	G	A	D	E	G	H	I
INFORMATION INPUT REQUIREMENTS	.8 .9	.3	.3	.3	.8	.3	.8 .9	.3	.2 .4 .5	.4	.2	.4	.2	.5	.1 .5	.5 .6	.6	.2 .7	.4 .3	.3
External Source Intelligence				X						X					X	X				
External Source Validations																				
Planned Responses/Actions									X	X		X	X	X		X	X			
Degree of Expected Disclosure										X										
Delegation of Authority	X				X		X		X	X			X	X						
Requests for Assets										X										
Historical Plots-Contacts/ Tactical Picture							X			X								X		
TACNUC Authority									X	X										
Force BTs, Radiosondes																				
Internal Source Intelligence			X	X			X			X		X			X	X	X			
Internal Source Validation																				
Mission to Perform Strikes									X	X			X	X						
Access Between WCs, COORDs	X		X	X				X		X	X		X			X				
Reports on Specific Operations Status	X																			
Current Mission Capable Resources									X		X	X	X	X					X	
AIMDS Schedule/Capabilities																				
Logistics & Expendable Status							X		X			X		X						
BDA									X					X			X			

both computer-initiated and user-initiated dialogue.

Ramsey and Atwood (1979) indicate that a computer system that uses both computer-initiated and user-initiated dialogue works quite well except for one problem. As users become more experienced, they are annoyed by the computer-initiated dialogue but have not yet memorized the query language for user-initiated dialogue. A means is required for a smooth transition between computer-initiated and user-initiated dialogue.

It is recommended that the BGTT allow computer-initiated or user-initiated dialogue at user option. For the inexperienced user, all interactions will be menu driven and the user could select the desired option by way of a touch screen. Optional displays should be presented in a hierarchy, allowing users to work their way through the options to the desired display. When the user touches the desired display, it will appear along with its title and four letter abbreviated title. As users interact with the system, they will become familiar with the available displays and their abbreviated titles. The more experienced user may choose to type in from memory the four letter abbreviated title of a display that would require three or four steps to reach by selecting options on menus. A fully experienced operator will be able to access a desired display by typing in a single four letter command. If the operator forgets the title of a desired display, he can sequence through the menus by using the touch screen.

Menu Design

Mace, Harrison, and Sequin (1979) conducted a study of input errors in automated battlefield information systems and found that the labeling of menu options had a major impact. Labeling menu options with full English words produced the lowest error rate but tended to clutter the display and slow the responses. Using abbreviations and mnemonics produced few additional errors and reduced display clutter. The use of nonsense codes (e.g., A2) referenced in a user manual produced poor recognition and recall and led to high error rates. Abbreviations and mnemonics are generally suitable inputs in most situations, because abbreviated equivalents of English words are easily recognized. The recall of abbreviations and mnemonics can be facilitated by standardizing their length and introducing coding conventions which are consistently employed. Moses and Potash (1979) found that simple truncation is the most effective form of abbreviation and has the lowest error rate. Two studies of automated battlefield information systems found that a four letter abbreviation had the lowest error rate (Alderman, Ehrenreich, and Bindewald, 198[illegible]; Nystrom & Gividen, 1978).

For menu design in the BGTT system, it is recommended that menus of options list the names of the displays with the first four letters capitalized to indicate the abbreviated display title.

Screen Formats

One function of the CRT will be to assist the operator in entering messages for transmission to another warfare command. The following recommendations are based on extensive findings by Mace, et.al. (1979). The operator should be provided with preformatted displays matching all message formats. Each format should contain all standard words with blank spaces for entry of required information. Each blank space should contain codes (l - letter, n - number) for the legal entries in each space. The actual letters and numbers will replace the code letters as they are entered. The units of measure (e.g., nn000 yds) should appear after the blank field. The cursor should sequence to the next blank entry field after the previous field has been completed or the ENTER key is depressed. The operator should be allowed to review and edit the message before transmission. Although messages using both upper and lower case letters are easier to read, messages received at sea are all upper case. Typing messages in all upper case is faster and is the recommended approach.

Error-Handling

Since humans are error-prone and computers require error-free input data to work properly, the BGTT trainer must have extensive error-handling features in order to operate smoothly with the inexperienced user. An important requirement in error-handling is informing the user about entry item error and how the error can be corrected (Shneiderman, 1980).

During entry of a number of fields on one format (e.g., arm and fuel an aircraft), each field should be checked for legal entries as it is entered. The immediate error message allows the user to correct the error and continue. If the trainer cannot check entries by field, then the error message issued after all of the fields have been entered must clearly specify which field is in error, preferably by highlighting the field. The user should be allowed to correct that field without reentering all other fields.

Error terms such as ILLEGAL ENTRY are of limited value to the user. Error messages such as TYPE MISMATCH and OUT OF LIMITS are useful to the experienced user but do not help the inexperienced user correct errors. Field checking routines are basically a series of IF statements in the computer. The routine should have a separate error message for each IF statement. This approach will allow the trainer to display specific error messages that indicate how the error can be corrected (e.g., NUMBERS REQUIRED, LETTERS REQUIRED, NUMBER TOO LARGE).

Another requirement in error-handling is the provision of helps. If the user does not understand the error message, he should be able to enter a code (e.g., HELP, H, ?) and have displayed the legal entries for that field.

Finally, the reason for nonavailability of information should be clearly stated. If a player misspells the name of a ship, the error message should say SHIP NAME NOT FOUND. If the player requests the position of an undetected enemy submarine, the error message should say DATA UNAVAILABLE TO BLUE FORCES.

Instructional Support Features

Instructional support features can provide automated computer assistance to routine nontraining activities and direct training quality support instructional activities. Instructor tasks which are quantifiable, consume time and divert attention away from students should be automated. The automation of such tasks will free the instructors to perform necessary and relevant tasks to facilitate training. A variety of instructional support features were examined for BGTT system applicability leading to recommendations. The features examined were demonstration, malfunction simulation, freeze, hardcopy, record/rerun/replay, store/reset current conditions, remote display, automatic performance measurement, file flags, game rates, modification of events and system alerts.

Demonstration

Demonstrations are used primarily to provide standardized instruction of complex new material. Demonstrations can provide students with familiarization to sequential events, a performance model, commented practice, and a permanent record/playback, and can be used to evaluate, develop, and critique proposed tactics (Hicklin, 1980; Link Division, 1978; Semple, Cotton, & Sullivan, 1981).

The demonstration feature could assist the BGTT control group in preparing the student for the gaming exercise, learning system operations, and evaluating new tactics. However, as a primary or required instructional feature, full demonstration capabilities are not necessary since learning the operation of complex trainer scenarios is not the training objective. Preparation of full demonstrations can be time-consuming and labor-intensive. Since skills in trainer proficiency are not being taught, other features recommended in this section can fulfill any demonstration need that might arise.

Malfunction Simulation

Malfunctions can be inserted into the training scenario automatically or manually. The malfunction feature allows total or partial failure of a game parameter independent of the training scenario. The player learns malfunction-compensating skills and decision processes transferable to actual situations (Caro, Pohlmann & Isley, 1979). Semple, Vreuls, and Cotton (1979) found that instructors preferred manual capabilities over automatic. However, they used a flight trainer with automatic malfunction that was too rigid and not capable of instructor control. Cohen (1977) suggested using an index page (or menu) displaying active preprogrammed malfunctions and subsidiary pages for insertion and deletion of detailed parameters. This type of access to existing malfunctions would be beneficial during exercise preparation.

The BGTT objectives require malfunction capabilities. It is recommended that the control group be capable of preprogramming these malfunctions based on requirements and overriding the program during the exercise if necessary. An index of current malfunctions would facilitate game file modification tasks, with items retrievable by mission phase, malfunction category or type, specific name and malfunction receiver. Instructor flexibility in malfunction programming is important for tailoring exercises to meet specific objectives, such as practice of emergency tactics, or acquisition of compensatory skills.

Freeze

The freeze feature can be categorized as manual, automatic or parameter. The manual and automatic freeze permit interruption of simulation to allow for other activities and the automatic freeze is usually contingent on situational events (Caro, et.al., 1979). The parameter freeze allows the instructor to reduce simulation "clutter." This type of freeze feature is used for flight trainers and is not required for BGTT. However, the manual and automatic freeze features are recommended for the BGTT, particularly to control current events if the gaming exercise were to deviate dramatically from intended objectives or to end play for the day.

A partial freeze feature, the "snapshot," is used for compiling the game history file, for freezing the game status when file recording, or for saving game events to facilitate recovery after an interruption. This feature is recommended for BGTT.

Hardcopy

The hardcopy feature allows the instructor to reproduce alphanumeric or graphic display data on a paper medium. It provides readily usable data for supplementing the debriefing process in an efficient and cost-effective manner (Link, 1978). The alphanumeric and graphic printers can supply hardcopies of display information for use in the Game Book, retrieval of salient information, and briefing/debriefing material handouts. One graphic printer is recommended for the control group. Further workload analysis should be conducted to specify alphanumeric printer requirements based on number of control group personnel.

Record/Rerun/Replay

Event recording provides an historical file which allows controllers and players to examine performance. After file recording, game events can be reproduced as played during the game and rerun at a pace determined by the instructor. The rerun feature can utilize the recorded file in its entirety or only in salient parts. The game can be replayed from specified points to examine alternative tactics and decisions. The replay feature can be used in post-game analysis to present alternatives or during the game as a backup feature to utilize a new event sequence. A prototype Naval Training System, the Submarine Advanced Reactive Tactical Training System (SMARTTS), uses these features to compare and contrast predicted data with actual developments (Eclectech, 1979). The record rerun/replay feature is a highly detailed and dynamic memory aid for controllers and is recommended for the BGTT.

If a demonstration is required, the recorded file can fulfill this requirement. The game can be rerun to demonstrate the system or to brief observers, and the replay can be used to analyze tactics used in a given set of conditions or to examine the applicability of new tactics.

Store/Reset Current Conditions

The store/reset feature permits the simulation to be returned or reset to a set of conditions that existed at an earlier point in time. The primary purpose is to return the operator to a previously encountered set of conditions to repeat performance tasks. The store/reset feature is most conducive to discrete performance tasks and therefore would not be recommended for BGTT. However, the ability to retain conditions and restart after an interruption (e.g., lunch break) is required. Features discussed in this section present alternatives to how the game can be saved and restarted through snapshot freeze and file recordings.

Remote Display

Remote display is an instructional feature that permits the controller's alphanumeric and graphic display data to be simultaneously displayed on the player's terminal. While this feature is normally used when simulation is in the freeze status (Caro, et.al., 1979), it can also be used in conjunction with the record/rerun/replay to support the post-game debriefing. The control group can present graphical and alphanumeric truth levels, alternative tactics and replays to the student without having to assemble players around the control group areas. The remote display capability will also facilitate the playing of games at remote sites. Therefore, a remote display feature is recommended for BGTT.

Automatic Performance Measurement

Automatic Performance Measurement (APM) provides the control group with player performance ratings based on pre-established criteria. The BGTT is an experiential decision making trainer, not designed to meet the rigid APM requirements for proceduralized and standardized tasks. Performance measurement and analysis have therefore been allocated to the control group rather than the trainee. However, several types of APM data files and reports can be incorporated, such as recording operator input errors in formatted operational directives (e.g., filling out forms), number and types of student information requests (including invalid force truth requests), and instructor actions. The BGTT can also provide the instructors with data files and reports which compile game records into a readily usable format. For example, Semple (1980) describes 5 types of APM data files: 1) student history (defines computer-resident syllabus), 2) student and class (student background), 3) measures collection (requires valid criteria for performance), 4) performance norms (current normative data), 5) instructor actions (records significant actions). Likewise, Hicklin (1980) describes 4 types of reports attainable from APM files: 1) summary report (last graded practice - strengths and weaknesses), 2) task performance report (actual scores in skill categories), 3) problem performance report (detailed review of a particular problem), 4) expanded task summary (used for research purposes). Summary programs of normative performance data and measures of effectiveness (MOEs) can improve the quality of player feedback on both individual and group performance.

A performance indicator display gives trainees feedback on tactical variables, such as range versus time, probability of counter-detection versus range, and solution accuracy versus time and would enhance BGTT feedback. BGTT programs may include C^3 MOEs for response times, lead times, detection opportunities, and support/information transfer functions. Performance information could also be provided with the alphanumeric hardcopies which contain platform status, weapon load mix and other decision data. The ability to overlay ground truth and force truth on the graphic display is a recommended performance measurement feature. Initial programming could provide an index of available measures, which could be selected by controllers prior to the exercise. A modified and flexible means of APM is recommended for BGTT.

File Flags and Annotations

As the training system is recording game events, the file flag and annotation feature allows the control group to note salient events. This feature is used primarily to relieve the post-game analysts from having to review the entire file volume or even all the snapshots prior to debriefing. The flags and annotations key the reviewer to salient game events or important events requiring review. The ability to flag or make a short note directly on the historical record eliminates the need for extensive paper and pencil records and identifies the event precisely at the time of occurrence. Game play is not affected by this feature. Additionally, providing the flag and annotation capabilities to the players can assist their participation in the debriefing discussions. The ability to make historical

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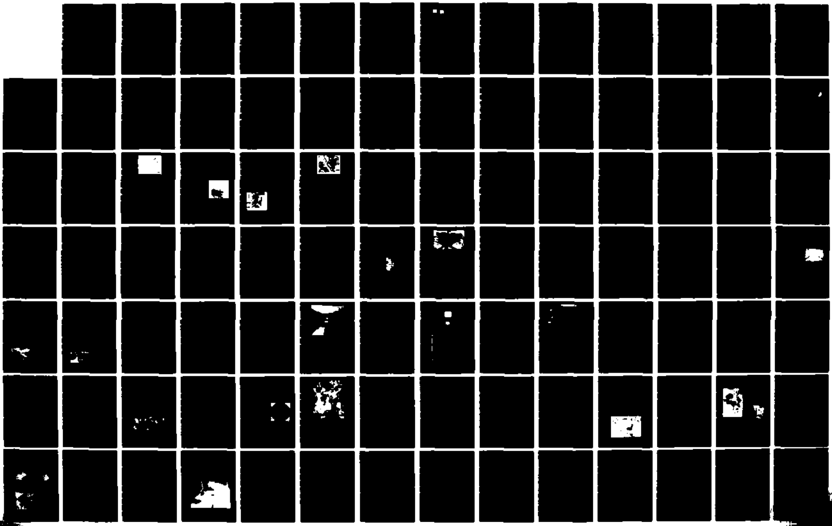

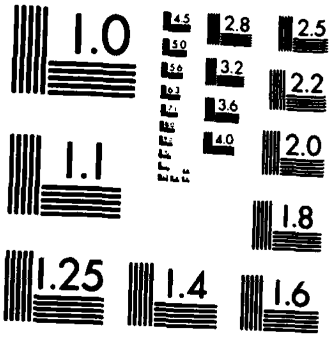

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file flags and annotations for players and controllers is recommended for the BGTT.

Game Rates

An important instructional feature is the capability to manipulate the rate at which the game is played. Instructors can set the ratio of exercise time to real-time, to accelerate, decelerate, or suspend the game, or step-ahead without the intervening steps. During initial exercise stages, the game may be played at an accelerated rate while planned actions are being implemented. As the exercise progresses and rapid decisions are required, the game rate may be decelerated to achieve training objectives. If a long period of time needs to be covered quickly, controllers can step the game ahead in time. During this time step, they may or may not want to pause for salient events or record the intervening steps. This feature allows tailoring the game speed to player proficiency, game movements or actions, and training objectives. It is recommended for BGTT.

Modification of Events

Instructional intervention allows the control group to modify automated events. Too much usage of this flexibility will negate the standardization benefits of automation. However, not allowing the control group any intervention capabilities is likely to inhibit user acceptance of the system and make it more difficult to tailor events to meet objectives (Semple, et.al., 1979). The BGTT system should allow the controllers to override the system to change, delete, delay, or suppress events. Instructors have indicated that the override capability is necessary in automated systems (McCauley and Semple, 1980). This override capability should not be used arbitrarily, but should be based on training and instructional objectives and monitored by senior personnel. For example, the control group may decide to relinquish neutrality and modify player actions to facilitate objectives. The ability to modify events is recommended for BGTT controllers.

System Alerts

The primary purpose of system alerts is to notify the controller of problems or errors which require attention. They can notify the control group when a parameter has exceeded preestablished criteria by auditory and/or visual means. This feature frees the instructor from the tasks of continually monitoring these parameters. The BGTT control group could benefit from maintenance alerts which notify the controller of a malfunction in the system. The malfunction may or may not be critical enough to warrant immediate attention, but the controller can make that assessment. Alerts which notify the control group of excessive message format errors, "illegal" information requests, or trainer command errors by players would assist the controllers' player-monitoring tasks. Those performance parameters which are specifiable for the APM and indicate errors may require further assistance or clarification to the player. It is recommended that maintenance alerts be provided for BGTT, as well as a flexible performance parameter alert capability.

SUMMARY AND RECOMMENDATIONS

The purpose of this initial human engineering analysis was to examine the BGTT's training requirements and objectives, then to provide comprehensive recommendations on system hardware, software, and instructional support features. The analysis was based on an extensive review of the BGTT documentation and human engineering literature, site visits to representative Naval user commands, and interviews with Fleet personnel and SMEs. The recommendations resulting from the analysis are summarized below.

(1) Provide means for player access and output of the information specified in the requirement tables.

(2) Provide means for control group access and output of the information specified in the requirement tables.

(3) Provide the following hardware at each player station:

- o An Alphanumeric Display
- o A Standard ASCII Keyboard and Keypad
- o A Graphics Display with Touch Screen
- o An Alphanumeric Printer
- o A Game Book
- o A Secure Telephone
- o A Work Surface for Maps and Hardcopy
- o Facilities for Storing and Retrieving Hardcopy
- o Chairs for Players

(4) Provide the following additional hardware at each control group station.

- o One Graphics Printer for the Control Group
- o Access to a Word Processing System
- o Access to an Overhead Projector and Screen, and Viewgraph Production Means

(5) Provide a 12-inch (or larger) diagonal standard resolution monochromatic CRT as the alphanumeric display for the player and controller stations.

(6) Design a'phanumerics on the CRT per MIL-STD-1472C for a 36-inch viewing distance.

(7) Design all work surfaces for sit-stand operations per MIL-STD-1472C.

(8) Provide a touch screen (using a light bezel) as the primary means of player interaction with the CRT, as well as a training aid for operations and controllers.

(9) Provide a high resolution (1024 lines or equivalent) 21-inch color display as the graphical display, with color and shape coding of symbols (NTDS symbols for players). To locate and identify targets and platforms on the

display, a light pen or trackball is recommended. A keypad is appropriate for selection of optional display functions and simple interactions, while a standard ASCII keyboard is recommended for more complex inter-interactions by the operator.

(10) Provide a 180 CPS dot matrix printer with sound baffle and dual tractor feed and capabilities for upper and lower case letters, bold face and underlining for the warfare command stations and control group stations.

(11) Provide for tabular output of force capabilities, resource status, current policies and orders, or other quantifiable data for inclusion in the *Game Book*.

(12) Provide the control group access to a word processing system with storage files of Game Book data not available in the exercise data base. This word processor should be a standard commercially available system, utilizing hard or floppy disks for file storage. A medium speed (100 CPS) daisywheel printer is recommended for the printing quality needed in the *Game Book*.

(13) Design the software such that:
   (a) The man-machine interface will be computer-initiated or user-initiated dialogue at user (player, operator, control group) option. In computer-initiated dialogue, the system will prompt the user with options on a menu, and the user will select options by touching the CRT screen. In user-initiated dialogue, the user will type an abbreviated title of the desired display on the keyboard or keypad.
   (b) Menus of options list the names of the displays, and the first four letters of the names are capitalized to indicate the abbreviated title of the display.
   (c) Provide preformatted displays to operators for each message between warfare commands and to the control group for task preparation. The formats should contain blanks where the information is to be inserted and provide indications of legal entries and units of measure. The cursor should sequence to the next blank field after each complete entry. All messages should be all upper case letters.
   (d) Provide rapid input field error-checking routines that clearly indicate to the user the input field in error and means for correcting it without having to re-enter information in other input fields. Legal entries for each field should be available at user command. Reasons for unavailable information should be clearly stated.

(14) Provide the following instructional support features:
   o Automatic Malfunction Insertion with Manual Override
   o Automatic, Manual, and Snapshot Freeze
   o Alphanumeric Hardcopy
   o Graphic Hardcopy
   o Record/Rerun/Replay
   o Remote Display
   o Modified Automatic Performance Measures
   o File Flags and Annotations
   o Game Rate Control
   o Event Modification
   o System Alerts

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TRAINING ASSISTANCE TECHNOLOGY

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ABSTRACT

Training Assistance Technology is the collection of tools that are provided as part of the training system to assist the instructor in conducting the training process. They would typically consist of automated capabilities designed to support specific parts of the training process, such as to provide detailed postscenario feedback to the trainees. Many of these capabilities would be implemented as a part of the computer-driven training device, although usually not impacting the simulation fidelity, and thus comprising the training subsystem of the training device. The Submarine Advanced Reactive Tactical Training System (SMARTTS), the direct product of a long-term research and development program sponsored by the U.S. Naval Training Equipment Center, is the initial preprototype implementation of Training Assistance Technology in an applied environment. SMARTTS is provided, as integrated with a Submarine Combat Systems Trainer. Other applications of this generic technology are presented, with detailed examples.

INTRODUCTION

The Submarine Advanced Reactive Tactical Training System (SMARTTS) has been developed as the "training subsystem" of the Submarine Combat System Trainer (SCST), the primary training device employed to achieve submarine crew tactical proficiency (SMARTTS Final Report, Hammell, 1983)(1). The purpose of the preprototype SMARTTS was to implement a variety of Training Assistance Technology (TAT) capabilities which have been identified on the basis of laboratory research as having the potential for greatly increasing the effectiveness of simulator-based training systems (e.g., Hammell, Manning, and Ewalt, 1979)(2). TAT capabilities support the instructor, trainee, and system management; they are generic in that they are relevant to every training process. These capabilities are an addition to the typically provided simulation capabilities (e.g., target, ownship, environment simulation). The specific subset of TAT capabilities implemented in the SMARTTS preprototype at the Fleet ASW Training Center, Norfolk, Virginia are tailored to address individual operator and combat team training requirements associated with the SSN MK117 fire control system. The capabilities of SMARTTS, however, in the form of TAT, are generic and generally applicable to most training devices.

TAT Background

An instructor station has traditionally been a part of every simulator/training device. However, it has often been a misnomer consisting of little more than an operator station for the controlling of the sophisticated simulator. Relatively few capabilities to enhance the instructional process have typically been provided as part of the instructor station. The necessary technology has existed, both in the form of hardware/software capabilities and training/instructional techniques, for the development of highly cost-effective training tools integrated into the training device to enhance the instructional process. Thus, a bonafide training subsystem embodieing TAT capabilities can, and should, be a part of every training device. The extent to which these capabilities should be implemented, of course, depends upon the particular training system and training situation. The General Accounting Office in their report to Congress concerning "How to Improve the Effectiveness of U.S. Forces through Improved Weapon System Design" (1981) focused on the importance of the operator to the overall effective functioning of the weapon system. They estimated that human errors account for at least 50 percent of the failures of major weapon systems. Several of their findings point to the obvious need to design the training system with particular regard for the instructor and trainee interfaces. This is precisely the thrust of TAT, and the SMARTTS preprototype.

The problem of developing a more effective training system is not really new, since the training community has always been concerned with the effectiveness of instruction. The predominant emphasis in the design of training devices and systems in recent years, however, has been placed on the engineering aspects, such as concern over adequate simulation fidelity and the technology to achieve that fidelity. Research has shown that the instructor can have a substantially greater impact on the effectiveness of the training system than major differences in simulator fidelity (Hammell, Gynther, Grasso, and Gaffney, 1981)(3). The importance of this finding is that it strongly suggests that many non-simulation aspects of the training device/training system (e.g., exercise design, monitoring of student performance, student feedback) are extremely important to the effectiveness of the training process. TAT encompasses capabilities to directly support these essential aspects of the training process. The training device, therefore should be more than just a simulator! If should provide computer-based capabilities to directly support the instructor and trainee interfaces, and hence directly support the <u>training</u> process.

The advanced training concepts embodied in TAT, and those included as a subset in SMARTTS, directly stem from two studies sponsored by the Naval Training Equipment Center (Hammell, Sroka, and Allen, 1971;(4) Hammell, Gasteyer, and Pesch, 1973)(5). These studies investigated the then-current and future needs of submarine tactics training devices. A variety of recommendations were forthcoming, addressing individual and team training needs at basic to advanced levels; and new training devices, as well as modifications to existing training devices. The SMARTTS preprototype operating today is largely a subset of the TAT capabilities that were recommended as part of these earlier investigations, and as refined and tailored to the specific application of the preprototype.

The need for TAT capabilities to support the complex submarine tactics training process was readily evident upon investigation. Several subsequent efforts investigated laboratory prototypes of TAT (e.g., Hammell, Manning, and Ewalt, 1979), finding that this type of technology would indeed substantially enhance the tactics training process. Callan, Kelly and Nicotra (1978)(6) implemented several of the recommended TAT capabilities on the 21A40 SCST in San Diego for evaluation in an applied training setting. Their results verified the potential of TAT capabilities to make a substantial contribution to submarine tactics training. The SMARTTS program emerged as a result of a series of investigations indicating the potential for substantial training effectiveness gains to result from TAT, the ready availability of hardware/software to achieve the TAT capabilities, and the support shown by the submarine tactics training community.

SMARTTS Description

The SMARTTS preprototype is a strap-on subsystem designed to support the tactics training process associated with the MK117 fire control system of the SSN 688 class fast attack submarine. SMARTTS can operate in direct support closely integrated with the already existing SCST simulation system, or as a standalone subsystem in the attack center and/or the adjoining classroom. The SMARTTS instructor and student/trainee interfaces (Figure 1) consist of (1) two overhead displays, an instructor console, and a student entry flag unit in the attack center; and (2) a large screen display and an instructor's console in the classroom. The attack center overhead displays are used for presentation of information to the fire control party prior to, during, or immediately following the exercise scenario. The instructors console is the primary command device in SMARTTS, and also the major information presentation medium for the instructor. The instructor, using this console, can set-up, initialize and control the scenario in the attack center. He can monitor the variety of tactically relevant parameters that occur throughout the scenario, as well as specific aspects of individual and team performance. Subjective observations made by the instructor can be entered via this console. Finally, information to be presented to the students on the overhead displays is controlled from this console. The instructor's console includes an upper color-graphic CRT used for presentation of information and a lower touch-sensitive plasma panel for presentation of information and for effecting entry commands by the instructor. Typically, the instructor would enter a command by simply pointing to the appropriate English language-text choice on the plasma display. An additional interface device in the attack center is the student entry flag. The five student entry flags can be readily located in different positions around the attack center, enabling the trainees to indicate points in the scenario that they wish to make a note by simply pressing an entry flag button. This flag is automatically recorded in the scenario, and can be used as a cue during the postproblem briefing session. The instructor has a similar entry flag located at the instructor's console, also for similar purposes.

The classroom large screen display presents information similar to that presented on the attack center overhead displays. The control of information on the large screen display is effected via the instructor's console in the classroom. The classroom display and instructor console are typically used for preexercise and postexercise scenario briefings, and also for classroom standalone purposes.

SMARTTS has four major functions:

1. Simulation Control -- this provides capabilities for scenario generation and problem control (i.e., control of the 21A41 SCST scenario in the attack center, or control of problems run standalone under SMARTTS in either the attack center or classroom).

2. Data Generation -- performance indicators, environmental and platform models (i.e., used primarily during alternative tactics sessions), and the automatic interactive target (AIT).

3. Data Collection and Analysis -- recording of performance indicators and other relevant information, data management and performance information analysis and feedback.

4. Trainee Interactions -- scenario playback and evaluation, alternative tactics analysis, and display generation and control.

The SMARTTS processing capabilities are extensive and extremely flexible, allowing for a wide range of operations. For example, the scenario generation and control subfunctions can be used off-line by the instructor to develop and generate a complex scenario. The subfunctions would then also be used to automatically control the scenario while it is in progress. Alternatively, the instructor could interrupt this automatic control, and take over manual control of the scenario while in progress.

The essence of SMARTTS is its capability to collect and generate a variety of information pertinent to the tactical training problem; to display various combinations of that information on the instructor's console, classroom large screen display and the attack center overhead monitors, at appropriate times during the

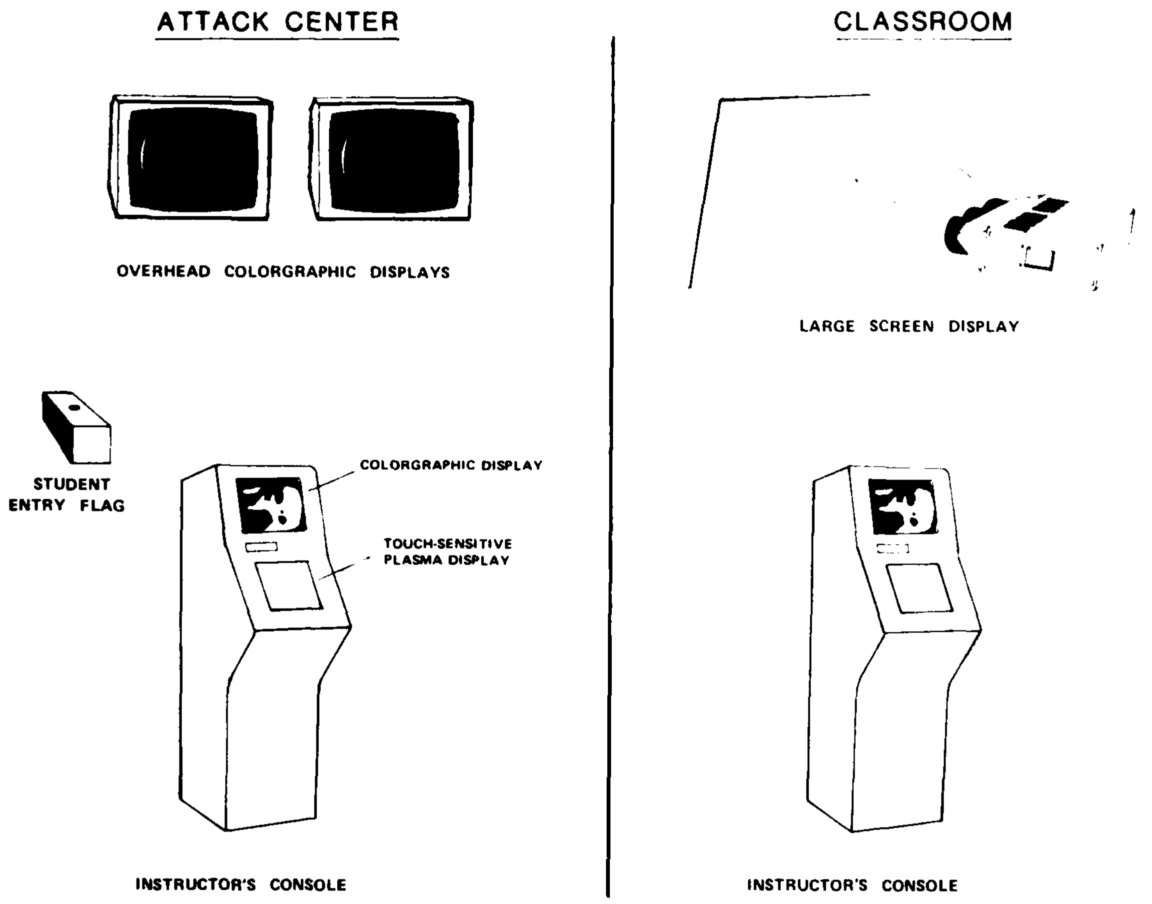


Figure 1. SMARTTS Instructor and Trainee Interfaces

training process; and to dissect and analyze details of the tactical problem (e.g., detailed aspects of trainee performance, relationships between tactical parameters of interest, and so on).

It should be noted that SMARTTS addresses many aspects of the total training system, in addition to those that are implemented via the computer-based simulator/training device. The submarine officer tactics training process itself has been modified to some extent under SMARTTS. For example, SMARTTS emphasizes the conduct of a prebriefing prior to beginning the attack center exercise scenario. The various SMARTTS capabilities support the conduct of this prebriefing in the classroom or in the attack center, presenting various information to the students on the SMARTTS information displays under control of the instructor. Another example is the instructor's course provided as a part of SMARTTS. This course is in addition to the normally provided operator's course, which instructs how to operate SMARTTS. The instructor's course focuses on the use of the SMARTTS capabilities to improve the effectiveness of the training process. Various instructor support materials (e.g., instructor handbook) have also been provided with SMARTTS. The SMARTTS capabilities presented in this paper are those which are typically implemented via automated or semi-automated means with the assistance of computer processing. Although these represent a substantial part of SMARTTS, and that which is most visible to the observer, other major aspects of the training system have also been addressed.

SMARTTS CHARACTERISTICS

The three major aspects of SMARTTS are shown in Figure 2. The major hardware has been addressed above. In addition, several off-line terminals are also available under SMARTTS for generating exercises, modifying software, and so on. The major modes of SMARTTS operation are preview, run, and playback. They provide for support of an integrated training process -- preview discussion prior to actually running an exercise in the attack center; monitoring and control during the actual conduct of the exercise scenario in real-time in the attack center; and for the debrief/playback that occurs immediately following completion of the attack center exercise scenario. Other modes of SMARTTS operation are also possible, including standalone operation in the classroom and off-line exercise generation by the instructor.

A variety of training-related capabilities are a part of SMARTTS, with the major capabilities

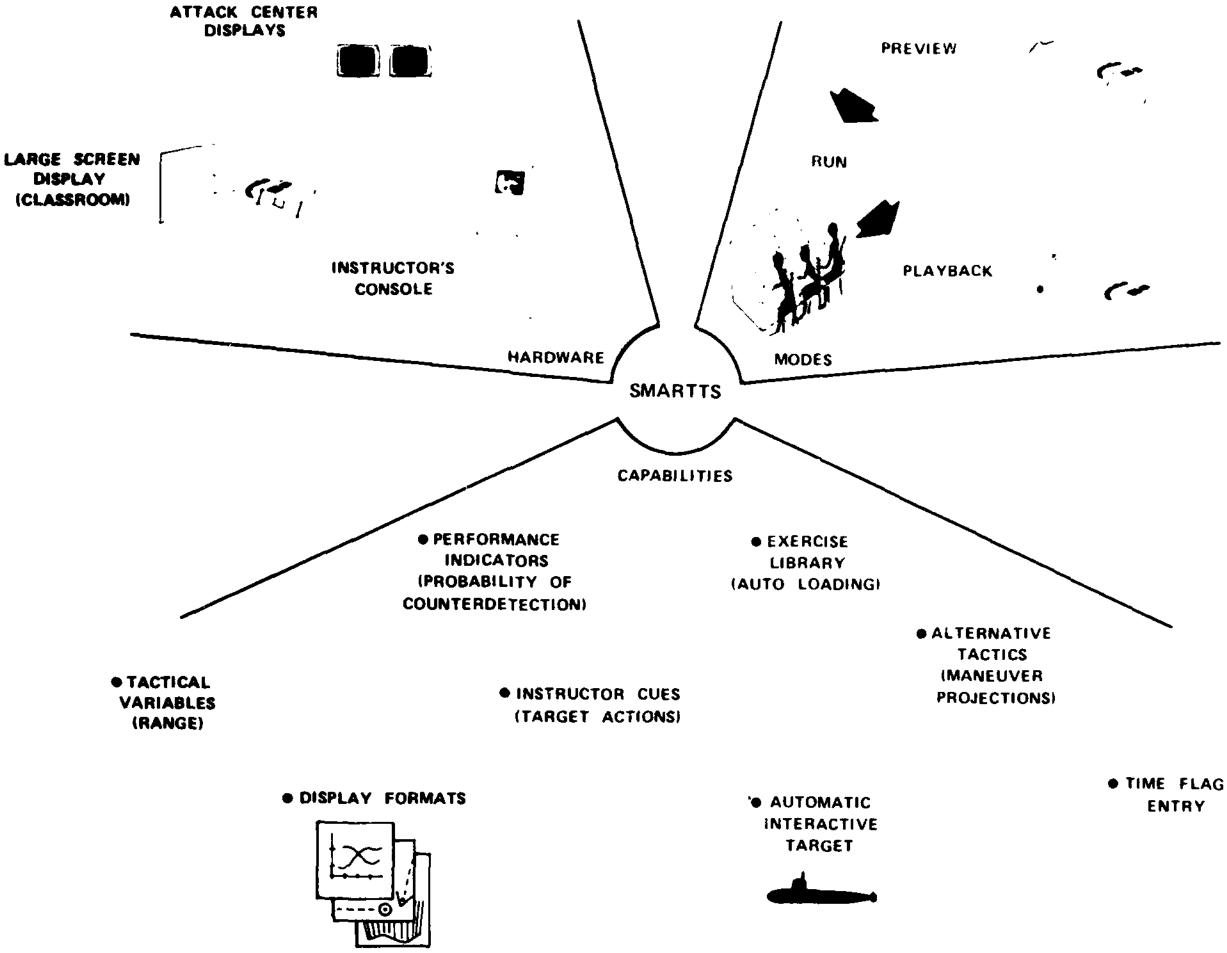


Figure 2. Major Aspects of SMARTTS

listed in Figure 2. Additional capabilities exist that support the training process itself, as well as off-line functions (e.g., exercise development). Each of the capabilities listed in this figure are described briefly below.

A set of generic capabilities are resident in SMARTTS, in addition to those addressed below, that permit its functioning as a sophisticated training aid. These are implemented via software routines, and are critical to the effective functioning of SMARTTS. They include the capabilities of data collection, storage, retrieval, manipulation and analysis. Most of the SMARTTS capabilities that are described below rely on the system's ability to collect information from the simulation computer and the MK117 fire control system, to process that information for data storage and/or information presentation, and to retrieve that information to configure the necessary display formats for presentation to the students.

Instructor's Console

The instructor's console is the main interactive control device in SMARTTS. The stand-up console consists of an upper 13 inch color graphic CRT that presents information to the instructor. The lower touch-sensitive plasma display is used as the entry device. This console is used by the instructor to (1) select and set-up exercise scenarios both in the classroom and in the attack center; (2) modify the scenario prior to running, and store the modified set-up parameters if so desired as an additional scenario; (3) monitor details of the ongoing exercise, student activities, and student performance; (4) receive cues automatically from the system; (5) control the scenario (e.g., target actions); (6) enter and store subjective observations; (7) configure and control display information to be visually presented to the students in the classroom and attack center; and (8) manipulate information on the displays as appropriate (e.g., alternative actions).

A unique capability of the instructor's console is the plasma entry device, which is a touch-sensitive display. The typical instructor is an individual with an extensive operational background, who may have some background with computers. Nevertheless, his previous experience did not typically include programming. To operate a sophisticated trainer, however, he is often required to learn an extensive set of entry commands, formats, and so on. The plasma entry device on SMARTTS substantially reduces the need for this type of learning by the instructor. It presents limited sets of possible instructor entry commands on the plasma display at the appropriate point in time, typically up to 8 command choices, using readily understandable English-like text. The presentation of command choices on the plasma is highly structured in accordance with the operations being performed by the instructor. This type of an interface has been found to reduce the instructor's load and greatly facilitate his learning of the system operation. The plasma entry device is one of the bestliked features of SMARTTS. The particular sequence of plasma formats/entry command choices can and should be continually modified to further improve the instructor's operating effectiveness. The plasma interface allows this type of evolutionary modification to continuously improve the system's effectiveness.

Performance Indicators and Tactical Variables

The performance indicators (PI) and the tactical variables (TV) comprise the main body of information relevant to specific aspects of individual and team tactical performance. The PI's are generated from TVs. The PIs and TVs are collected, stored, manipulated, and presented via the information displays. They constitute the trainee guidance and feedback information critical during the training process.

The TVs are specific parameters collected from either the simulation computer or the MK117 fire control system. They provide information relevant to specific aspects of the tactical situation. Examples include:

- target range
- sonar signal to noise ratio
- time of target zig

The two types of PIs are (1) objective PI's which are automatically calculated by the computer, and (2) subjective PI's which are manually evaluated by the instructor and entered into the SMARTTS system via the instructors console. The objective PI algorithms use the TVs and other data which are normally generated throughout any trainer exercise. Many of the objective PIs are calculated continuously and available for display at any time during the exercise or following completion of the exercise, in graphical format on the instructors console or on an information display in the attack center and/or classroom. Examples of objective PIs are:

- probability of counterdetection
- system solution range accuracy
- periscope exposure time

The subjective PIs address aspects of performance that cannot be readily calculated by automated means, but are of vital importance to the training objectives. Occasionally, a cue or an alert is provided to the instructor via the instructor's console to indicate a particular occurrence in the problem, after which the instructor may wish to enter a subjective PI evaluation. When the instructor makes a subjective PI observation he can enter his evaluation into SMARTTS by indicating the appropriate choice on the plasma entry device. Similar to that of the objective PIs, the recorded subjective PIs can be displayed during or following an exercise upon command of the instructor. Examples of subjective PIs are:

- initial target range estimate
- periscope observed target aspects
- fire control coordinator effectiveness

The PI's and TV's comprise the information that is presented to the students via the attack center and classroom information displays. This information pertains to overall and specific operations of the fire control party and individual members. The information is used to present and assess sets of tactical actions during preview, to assess the student's performance and in some instances provide information during the real-time exercise scenario in the attack center, and to provide the student with feedback information after completion of the exercise scenario. These parameters are also used via the information displays to evaluate the impact of alternative tactical actions (i.e., see alternative tactics below).

Information Displays

Much of the work performed by SMARTTS is the collection of data from various sources; the transformation of that data into meaningful tactical variables and performance indicators; and the presentation of relevant information on displays to the instructor and trainees. The information presented to the instructor directly supports his functions of exercise development, monitoring and control of training and control of information presentation to the trainees. The information presented to the trainees on either the overhead displays in the attack center or the large screen display in the classroom is primarily used to summarize, dissect and investigate particular aspects of tactical problems; to provide status information concerning the particular exercise run on the training device; and to provide feedback information concerning the myriad of details regarding the tactical performance that occurred during the exercise. Four classes of display formats are used in SMARTTS:

1. Alphanumeric status information -- tabular listing of TV's and PI's.

2. Geographical plot -- a geographical plot of ownship and other vessels, including their history tracks. This display format is usually combined with other alphanumeric and/or graphical information, both sharing a common display surface. For example, a line-of-sight diagram may be presented simultaneously with the geographical plot display via a split-screen presentation.

3. General purpose X-Y plots -- this format (see Figure 3) presents a selected PI or TV on the vertical axis versus any other PI or TV on the horizontal axis. Usually, time is used as the horizontal axis parameter, thus presenting a particular parameter over the time of the scenario. Up to 9 parameters plotted over time can be presented simultaneously

on a SMARTTS information display. This format is extremely useful for (1) identifying events as they occurred throughout the scenario; (2) presenting information concerning individual and team performance throughout the exercise; (3) presenting cause and effect information relating PIs and TVs; and (4) determining and evaluating the relationships between various PIs and TVs. The simplified example of Figure 3 shows in the upper graph the time-range plot to the target during the exercise; a closing range was achieved through most of the problem, with a nearly constant range near the end. The Probability of Counterdetection (PCD) PI throughout this problem is shown in the middle graph; the peak PCD occurred around time X. Furthermore, the relationship between Range and PCD can be seen by correlating these two curves, with PCD increasing as range decreases. However, a step decrease in PCD can be seen at time X, not in correspondence with range. This step change was due to a decrease in ownship speed at time X, shown on the lower graph, which achieved that desirable decrease in PCD. This example shows the type of discussion that would occur in the classroom immediately following the exercise scenario, using the SMARTTS capabilities.

4. Special purpose display formats -- these are display formats designed to address a particular aspect of tactical operations or training. They are designed for particular objectives and are generally not applicable across the range of training applications. An example is a time-bearing plot, which is used for evaluating and discussing manual plotting techniques.

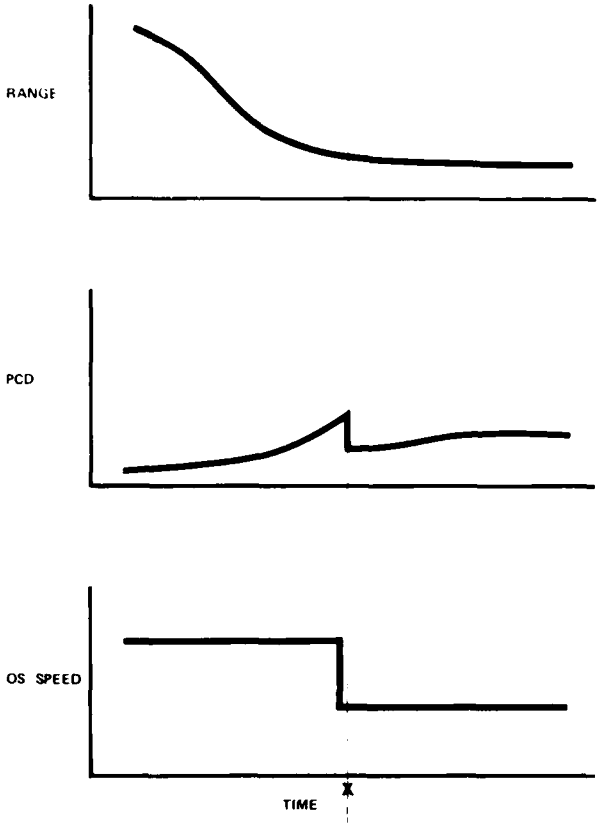


Figure 3. PI's and TV's Presented as Feedback During Debriefing

Alternative Tactics

Learning by example has been traditionally accepted as an effective training methodology. The alternative tactics feature of SMARTTS provides a computer-based capability to rapidly generate and investigate alternative example problems. Prior to conducting a real-time exercise on the training device the instructor may wish to explore particular concepts in the classroom (e.g., various barrier patrol patterns to intercept a transiting submarine) by illustrating the impact of various ownship or target alternative actions on the performance indicators of interest. This would provide the trainees with an understanding of the trade-offs associated with the range of actions available to them. Similarly, after investigating a previous exercise scenario during the feedback session the instructor may wish to present ownship and target action alternatives to those that actually occurred during the scenario, so as to explore the possible results of alternative sets of tactical actions in contrast with those that ownship actually did. For example, after a two-hour exercise during which ownship was on a barrier patrol and encountered a transiting enemy submarine, took appropriate action to approach and attack, and eventually completed the scenario, the instructor may wish to illustrate the effectiveness of other types of approach tactics for ownship in that particular problem. These alternative sets of actions may be equally effective, les effective, or more effective than those which the crew actually did. From a training standpoint, it is important that the trainees understand the various trade-offs involved with the particular actions that they took in comparison with the other available actions. The knowledge gained from this type of activity constitutes learning.

The alternative tactics feature is also of considerable use during the exercise design process. The instructor can generate and investigate alternative sets of ownship and/or target actions while constructing a particular scenario. This type of evaluation will enable him to more rapidly construct a valid scenario. The alternative tactics capability includes the following:

- Up to five future ownship maneuver legs can be projected
- Up to five target maneuver legs can be projected
- Objective PIs and TVs are rapidly calculated during the projected maneuvers
- Projection times can range from 1 to 120 minutes

Instructor Cues

Cue information is provided to the instructor in real-time via the instructor remote console in the attack center during an exercise scenario. Two types of cues are provided for training purposes:

1. Notes -- cues embedded in the script of each exercise scenario, such that they are displayed at predetermined times (e.g., list of training objectives displayed at the start of an exercise).
2. Alerts -- a cue provided to the instructor on the basis of one or more events having occurred during the exercise. The time at which the alert is issued depends upon the real-time occurrence of particular events in the scenario. For example, an alert may be given when the probability of counterdetection exceeds a predetermined value, such as 50 percent.

Exercise Library

The library contains a set of exercises developed to support a variety of tactical training objectives. Each exercise can be selected and automatically initiated on the system. This automatic initiation greatly reduces the instructor's workload in setting up an exercise. Additionally, various aspects of the exercise can be previewed and modified by the instructor immediately prior to automatic loading on the trainer. If he chooses to modify exercise parameters the modified exercise can be automatically saved if so desired, and added to the exercise library.

Automatic Interactive Target

The automatic interactive target (AIT) has been included in SMARTTS for the dual purpose of reducing the instructor's workload, and improving the target simulation. The AIT is a computer controlled target model, driven by the decision structure of an enemy submarine platform. The AIT acts as an intelligent adversary, whose ship has capabilities equivalent to those of the actual at-sea enemy submarine platform. The AIT reacts to ownship actions as he would be expected to receive information through the environment and intelligence sources, interpret that information and select his tactical actions. The AIT structure is based on a dynamic probabilistic decision model, with three levels of competency ranging from basically capable to highly capable. The actions available to the AIT and their probabilities of occurrence are keyed to the AIT's level of expertise and other factors (e.g., operational mission). Examples of the major maneuvering sequences available to the AIT, of which alternative sets of actions will occur on a probabilistic basis, are:

- transit tracks
- patrol search patterns
- baffle clearing maneuvers
- approach and torpedo attack

Monitoring and control capabilities are provided to the instructor for overseeing the AIT actions. Alerts are provided on the instructor's console in the attack center informing him of decisions being made by the AIT and impending AIT actions prior to their actual occurrence. The instructor can override planned actions, and can also initiate a preset pattern of actions (e.g., a particular baffle clearing sequence). These AIT capabilities greatly reduce the amount of instructor work in controlling the target, and will often increase the fidelity of target actions.

GENERIC TRAINING ASSISTANCE TECHNOLOGY

The SMARTTS preprototype embodies the initial major application of training assistance technology (TAT) in an operational training setting. These capabilities are generic in that they are applicable to many computer-based training systems. The particular TAT capabilities and the manner in which they should be implemented depends on the particular training system and training situation. Nevertheless, many of the TAT capabilities, as exemplified by those in the SMARTTS preprototype, should be a part of most training systems. Several of the major generic TAT capabilities are:

- Performance indicators (PI) -- both objective (automatically calculated by the computer), and subjective (observed by the instructor and manually entered into the system).
- Relevant situation variables (SV) (similar to SMARTTS TV's) -- automatically collected and recorded.
- Student information displays -- such as a large screen display in the classroom; used for presenting a variety of information to the students (e.g., preexercise briefing, postexercise feedback; performance indicators, scenario data).
- Instructor's console -- located both in the classroom and in the relevant simulator operations area; it should provide information for monitoring the problem status and student performance; it should have capabilities to control the scenario, and to control information presentation to trainees via the displays and other TAT characteristics.
- Alternative actions (similar to SMARTTS alternative tactics) -- for presenting fast-time examples in the classroom context; this learning-by-example technique is useful for investigating a range of relevant problems and own-platform actions during the prebrief, and for diagnostically investigating alternative actions during the postbriefing.

TAT capabilities are currently operating as part of at least one training device in an application area very different from that of SMARTTS -- commercial merchant marine shiphandling training via a ship bridge simulator. Furthermore, the applicability of TAT characteristics has been investigated with regard to application in several other contexts, including CIC training and sonar training. The specifics of TAT application differ for each of these areas, and for the SMARTTS preprototype. However, the generic TAT capabilities remain the same in each application, with the specifics tailored to the particular training situation. The application of TAT capabilities in each of these three areas is discussed briefly below.

Shiphandling Training

Shiphandling training has traditionally been accomplished at-sea, for both military and commercial applications. The shiphandling/ship bridge simulator, or training device, is a relatively recent development. Less than two dozen such training devices have been placed in operation over the past 15 years. The commercial merchant marine (i.e., including Maritime Academy Cadets, deck officers, and harbor pilots) have steadily increased their acceptance of training via the training device/simulator over the past 5 years to the point that these devices have recently become widely acclaimed as a cost-effective means for achieving a considerable amount of shiphandling training.

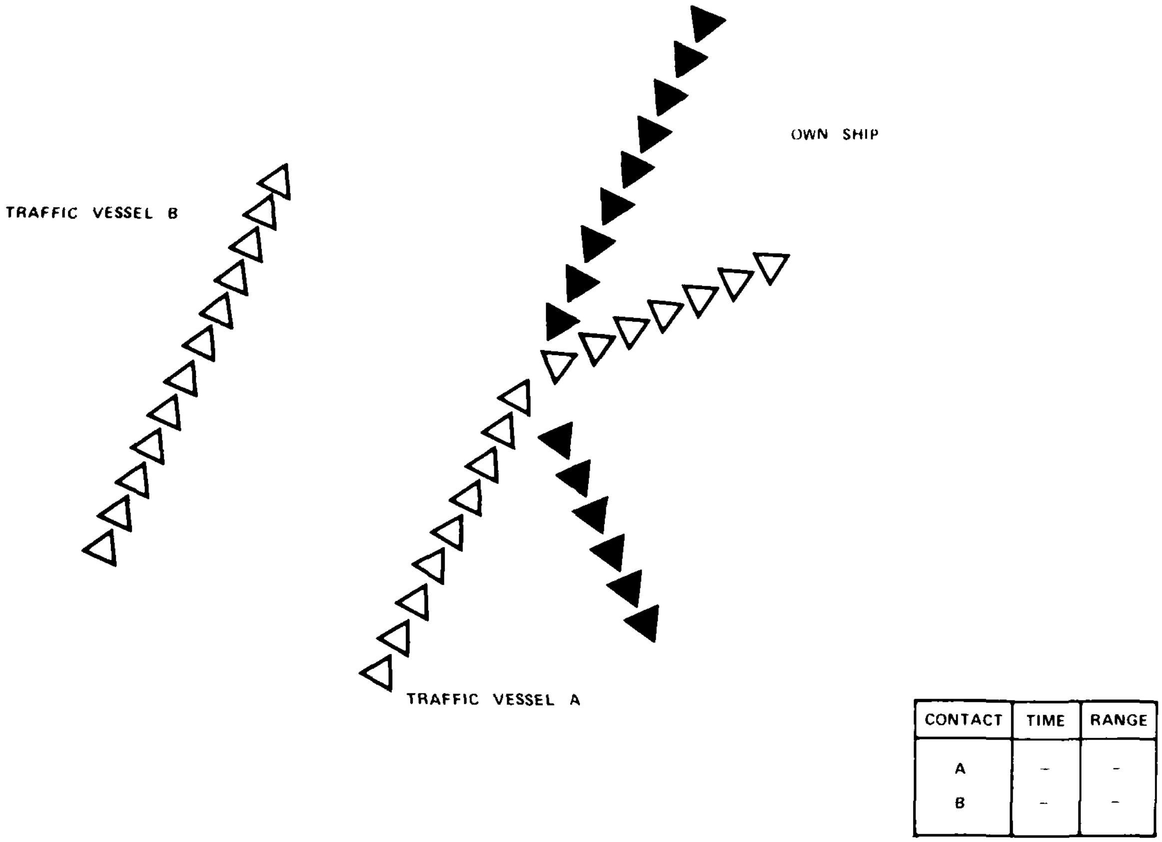
The ship bridge training device consists of a general bridge area containing the various instruments and controls typically found on the bridge of a commercial vessel (e.g., internal and external communications systems, steering stand, rudder and rpm controls, various navigation electronics, radar, and so on). The sophistication and complexity of the bridge simulator lies in the large-scale visual scene that is a necessary part of this training device. Various methods have been used to generate an appropriate visual scene. As a result, the simulators worldwide differ greatly with regard to their visual scene capabilities (e.g., some are nighttime only, while others present both daytime and nighttime scenes; some can present traffic vessels in the harbor area, while others cannot). Computer generated imagery is becoming a stable technology for the generation of the visual scene for this type of training device.

The training objectives that have been addressed on ship bridge training devices encompass a number of areas, including the application of navigation principles, emergency maneuvering of the vessel, maneuvering under conditions of shallow water and bank effects, communications within and between ships, bridge team work, and collision avoidance maneuvering.

The Ship Analytics' ship bridge training device, and a similar unit currently being installed for the Marine Engineers Benevolent Association (i.e., a maritime trade association) have incorporated a variety of TAT capabilities. These include performance indicators, situation variables, student information displays, and alternative action capabilities. For example, the situation variables and performance indicators can be played back in a manner similar to those of the SMARTTS preprototype (i.e., detailed diagnostic feedback). A variety of commercial organizations and U.S. Coast Guard Cadets and officers have received training on this device, utilizing the TAT capabilities. These capabilities are generally regarded as one of the unique and most effective aspects of this training device. Examples of TAT use are presented in Figures 4 and 5. Figure 4 shows a classroom reconstruction of the immediately preceding exercise (i.e., feedback during debriefing). This reconstruction, which is automatically presented on the classroom large screen display, shows ownship track through the exercise (indicated by the successive line of ownship images), and those of other contacts during the problem (A and B). The primary contact during this collision avoidance training exercise (i.e., contact A indicated by the black ship images) was the Give-Way vessel, required by international law to maneuver to avoid the impending collision. Ownship was the stand-on vessel required by law to maintain course and speed until safely passing contact A, or until it becomes apparent that contact A is taking insufficient action to safely avoid ownship, whereupon ownship must take action to avoid a collision. In this particular exercise, contact A did not take early and substantial action, and took action only shortly prior to a collision with ownship. Ownship, on the other hand, prudently executed action as a stand-on vessel to avoid a collision after it was apparent that contact A was not acting prudently. However, although not prohibited by the international rules-of-the-road from doing so, ownship maneuvered to port rather than starboard. Contact A did take late action, and also maneuvered in the same direction as ownship, thus ultimately creating a near collision.

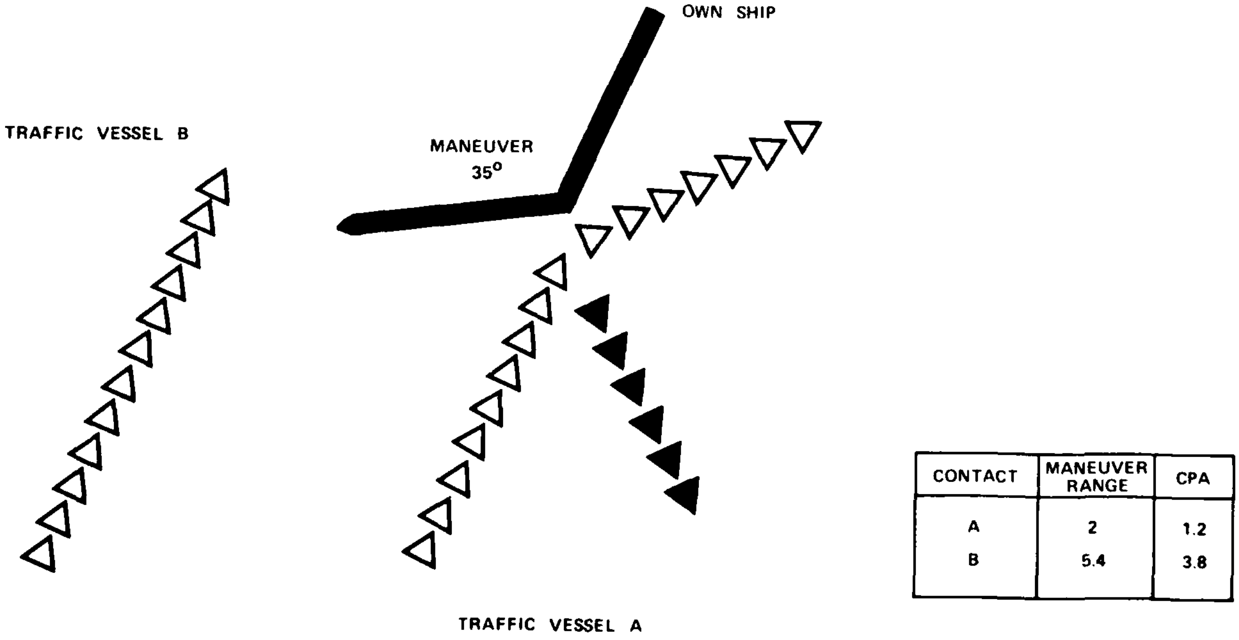
The postproblem briefing would typically play back the scenario in fast-time, keying on the events as they occurred and the relevant information (i.e., range to all contacts, projected time of collision with contact A, ownship maneuvering options available, and so on). These data are automatically collected on the training device and made available for presentation throughout the postproblem briefing. Range to the various contacts, for example, is presented on the feedback display of Figure 4, corresponding to the current time, and updated accordingly as playback occurs. Hence, this feedback display would be used to discuss the scenario that was just completed on the simulator/training device.

The focal point of feedback in this example would obviously be the selection of the ownship maneuver to port, rather than starboard. As noted above, the port maneuver is not prohibited. However, the rules-of-the-road suggest a maneuver to starboard, because of the potential of a late give-way vessel maneuver as occurred in this particular scenario. The instructor would discuss maneuvering options available to ownship as the stand-on vessel, particularly starboard maneuvers. Perhaps the students were concerned with contact B which appears to present a maneuvering constraint to



CONTACT	TIME	RANGE
A	–	–
B	–	–

Figure 4. Collision Avoidance Scenario Feedback Display



CONTACT	MANEUVER RANGE	CPA
A	2	1.2
B	5.4	3.8

Figure 5. Alternative Actions Example

the starboard side. The alternative actions TAT capability would be used at this time to investigate alternative maneuvering options available. Figure 5 shows one such alternative. The alternatives (i.e., ownship course change and time or range of maneuver) are entered by the instructor, rapidly calculated by the computer and added to the feedback display as shown in this figure. Appropriate performance indicators and scenario variables are also generated and presented. In this example, an ownship maneuver of about 35 degrees at a range of about 2 miles from contact A would have resulted in an acceptable passing distance with contact A, whether or not A maneuvered; and would not have developed into a close situation with contact B. Additional maneuvering options could be investigated in a similar manner.

The use of the TAT capabilities enabled the instructor to reconstruct the scenario and present a detailed playback picture of the events that occurred, and to conduct an in-depth discussion of the student's actions. Furthermore, these capabilities enabled the instructor to investigate alternative actions (i.e., learn-by-example) across the appropriate range of potential maneuvers available, and thus provide the students with an understanding of the range of options available, and their likely outcomes.

Research conducted for the U.S. Coast Guard (Gynther, 1981)(7) has shown that application of these TAT capabilities to a ship bridge trainer resulted in a more effective shiphandling training process. Prior to this application of TAT, ship bridge training devices provided relatively little capability for instructional support. Other of the TAT capabilities are also resident on this ship bridge training device.

Sonar Training

The skills and knowledge required to function as a proficient sonar operator and sonar team are different from those of both submarine tactics and shiphandling. The sonar team conducts a constant search of the ocean environment relying on both active and passive sonar devices, studying both aural and visual information. Upon detecting a noise source that might be a contact of interest, classification procedures begin using various processing devices, again using both aural and visual information. After the noise source has been classified as a contact of interest, tracking begins. Tracking can be manual with one or more sonar operators manually training sonar beams on the contact of interest as it moves through the environment, or can be automatic via sophisticated tracking devices. Training for sonar operators and the sonar team occurs at-sea using the actual sonar equipment, and on shore-based training facilities using sophisticated sonar training devices.

Although the particular skills and knowledge are substantially different from those of tactics training, the SMARTTS-type generic TAT capabilities are applicable. For example, capabilities such as the automatic generation of PI's and SV's and their presentation on information displays are important tools that can be used by the sonar instructor to enhance the sonar training process. Once again, the automatic collection and recording of these data, and having them available for presentation to the students during the postbriefing (i.e., as feedback) should substantially improve the sonar operator/student's understanding of the sonar problem and his performance.

An example of the use of several TAT capabilities is presented in Figure 6. The ability of each individual sonar system to detect a contact depends on the particular characteristics of the contact, the manner in which the equipment is set-up, and other factors. Assume that the training objective in this example addressed equipment line-up. The feedback display presented in Figure 6 would be used by the instructor to address the range of coverage actually achieved by the equipment line-up used during the immediately preceding scenario. This display would be presented in the classroom during the debrief. The area of coverage achieved by the sonar team shown on this display as line-up A. A 360 degree area of coverage around ownship was achieved out to a range of XX yards. At the outer boundary of this area a 50 percent probability of detecting targets of interest exist. Targets further inside this area would have a higher probability of detection. The areas of coverage that would be achieved with alternative equipment line-ups are also included on this feedback display. For line-up B (e.g., particular filter settings) a 360 degree area around ownship would be covered out to a range of YY. This YY sonar range is substantially less than that actually achieved by the sonar operator/students, which was a range of XX yards. However, equipment line-up C would achieve a range of coverage slightly greater than that achieved by the sonar operator (i.e., a range of ZZ yards).

This type of feedback information and investigative capabilities are unavailable in the current sonar training devices. Although the existing trainers are excellent, they do not have the added training assistance technology capabilities which can substantially assist the instructor in conducting an effective training process. The very simplistic type of information presented in this example would have to be presented verbally by the instructor, and even then the instructor would not have the capability to rapidly determine the appropriate ranges of coverage. This initial feedback display showed the performance achieved by the operator/trainees during the problem in the form of visual feedback. The alternative actions capability enabled the instructor to expand that problem and address the line-up options available to the students, and their likely outcomes. This would help to both reinforce appropriate performance by the operators, and to identify and help overcome areas that require improvement.

Surface CIC

The SMARTTS-type TAT capabilities have been investigated for their applicability to the training of surface CIC teams. A variety of recommendations for the incorporation of TAT

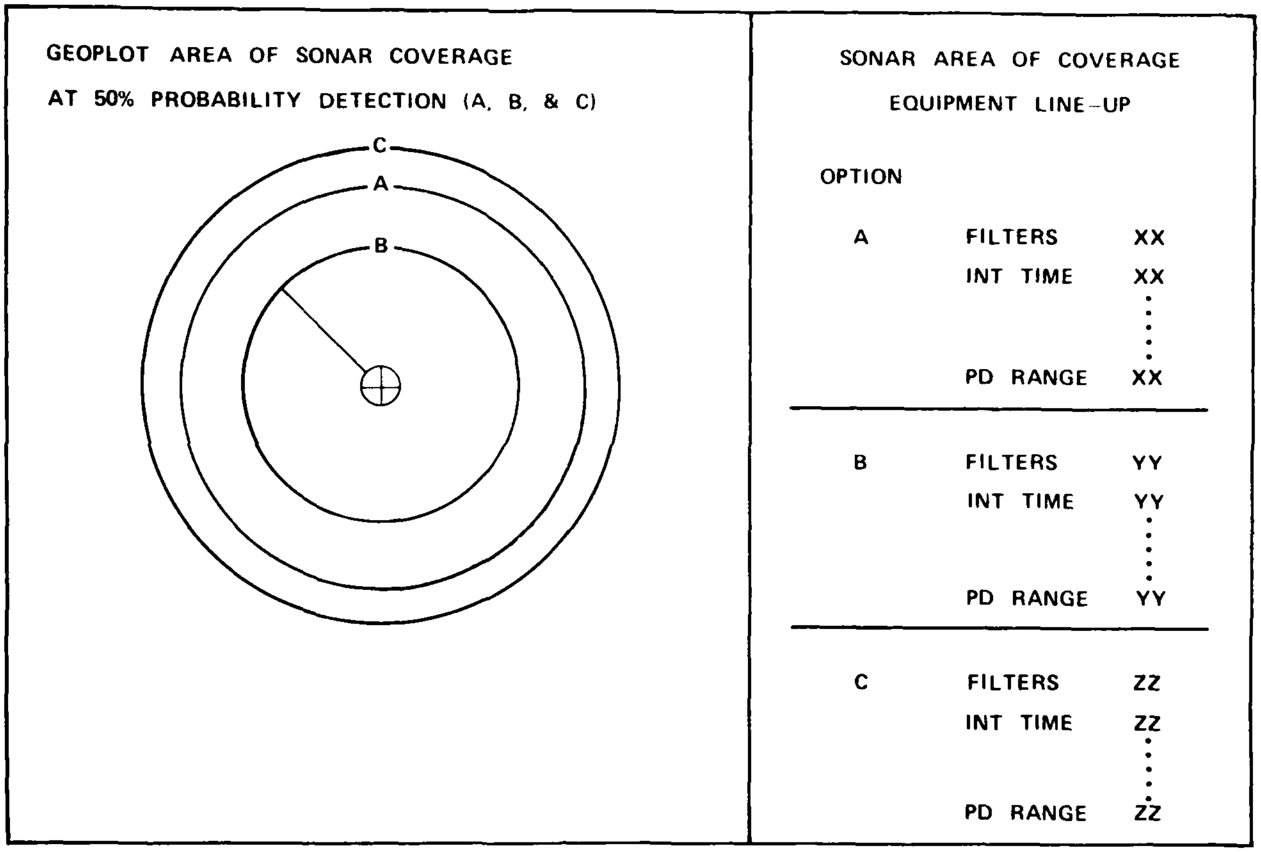
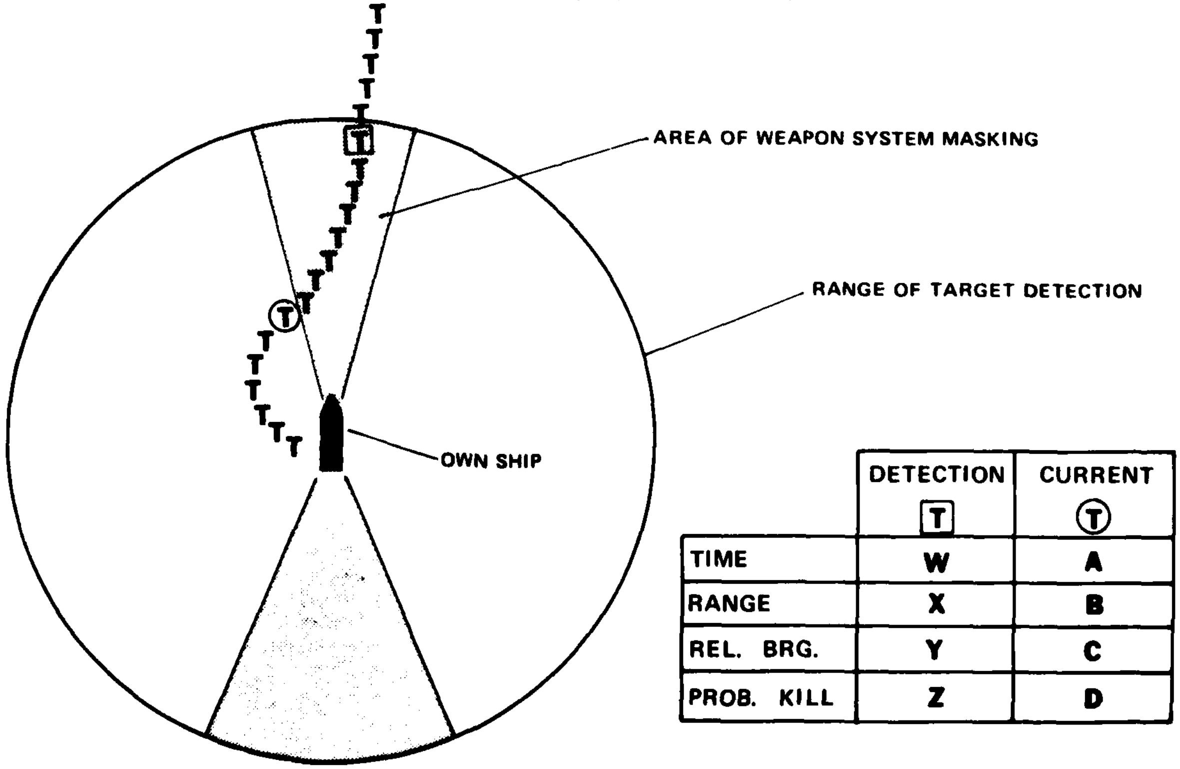


Figure 6. Simplified Hypothetical Feedback Display For Sonar Training, Addressing Equipment Line-up



	DETECTION T	CURRENT Ⓣ
TIME	W	A
RANGE	X	B
REL. BRG.	Y	C
PROB. KILL	Z	D

Figure 7. Feedback Display Showing Target's Relative Track and Weapon System Masking

capabilities was forthcoming from this investigation (Natter, Hammell, and Shortall, 1981)(8). The types of generic capabilities discussed above were recommended, again with the specific content required to be developed specifically for the surface CIC problem.

An example of the use of TAT in CIC training addresses the unmasking of a weapon system to engage an incoming target. Most surface vessels are designed such that certain weapon systems are prevented from firing in certain relative directions since the ownship super structure (other gun mounts, etc.) would interfere with the outgoing ordnance. Hence, it may be important to unmask a particular weapon system prior to firing at the target; this would involve an ownship maneuver to position the ship to enable the weapon system to have a clear shot at the target. The time and manner in which unmasking should occur is dependent on a number of factors related to the particular problem situation. Generally speaking, it is desirable to unmask the weapon system as soon as possible, thus allowing a weapon to be fired at the earliest appropriate time.

An example of a feedback display pertaining to weapon unmasking is presented in Figure 7. This would be used in a manner similar to the examples presented above, during the postbriefing session in the classroom. The display format shows the range of radar coverage of ownship along with the areas of weapon system masking (i.e., shaded areas in the figure). The incoming target position and track is shown by the series of T symbols, developed in fast-time during playback. The target was detected by ownship radar at a relative bearing on which the particular weapon system was masked (see Detection Column in figure). As the problem develops during playback the operator trainees can see the track of the target as well as the point at which the ownship maneuver unmasked the weapon system. In this feedback display example the instructor could investigate target range and bearing at various points in the problem (i.e., current time is indicated by T on the display, with appropriately corresponding data in the alphanumeric table) by manually stepping through the scenario time increments. Ownship maneuvered to unmask the particular weapon system, in this example, and achieved unmasking at time "A", with a corresponding probability of kill of "D". Alternative actions could be used to investigate the impact of earlier or later maneuvers, or different types of maneuvers, on relevant PI's (i.e., such as the probability of kill).

This example presents the application of TAT capabilities specific to CIC team training, although again the capabilities themselves are of a generic type (i.e., automated performance indicators and information feedback displays). Their applied use in this example is different from those presented above, although the fundamental elements of the training process are similar (e.g., visual feedback). The particular application of the TAT capabilities depends on the many considerations surrounding the particular training application.

SUMMARY

The common thread across the above three examples of the application of SMARTTS-type training assistance technology has focused on the postproblem briefing using objective performance indicators that have been automatically collected and presented as feedback to the trainees via a classroom information display. Additionally, in several examples an alternative actions capability was used to expand the investigation to the various options available and their likely outcomes. The generic capabilities have been the same in each of the examples, although the specific content differed and was tailored to each. The training process, of course, was basically the same across each of the three areas investigated -- the types of skills and knowledge to be trained were generally of a cognitive decisionmaking nature, requiring an in-depth understanding of the relationships between a variety of parameters, and their trade-offs in achieving operational goals.

The training strategy under which the TAT capabilities would be used, may differ substantially for each training application. For example, at a basic level of training considerable immediate feedback presenting the automated performance indicators on feedback displays in the operational environment itself may be desirable; conversely, at intermediate and advanced levels of training the feedback should be delayed and presented during a postproblem briefing.

These examples demonstrate how instructor and trainee interface capabilities can enhance the training process when added to the simulation capabilities of training devices.

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Dr. Thomas J. Hammell, Vice-President, Research and Development, Ship Analytics. Dr. Hammell directs research and development programs addressing the design and application of advanced training technology, simulator-based training systems, and the person interface in complex systems. His work has addressed merchant marine, U.S. Coast Guard, and also Navy training systems; submarine tactics and sonar, surface ship CIC, and commercial nuclear power plant training systems. Dr. Hammell was the Program Director for SMARTTS, as well as the principle investigator during the series of projects originally conceiving and investigating the Training Assistance Technology/SMARTTS capabilities. He holds educational degrees in Electrical Engineering, Management Science, and Experimental Psychology. Dr. Hammell is the author of numerous reports and papers in the fields of training and human factors.

THE PLATOON GUNNERY SIMULATOR (PGS) : A REAL TACTICAL TRAINING TOOL

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ABSTRACT

The training requirements and the project schedule for the PGS (Platoon Gunnery Simulator) will be presented by the French counterpart of the PM Trade. Then the firm under contract for the design and manufacture of the PGS will give a more detailed presentation of the equipment, emphasizing the system features : - an equipment unique in its kind, providing combat training in a classroom for the crews of a platoon of tanks - total compliance with ergonomic aspects - extraordinary detail and realism of the landscapes into which are inset up to 8 fixed and/or mobile targets - consistent representation of all the effects of firing (noise, flash, recoil, observation of the shell trajectory) - perfect adaptation to each type of turret - versatile and easy to use for the instructors.

Two simulators are to be delivered to the French Army in 1984 - 1985.

PGS PROGRAM DESCRIPTION

In 1979, the French Army Staff Headquarters issued a requirement for a training device providing initial training and continuation training for crews of AMX30-B, AMX30-B2 and AMX10-RC tanks.

Objectives

Classroom training and instruction for tank crews in all the listed combat actions (observation roles, observation, detection, reconnaissance, identification, allocation of targets, engagement of targets by main gun with appropriate firing sequence, adjustment of aim for second shot). These objectives need a representative (high fidelity), realistic and high performance training tool.

1. Who is to be trained

(a) The two most important members of the turret crew - the tank commander and the gunner.
(b) All the "pairs" (gunner and commander) from the tanks in a platoon under the command of a platoon commander.

Justification : It is generally true that platoon commanders are either excellent platoon commanders, in which case they tend to lose touch with their own tank ; or they are excellent tank commanders who tend to lose touch with the platoon.
Platoon commanders must therefore be specially trained in company with the tank crew teams they are commanding. Only a high performance training tool incorporating effective monitoring devices and operated by one or more instructors is capable of solving this training problem.

2. Simulator destination. Two simulators have been ordered :

No. 1 Pre-range training with platoon gunnery at CPCIT, CANJUERS.
No. 2 Ecole d'Application de l'Arme Blindée et de la Cavalerie at SAUMUR (school roughly equivalent to Fort Knox).

3. Staff Headquarters recommendations and requirements.

(a) Visual system of high quality. The landscape must have excellent definition, enabling targets such as tanks, helicopters and all-terrain vehicles to be detected in a real vegetation at ranges up to 3500 meters in daylight.

(b) The device must be fully utilized. To achieve this, the device must have the following qualities :
- simplicity of use,
- realism of scenarios, turret space, aiming and firing sequences and effects of fire,
- reliability.

(c) The device must have reasonable acquisition and maintenance costs, and provide :
- reduction of instruction and training time, accompanied by an improvement in quality of gunnery,
- savings in resources such as carriers, fuel, ammunition, ranges.

(d) The device must be set up as quickly as possible, ideally in the same time as the operational equipment.

(e) The device must be capable of being easily modified to keep pace with changes to the operational equipment and its uses.

4. Organization of the analysis, design and manufacture

The French Army Staff Headquarters gave the DTAT responsibility for developing the program. This responsibility was delegated to the electronic center, the SEFT. THOMSON-CSF Division Simulateurs was chosen to design and manufacture the simulators and provide logistic support. Previously, at SEFT's request, THOMSON-CSF participated in discussions with various Staff Headquarters subordinate organizations to delineate the capabilities of currently available techniques. The outcome of this analysis phase was a good definition of the two identical simulators in the form of a precise, detailed and complete design specification. Subsequently, THOMSON-CSF was awarded the contract, but the discussions continue in the form of four permanent working groups (Man/machine interfaces, Scenarios/exercises, Facilities, Role of the instructor and definition of the instructor's station).

5. Schedule

Preliminary statement of requirement	III/79
Analysis	III/79 to III/80
Final statement of requirement	III/80
Design specification	I/81
Contract award	III/81
Acceptance of 1st PGS	II/84
Delivery of 1st PGS	III/84
Acceptance of 2nd PGS	I/85
Delivery of 2nd PGS	II/85

PGS TECHNICAL DESCRIPTION

PGS is, at the present time, *the only* genuine platoon gunnery simulator in existence. Its innovative aspects lie both in general performance and in the technical designs of visual and recoil generation systems. We shall give subsequently :

1. the PGS general description

2. description of the visual and recoil generation systems.

PGS GENERAL DESCRIPTION

The PGS achieves simultaneous basic and tactical training of crews of 3 turrets either in individual or in platoon mode.

Personnel to be trained are :
- 1st turret : 1 platoon commander and 1 gunner
- 2 nd turret : 1 tank commander and 1 gunner
- 3 rd turret : 1 tank commander and 1 gunner

The platoon has to react to tactical situations occuring in a 90° forward angle. Hull-up and hull-down movements are simulated and so are relative occultations resulting from distances between each of the three turrets on the field. Main features of PGS are given in tables below. They confer to the PGS the following characteristics :

- high training realism,
- multipurpose simulation,
- variety of operational conditions,
- powerful and easy-to-use instructor's facilities,
- maintainability,
- flexibility for future evolution.

(a) High training realism. A highly realistic environment was one of the major basic requirements. This realism is necessary when simulating the mechanical, visual and aural environments.

- Mechanical environment. Simulator turrets faifhfully reproduce the internal arrangement of real turrets. This is achieved by means of well known techniques using both real and simulated equipment. An important initial requirement was to provide the simulator with a good recoil simulation. It is very important to train pupils not to be taken by surprise when they fire, remaining ready to observe their own results. It is therefore a must to have a good mechanical reproduction of the recoil effects when rounds are fired. For this purpose, the PGS includes a very realistic recoil system acting not only on the sights but on the whole turret. The design of this system is described in detail belows.

- Visual environment. The quality of a gunnery simulator is closely linked to the quality of its visual system. Training in tactical operations such as observation and detection of targets in the landscape requires a particularly high degree of realism in visual simulation. Basic requirements of this visual system are given in the tables above. System design is described in detail below.

- Aural environment. PGS reproduces main sound effects such as - report when shot is fired - idling noise of the main engine - turret drive system.

(b) Multipurpose simulation, versatility, flexibility. PGS is designed to meet all the training needs of the training centers.

- Functioning according to different modes : Platoon or separate crew mode. The instructor has the capability of programming simultaneous training of the three turrets facing a common tactical situation (platoon mode). In this case, each turret can observe the firing effects of the other turrets in the platoon. Platoon training can be conducted by a single instructor. Separate training can also be achieved (separate crew mode). In this case training of each turret is quite independent. Separate mode requires 3 instructors.

PGS MAIN FEATURES

- CREWS TRAINED SIMULTANEOUSLY = 3 TURRET CREWS

TANK COMMANDER	PLATOON COMMANDER	TANK COMMANDER
GUNNER	GUNNER	GUNNER

- TRAINING AIMS

	TURRETS TRAINING	. INITIAL TEST OF TURRET (FIRE CONTROL, RADIO, SIGHTS ...) . DETECTION, RECOGNITION, IDENTIFICATION OF TARGETS . AIMING . USE OF FIRING SYSTEM (QUICKLY AND ACCURATELY) . FIRE OBSERVATION AND ADJUSTMENT . MALFUNCTIONS
PLATOON TRAINING		. COMMUNICATION BETWEEN TURRETS, AND WITH THE INSTRUCTOR(S) . ALLOCATION OF TARGETS BY PLATOON LEADER . FIGHTING AGAINST 8 TARGETS IN THE COMMON LANDSCAPE . PLATOON FIRE OBSERVATION AND ADJUSTMENT

- SIMULATION FIRING EVALUATION CAPABILITIES :

  - PLATOON TRAINING = FIRE COORDINATION BETWEEN TURRETS
  - PLATOON AND TURRET TRAINING = FIRE QUALITY :

    . SUCCESSION OF BASIC PHASES OF FIRING SEQUENCE
    . ACQUISITION OF FIRING PARAMETERS (WIND ...)
    . AIMING, RANGEFINDING (DOUBLE-ECHO), TACHIMETRY ...
    . FIRING
    . ADJUSTMENT OF FIRE FOR NEXT ROUND

- STATIONARY POSITION . HULL-UP, HULL-DOWN MOVEMENTS
- TURRET TYPES :

  3 x AMX 10 RC
  or 3 x AMX 30 B2
  or 3 x AMX 30 B

- TRAINING MODES

  - PLATOON MODE (PLATOON + TURRET TRAINING)
  - SEPARATE CREW MODE (TURRET TRAINING)

- SIMULATION OF ALL PLATOON VIEWING DEVICES WITH PROPER MAGNIFICATION

  - GUNNER SIGHTS
  - TANK COMMANDER SIGHTS
  - PERISCOPE

- SIMULATION OF RECOIL EFFECT ON THE WHOLE TURRET

- RELATIVE OCCULTATIONS RESULTING FROM DISTANCE BETWEEN TURRETS

- N.B.C. TRAINING

PGS VISUAL MAIN FEATURES

LANDSCAPE

- REALISTIC : COLOR
  NATURAL TERRAIN FEATURES
  HIGH RESOLUTION
- CHOSEN BY USER
- FIELD OF VISION (F.O.V.) = 90°
- EASY TO PROVIDE ADDITIONAL LANDSCAPES
- EASY TO CHANGE
- VARIOUS LIGHTING CONDITIONS

TARGETS

- REALISTIC
- STATIONARY - MOVING
- MANY SIMULTANEOUSLY (UP TO 8)
- DIFFERENT TYPES : MAIN BATTLE TANK
  LIGHT ARMORED VEHICLES
  HELICOPTERS
- REALISTIC ATTITUDES ACCORDING TO THE TERRAIN. INTELLIGENT BEHAVIOR.
- MASKING EFFECTS : TARGETS - TARGETS
  TARGETS - TERRAIN
- HIGH DETECTION/RECOGNITION RANGES

FIRING EFFECTS

- GUN FLASH AND SMOKE
- IMAGE MOVEMENT IN SIGHTS WHEN SHOT IS FIRED
- TRACER WITH PROPER BALLISTICS (AMMUNITION TYPE, WIND...)
- IMPACT ACCORDING TO : AMMUNITION TYPE
  GROUND
  WIND
- MASKING EFFECTS : IMPACT - TARGETS
  IMPACT - TERRAIN

- Training on any type of tanks. French PGS allows training on three different types of tanks : AMX10RC, AMX30B, AMX30B2. The PGS includes :

  - 3 AMX10RC simulated turrets
  - 3 AMX30 (B,B2) simulated turrets.

Switching between AMX10RC and AMX30 (B,B2) training is achieved by :

- changing of simulated turrets (crews move from one turret type to the other).
- selection of appropriate software program by the instructor.

Switching between AMX30B and AMX30B2 training is achieved by :

- subsitution of specific equipment in the simulated turrets.
- selection of appropriate software program by the instructor.

These operations require only a few minutes.

(c) Variety of operational conditions. One of the major requirements was to provide a large number of exercices. The reasons were :

- To have a set of progressively difficult lessons.

- To achieve effective training by preventing the trainees from becoming accustomed to repetitive tactical situations.

The PGS gives the following capabilities :

- Several landscapes : Initially, units are delivered with 2 different landscapes. Simulator design makes it possible to change the landscape on the simulator and to create new landscapes very easily.

- Large number of pre-programmed exercices (200).

- Possibility of modifying a set of parameters such as target speed - wind - temperature - optional recoil effects - at any time.

- Several kinds of targets - main battle tank - light armored vehicle - helicopters.

- Insertion of malfunctions of firing system.

(d) Powerful and easy to use instructor's facilities. An ergonomic study by the users and manufacturer established two requirements :

Versatile instructor stations capable of :

- programming of various exercices,
- modification of main exercice paramaters,
- supervision of trainees actions - display of firing results - use of training aids such as play-back, freeze, trainees evaluation ... etc.

Easy-to-use equipment : all these functions are achievable by means of very simple operations.

(e) Maintainability. Maintainability factors were taken into account at the very beginning of the design of the PGS. Proven technologies and a modular design have been used whenever possible. A full set of built-in tests are provided to achieve :

- Quick tests to check the overall correct operation of the simulator.

- Diagnostic tests for the visual system isolating the faulty board (and often the faulty components on the board).

- Adjustment tests and associated tools for easy bore-sighting of the system.

(f) Flexibility for future modifications. It was of great importance to provide the PGS with the capability of being modified as a result of changes in operational or technical requirements. Here we can give some examples of the possibilities of evolution which have been taken into account in the initial design :

- Addition of a 4th turret in the platoon.

- Additional landscapes.

- Additional types of targets.

- Night firing.

- Head up and binocular vision.

- Programming of exercices by the instructors.

- Additional simulated sound effects (closing of breech, cartridge ejection).

- Adaptation to any king of firing system.

VISUAL SIMULATION

General organization

The visual simulation system is designed to provide independent images for the various viewing devices of the turrets. These viewing devices are the following :

- Sights : PGS provides each sight with images at the correct magnification. Each sight allows independent observation anywhere in the landscape. The sights simulated are the gunner and tank commander primary and auxiliary sights. Identical performance is simulated for primary and auxiliary sights of the same trainee. This allows the use of only one generation system for both sights. Therefore, the total image generation system consists of 6 independent sights simulations (3 gunners and 3 tank commanders).
- Periscopes : the three frontal periscopes of each turret are simulated. Together they cover the field of view of 90° (3 x 30°), equal to the total field of view (FOV) of the simulation.

3 main sources are used to build the images :

- landscape generator,
- targets generator,
- firing effects generator.

Landscape generator.

This source generates the images of a realistic color landscape over a 90° FOV for each viewing device, with appropriate magnification.

(a) Limitations of available techniques. A first step in our study was to investigate the use of available techniques. Unfortunately, all of them revealed some important limitations with regard to the requirements.

CGI systems have been developed and used in many aircraft applications. In the case of gunnery simulation, they have proven suitable when their application is limited to aiming and firing operations. But we have to rule them out as soon as tactical training is considered. This is currently due to their lack of realism for a reasonable price. If and when future improvements in this technique make them suitable for these applications, PGS configuraticns may then be able to utilize them.

Model board techniques give a relatively high degree of realism. This advantage, together with a reasonable cost makes them particularly suitable for some applications such as Tank Driving Simulators. Unfortunately, model board techniques have a serious limitation in that it is pratically impossible to insert a large number of moving objects (targets, firing effects) while ensuring a high flexibility in their trajectories and attitudes.

Another solution is to store a digitalized photograph of the landscape and to observe at any moment the relevant part of it for each viewing device. Such a solution requires high capacity memories when color and many viewing devices are requested. It also requires high data exchange speed between mass memory and working memories.

(b) PGS solution : flying spot scanners. The chosen solution consists of a color slide and a flying spot scanner for each viewing device. The color slide represents the whole landscape at magnification dependent on the field of view of the simulated sight.

The flying spot scans the portion of the landscape to which is directed the object lens of the simulated sight. It delivers a high resolution color TV signal (875 lines). Aiming of the gun in azimuth and elevation is simulated by moving the landscape slide. Slide movements are produced by a carriage system servo controled by the general purpose computer in accordance with operation of the aiming controls.

The flying spot scanner system has the following advantages over a TV camera : 875 lines standard resolution, no registration problem, easy to adjust, better signal to noise ratio.

The advantages of this solution are the following :

- high realism, due to the color slides,
- high resolution due to 875 lines TV standard,
- ease of adding new landscapes,
- ease of changing landscapes,
- possibility of inlaying moving objects (targets, firing effects) by the use of TV techniques.

Target generator

The target generation system inlays up to eight targets in every viewing device of the PGS. Attitudes of targets are very faithfully reproduced according to the terrain.

We have chosen a specific technique which constist of :

- storing every possible target attitude in a digital library,
- inlaying the correct attitude in the terrain image after processing (size adjustement, masking effects, etc...).

The following paragraphs give a brief explanation of the target processing which is achieved by mean of a fast computer CRP 24 especially developped by THOMSON-CSF for visual applications.

(a) Target storage. Every possible attitude of the target in rotation, roll and pitch is stored on a disk.

The number of different attitudes is 2500. The angular increment varies from 1° to 3° according to the position of the target (front of lateral position). These increment values give excellent continuity in target movement. Size of the stored targets correspond to the largest apparent target size according to target type, target range and sight magnification.

Each attitude is stored in a matrix of 64 x 32 points. PGS is provided with files corresponding to three target types :

- main battle tank,
- light armored vehicle,
- helicopter.

(b) Choice of correct attitude. The general purpose computer also includes a file describing the relief of the landscape. This file is organized as a grid of altitudes. Minimum distance between 2 altitudes is 30 meters. This is sufficient to faithfully describe the relief.

At any time the computer can choose the correct attitude by comparing the position of the target with the relief file.

Use of a high resolution TV standard gives long detection or recognition range. The table below gives the resolution in TV lines of a target 2.5 m high, seen through a simulated optical system of 107 milliradians (sight) and 533 milliradians (periscope).

Target range	Resolution	
	FOV 107 mrd	FOV 533 mrd
800 m	24 lines	5 lines
2000 m	10 lines	2 lines
3500 m	6 lines	2 lines

(c) Masking generation. The general purpose computer possesses a masking file describing the outlines and ranges of landscape elements.

Descriptions of masks around targets are input to the fast comput CRP 24 which processes the masking priority between target, firing effects and landscape.

We must stress how easily the relief and masking files are created. They can be generated by semi-automatic procedures using PGS equipment.

(d) Scale processing. The fast specialized CRP 24 computer performs real time scale processing on tagets according to :

- their range,
- sight magnification.

(e) Target inlaying in the landscape. Each target is inlayed in the lanscape image of each viewing device by means of video techniques.

Anti-aliasing is used to provide very continuous target motion in the image (increment of 1024 pixels on a TV line).

(f) Target Trajectories. Target trajectories are defined in a very simple way in a specific file containing segment descriptions. Insertion of targets trajectories in the landscape is then achieved automatically by means of the processing described above.

Creation of new trajectories can be easily accomplished by the user. This operation requires no equipment other than the existing equipment of the simulator.

Targets can be assigned an intelligent behavior. A program sends them realistically to the nearest cover when they come under fire from the platoon.

Firing Effects Generator

Simulation of the visual effects related to firing consists of reproducing :

- the effects when the shot is fired - burst of flame, then smoke interfering with observation,
- the tracer of each shell,
- the effects of impact - explosion, smoke, target hit.

(a) Firing of the Shot. The simulator reproduces the difficulties of observation when the shot is fired, created by the burst of flame from the gun muzzle and the smoke.

These effects are simulated as follows :

- burst of flame : yellow coloring of the images observed through the simulated sights,
- smoke : transition from yellow to white of the images observed through the simulated sights. The smoke then gradually dissipates.

(b) Tracer

- The tracers of all the shells fired are simulated.

- The shell's trajectory faithfully simulates the real trajectory. It takes into account the ballistics specific to each type of ammunition and the influence of cross-wind, air temperature and altitude.

- Dipersion of the weapon/ammunition pair is simulated by random functions, highly representative of real dispersion.

- The tracer is masked when the shell penetrates a "soft" mask (bushes, leaves) and when it passes behind a "hard" mask (building, tree trunk or the target itself) but does not hit it.

(c) Impact. The flash and smoke of impact are displayed in the periscopes and the sights. In platoon mode, the same impact can be observed by all the turrets of the platoon.

In individual mode, the crews see only the impact of their own shells.

- Target hit : this hit is viewed as an explosion with release of yellow light. The target which has been hit continues to move a few meters under its own impetus then stops after turning blackish.

- Target miss : in the event of a target miss, impact of the shell on the ground is viewed as a release of smoke, the amount of which varies according to the type of ammunition and the shape of which depends on the cross wind. The smoke may be fully or partially masked when impact with the ground occurs behind the target, a building, a clump of trees or in a fold of the terrain. It may also mask a target or a terrain feature when it takes place in front of the target or terrain feature. All these effects are generated by video methods.

RECOIL SIMULATION

Purpose

A very realistic simulation of recoil was a key initial requirement. In this simulation, we have developed a recoil system moving the whole simulated turret.

Description

Turrets are mounted on guide rails.The recoil simulation system moves the cabin horizontally in the axis of the gun when shots are fired. The amplitude and variations of the movement as function of time are such that the crew perceives it as the recoil due to real fighting. The recoil simulation system includes :

- a fixed structure with anchor points for the guide system,
- a moving structure to which the cabin is attached,
- a pneumatically controlled motion system recreating : - a violent reaction at gun recoil and longitudinal oscillations - the damped return of the turret to its initial position.

The recoil system includes protective systems designed to ensure personnel safety.

Simultaneously, the images through the sights move vertically, giving the trainees complementary cues of turret motion due to the firing effect.

TRAINING PGS POTENTIAL

Preliminary tests conducted in 1979 on a research prototype gave the conclusions of the next table.

TRAINING PGS POTENTIAL (Example)
(8 hours/day - 21 days/month)

CREW TRAINING	PLATOON TRAINING
DAILY	
96 exercices 15'each	16 exercices 30'each
1400 shells	1000 shells
MONTHLY	
2000 exercices	330 exercices
30000 shells	20000 shells

The equipment is capable of being used if necessary, 16 hours a day, 7 days a week.

CONCLUSION

PGS appears to be an efficient tool to achieve basic and tactical training of platoon crews.

Operational advantages of PGS are twoflod :

(a) Training is more realistic than on an exercice terrain because the simulation gives a better approach to combat situations. This has been proven by the research prototype. Reasons are the following :

- the battlefields are absolutely natural and more realistic than the bare, shell raked firing ranges on which the location and displacement of the targets is overly familiar to the crews.
- the battlefields are interchangeable, which is not the case with firing ranges of which only a limited number exist.
- the targets are identificable and viewed at all attitudes.
- as in combat, the targets bound, zigzag in open country, remain exposed for a minimum time and are difficult to detect and hit.
- as in combat, the large number of enemy attack scenarios make it impossible to remember previous target trajectories.
- as in combat, when a target receives a direct hit, it blackens and stops moving.
- as in combat, a target under attack heads for the nearest cover.

- finally, and this is an essential point, simulation of the shot leaving the muzzle, its trajectory and its impact on the ground or the target, reproduces all the difficulties of tank gunnery and observation of the shots, and obliges the tank commanders to adjust the fire of the other vehicles in the platoon.

The multiple features of the PGS provide progressive training ranging from the initiation to gunnery procedures, to the tactical conduct of fire of a full platoon.

(b) Training is more effective and more rapid than with conventional means because :

- all the actions of a member of the platoon or a tank crew are immediately detected and any error can be corrected using the playback.
- continuous and detailed recording of firing results provides an objective evaluation of each crew member's performance, making a considerable contribution to crew motivation.

Innovative technical designs in the visual and recoil simulation bring a useful contribution to the family of existing systems. These solutions are ideal for many training applications (tanks, missiles, etc...). It is also interesting to note that the same techniques can be used to build turret simulators (gunner and tank commander) capable of being fitted in a tractor towed trailer, making it independent of all local infrastructures and readily available for use at different sites.

ABOUT THE AUTHORS

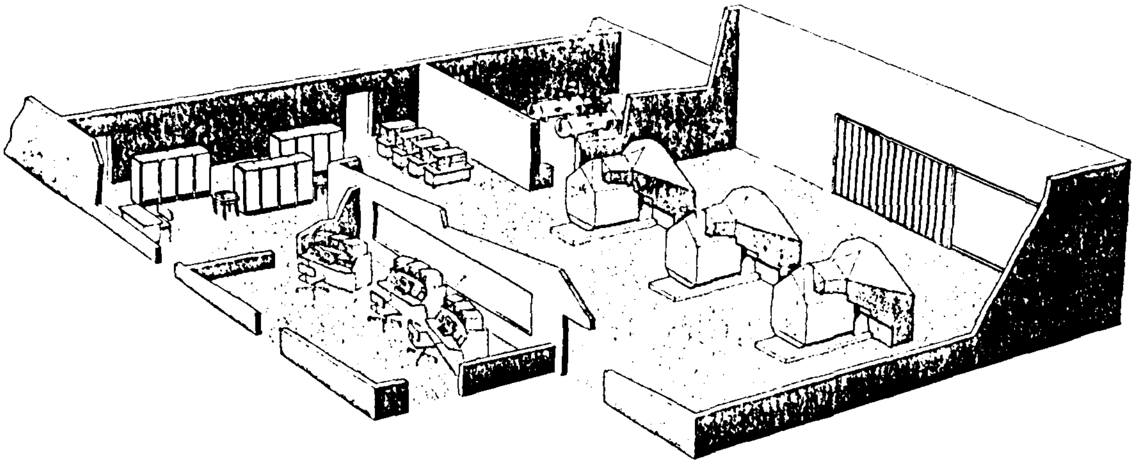
Claude J. QUINIOU, Ingenieur Principal l'Armement, obtained his engineering degree in 1964 from l'Ecole Technique Supérieure de l'Armement.

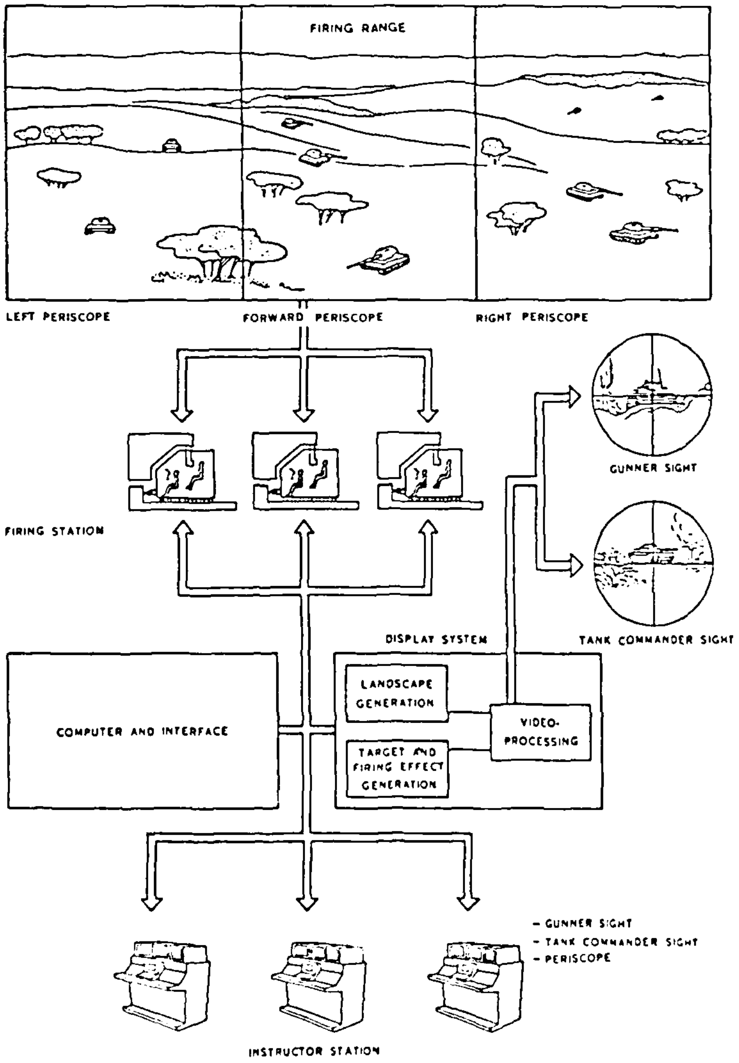
After graduating, he embarked on a career as a military engineer with the Délégation Génerale pour l'Armement which is directly attached to the Ministry of Defense. He is presently head of the "Anti-tank and Simulators" department at the SEFT, one of the technical centers of Direction Techniques des Armements Terrestres (DTAT), roughly equivalent to DARCOM. He is the counterpart in France, of the PM Trade.

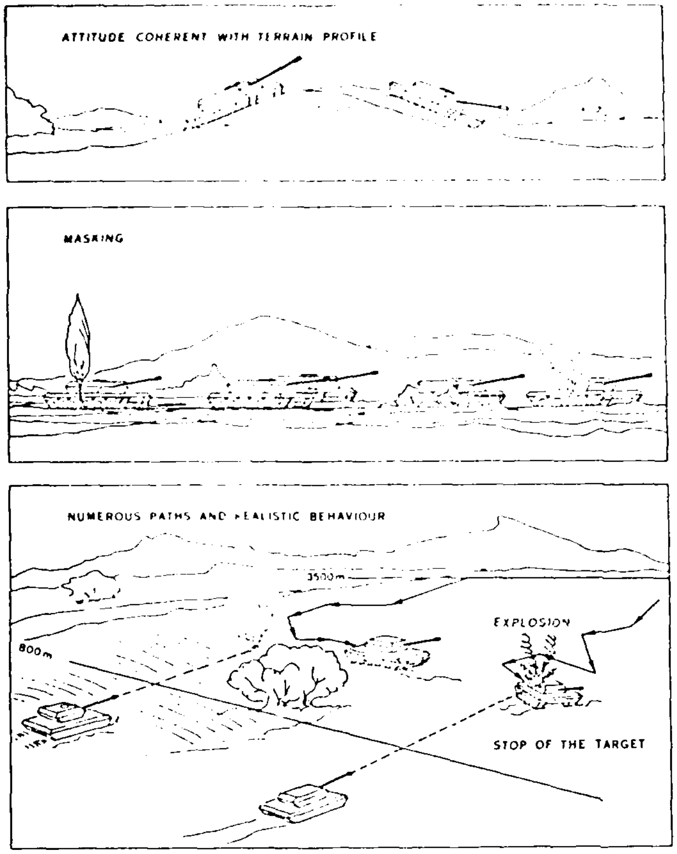
He assistant, Ingénieur de l'Armement Jean B. CORNELIUS, holds degrees from the Ecole Polytechnique (X 1971) and from the Ecole Nationale Supérieure des Techniques Avancées. Mr CORNELIUS has been with the SEFT since 1978 where he is a specialist in anti-tank and gunnery simulator problems.

Michel F. PERRIN is Project Manager for firing and driving simulators at the Simulator Division of THOMSON-CSF Company. He received an engineer IRG degree from Grenoble University in 1968.

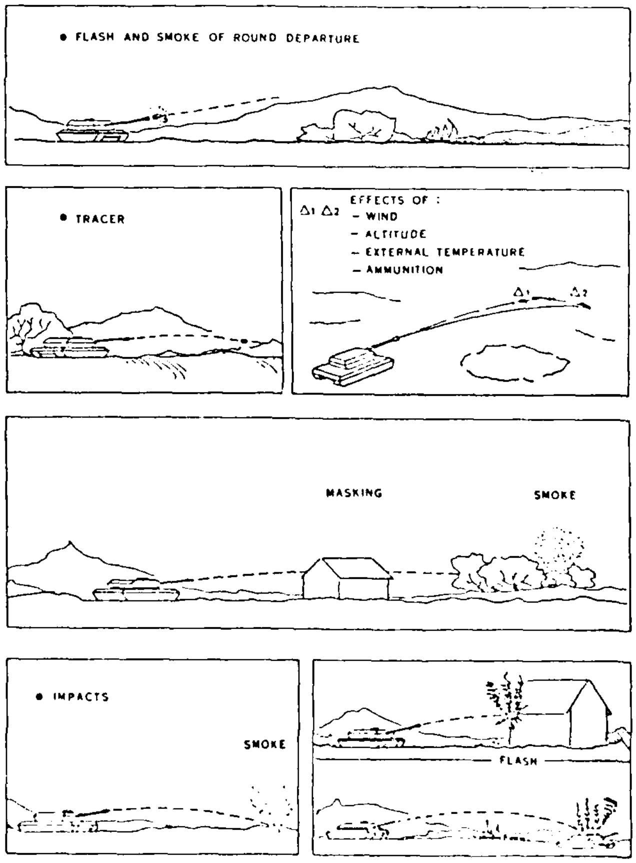
PCS GENERAL ORGANISATION







REALISTIC SIMULATION OF
TARGETS IN THE
LANDSCAPE



REALISTIC SIMULATION OF
FIRING EFFECTS

SYNTHETIC APERTURE RADAR SIMULATION

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ABSTRACT

During the 1980's, a new generation of airborne radar systems will become operational. These radars will have a number of new capabilities, but their synthetic apertures will have the greatest impact on simulation of the system since they provide a tenfold increase in resolution. Increased radar landmass simulator resolution is not the only problem implied by this increase. In particular, the sparsity of the DMA data bases presents a challenge in the generation of realistic images. Other new requirements include the simulation of anomalies caused by Doppler mapping. For the last two years, Link has conducted an R&D program to explore the requirements of these new generation radars. This paper reports on the results.

INTRODUCTION

Over the next decade, a number of new airborne radar systems will be introduced for such aircraft as the F-16, the F-15, the B-1, the F-5, and the F-18. These new multimode radars have significantly greater capabilities than present real-beam systems.

The new radars will enable users to perform a large number of new tasks and perform them much better than before. These radars have the following modes or capabilities: Real-Beam Ground Mapping, Synthetic Aperture/Doppler Beam Sharpening Ground Mapping, Ground Tracking, Terrain Avoidance, Terrain Following, Air-to-Air, Weather, Moving Target Indication, and Electronic Agility.

This multitude of capabilities allows the crew to perform missions not previously possible, but at the same time requires that the crew be given additional training. The present generation DRLMS systems are not adequate for this purpose. Doppler Beam Sharpening and Synthetic Aperture, two virtually indistinguishable modes, require the greatest changes in simulation technology.

TYPES OF MISSIONS

For strategic aircraft, the addition of synthetic aperture capability will primarily affect three tasks: navigation, weapon delivery, and damage assessment. In all three of these tasks the crew will be able to significantly improve its performance because, instead of the 100-foot resolution of real-beam radars, the new systems will have resolutions of 10 feet or less. Not only will it be possible to increase the accuracy of navigational updates, but also smaller landmarks not previously discernible, can be used as checkpoints.

For tactical aircraft the increased resolution means that the pilot will be able to use the radar to detect and identify targets, such as individual tanks, and to use the radar in weapon delivery on these targets. (See Figure 1.)

For both strategic and tactical aircraft, the crew must be trained to use the much higher-resolution image and to cope with some of the anomalies of synthetic aperture radars. The crew must also be trained to correlate radar and other sensor (IR and LLTV) images.

These goals can be reached only if the simulator can produce realistic images with resolutions typical of SAR and if the system can simulate the anomalies of SAR/DBS. Moreover, for effective training, the simulator should be able to reproduce the failure modes encountered in synthetic aperture systems.

In the following sections the limitations of the present hardware and data base for SAR simulation will be discussed, together with a proposed approach for a SAR DRLMS.

DMA DATA BASE

The DMA data base has four levels of detail. For any level, the data are organized into two files: terrain elevation file and planimetry file. The first of these contains only elevation data at grid points. All other information resides in the planimetry file, which consists of "features." A feature may be a lake, an urban development, a single house, or even a power pole. Each feature is described by a type code and a surface material designation. The geometry of each feature is defined by a series of vectors circumscribing the ground projection of the feature, together with its height.

The end points of the vectors are defined in terms of geodetic coordinates for all levels at a precision of +/- 0.1 arc second. This corresponds to about 10 feet at the equator, and less elsewhere. Consequently, the precision of the data is adequate for generating simulated SAR images. The deficiency of the DMA data base for very-high-resolution radar is in the amount of data included. Even the highest level of detail, Level X, by no means contain all objects 10 feet in size or larger; only features of tactical significance are encoded.

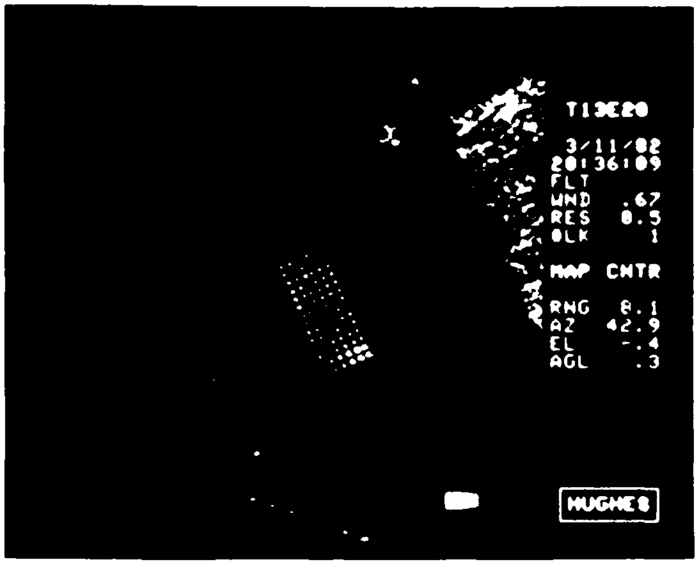

Figure 1 DEMONSTRATION OF THE 8.5 FT RESOLUTION CAPABILITY OF THE HUGHES APG-63 RADAR. ARRAY CONSISTS OF 84 TANKS, 11 FT BY 20 FT IN SIZE, 56 FT APART.

Most of the areas are covered only by the lowest level of detail, Level I. At this level a residential area may be described only as a single feature of several square miles, with a designated percentage of roof and tree cover. Individual houses or streets are not defined. Even highways are not included in most cases, although Edition 2 of Level I (to be issued shortly) will contain lines of communication.

Apart from lacking much detail, the DMA data base also omits some features required for realistic SAR simulation, such as airplanes, tanks, trucks, and ships. Clearly such data cannot be present in the data base, but are of great importance in training.

Finally, the coverage is still incomplete. Eurasia, the only area targeted for complete coverage, will not be available in its entirety prior to 1992 even at the lowest level of detail. There are no plans at present to provide overall coverage at any higher level of detail.

IMPACT OF HIGHER RESOLUTION

Since the emergence of SAR a number of ideas about SAR simulation have been advanced. One has been that the simulation of these radars will require a great deal more hardware because a tenfold increase of linear resolution implies that, over a two-dimensional image, a 100-fold increase of processing will be required. This view ignores the fact that a typical radar, which uses a raster type of display, has about 360,000 picture elements, and the number of picture elements is the same regardless of the resolution of the radar. The computational load is primarily a function of the number of picture elements and the number of features in the image area. Absolute accuracy is not the determining factor, only relative accuracy is. The relative accuracy for a high-resolution image is the same as for low-resolution, long-range radar. From the computational point of view, the greatest loads occur at low resolution and long ranges where the number of features is the greatest within the radar scan. Thus earlier systems which had adequate processing capacity are suitable for the SAR requirements, when the additional capabilities discussed below are incorporated.

It could be said that the problem is not that SAR requires too much computation, but the opposite: the data base is too sparse and, without enhancement, will not yield a realistic image.

This observation has given rise to the second fallacy: since present data bases do not have detail comparable to that seen on SAR images, there is little point in developing a new SAR simulator. That is, present real-beam radar DRLMS systems are adequate, since the limitation lies in the data base, not the simulator.

This thinking would lead to simulators that can produce only the imagery typical of low-resolution, real-beam radars. But this approach would, in effect, ignore the stringent training requirements of the SAR systems.

The solution to the problem is to supplement the DMA data base. Although augmenting the data base to include every object discernible on SAR would clearly be prohibitive, it is certainly feasible to manually insert the required data in small restricted areas, such as around navigational checkpoints. The necessary source material for this enhancement is obtainable from aerial photographs, maps, or actual SAR imagery. For strategic missions, this is clearly satisfactory, since SAR is to be used only at a few checkpoints and target areas.

In tactical training, the area to be covered is much larger because the mission may include the detection of targets in a large combat zone. While this requirement places a greater burden on the data base, the fidelity of the image to the real world need not be as great as for strategic missions. Certainly in a residential area the location of every house is not required for training. What is important is the ability to generate the signature of, for example, typical residential neighborhoods and the capability to insert targets, such as tanks, into such an area. Such data bases can train the pilot to detect the target in the presence of extraneous objects and to use the radar in weapon delivery.

Consequently, the real requirement is to produce data bases that faithfully represent the general character of the actual area, but provide accurate detail only in small areas of specific interest. This result can be achieved at a moderate cost.

A potential side effect of realistic SAR simulation will be loss of correlation, in some instances, between the SAR images and visual/IR/Low Light Level images. This problem is attributable to the fact that present visual systems which utilize Computer Image Generation (CIG) techniques do not provide the amount of detail that SAR simulators can deliver. New techniques in the visual area have the promise of eliminating these potential disparities.

ENHANCEMENT OF THE DATA BASE

There are two distinct requirements in the enhancement approach: how to insert features of tactical significance into the data base and how to produce generic detail. The methods are distinct and will be discussed separately.

The insertion of specific detail of tactical significance is not new to radar simulation. Many present systems have this capability in the form of an interactive graphics program that allows the modification of the real-time data base. This program, called the Small Area Update Routine, is capable of adding, modifying, or deleting a feature. The basic technique will not be affected by a tenfold increase in resolution.

However, because of the higher volume of enhancement activity, it will be desirable to achieve a higher level of automation and of computer-aided support. One approach to this requirement is to utilize the same type of interactive data base graphics methods employed for the CIG system. Commonality of graphics hardware and software will streamline the data base generation process and at the same time make the correlation of visual and radar data bases easier.

The second data base enhancement task is to produce realistic generic radar signatures. As an example, one may want to produce radar returns from a residential area described in the data base as 30% roof cover and 40% foliage.

There are two basic approaches that one may use to achieve this. This first is a fairly obvious one: replace the single feature of a residential area by a multitude of individual buildings, trees, etc., arranged in a typical way. This approach, while straightforward, has two significant disadvantages: the data base used by the simulator would increase significantly in size, and the computational load on the hardware would also increase.

The other approach is very much akin to the inclusion of "texture" in visual systems. Rather than augmenting the data base with synthetic material and processing this extra data in the hardware, it is possible to incorporate into the hardware a "synthetic signature generator." This generator uses table look-up methods to provide the necessary detail to generate the signature of typical areas. As an example, a collection of buildings, streets and vegetation would be generated in response to a code specifying a suburban single family residential area. Because this code is converted to "buildings, etc." relatively late in the computation process, the hardware loading from this approach is considerably less than synthetically generating a data base with comparable detail off-line and processing this data base in the hardware. A typical radar image generated by the Synthetic Signature Generator is shown in Figure 2.

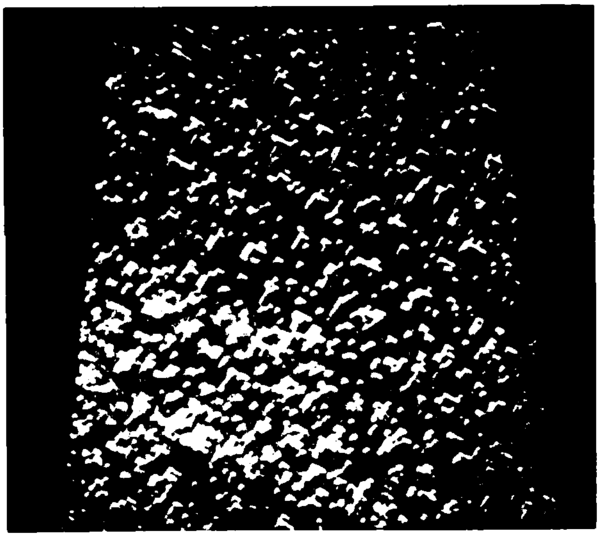

Figure 2 OUTPUT OF THE SYNTHETIC SIGNATURE GENERATOR FOR AN URBAN AREA. IMAGE MADE BY THE LINK EMULATION LABORATORY.

SAR ANOMALIES

Apart from the problem of producing higher-resolution images, SAR differs from real-beam radar in the way the azimuth angle is varied in the scanning process. In real-beam radars, the azimuth angle is incremented either by physically rotating the dish or by antenna phasing. In either case, the azimuth resolution is limited by the dish size: the larger the antenna, the higher the resolution. Physical limitations in the aircraft, therefore, determine the resolution of the radar. A discussion of theoretical aspects of these anomalies can be found in Reference 1.

For SAR, the size of the dish is not the determining factor in resolution because azimuth discrimination is achieved by calculating the doppler shift in the radar return caused by the motion of the aircraft with respect to the ground. Objects along the velocity vector of the aircraft will have frequency shifts of 2fv/c, where f is the frequency of the radar and v and c are the velocities of the aircraft and of light, respectively, while returns from objects perpendicular to the velocity vector of the aircraft undergo no frequency shift. The azimuth angle of any return may then be calculated from its doppler shift.

The actual radar image generated in an SAR mode is a mapping of range versus doppler shift rather than of range versus azimuth angle as in real-beam radar. This can cause anomalies. First of all, there is an ambiguity: more than one point on the ground may have the same doppler shift and range if the terrain is not flat. In general, there is a mapping distortion of any object not in the ground plane. In most cases, this distortion is not objectionable because a small displacement of a feature will not seriously affect the mission. Furthermore, if the elevation of the object is known, as in the case of a navigational checkpoint, it is possible to adjust for the error. More serious is the case where the distortion affects the interpretation. This may occur, for example, when a tall building is located adjacent to a river. The height of the building will cause a mapping error that can locate the radar return in the middle of the river! The operator may conclude that this is a ship, not a building. This mapping distortion, also called layover, is a function of the squint angle and under some circumstances will result only in an insignificant amount of displacement. The operator clearly must be trained to recognize when there is mapping distortion. (See Figure 3.)

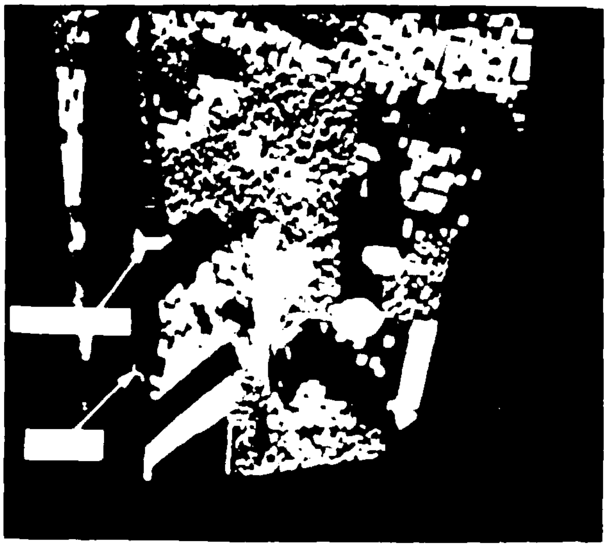

Figure 3 LAYOVER OF TALL BUILDING AT SMALL SQUINT ANGLE. SIMULATED IMAGE MADE FROM DMA DATA BASE BY THE LINK EMULATION LABORATORY.

Other unusual effects may occur whenever the return comes from a moving surface. For example, waves on the shore may produce a different frequency shift than might be expected from the shore's physical location. On a radar map this would manifest itself as a displacement from the shore's actual location. As a result the return may be superimposed on the adjacent terrain.

Moving vehicles cause similar problems. A train is displaced so that its return is mapped a significant distance from the track. Although the train itself is displaced, its shadow is not. (See Figure 4.) Unless they are properly trained in the anomalies of SAR, operators are likely to misinterpret the image.

Finally, the azimuth resolution of SAR decreases as the squint angle approaches the velocity vector. Operators should be trained so that targets do not go undetected as a result of this limitation of SAR systems.

HARDWARE MODIFICATIONS REQUIRED BY SAR

The mapping distortion due to elevation differences requires some additions to the basic hardware of the DRLMS. This subsystem is similar to the hardware needed to implement beam spread (horizontal antenna lobe) effect. Both effects constitute a distortion of the image in the azimuth direction. This distortion is a function of the squint angle and is most pronounced for small angles.

The decrease of resolution as a function of squint angle is easily simulated, but its mechanization can cause problems because the various radars tend to treat this problem differently. In some cases, the radar will allow the resolution to decrease naturally up to a certain point when the system automatically switches to real-beam mode. In other instances, the synthetic aperture computation time is extended to preserve the resolution. Yet another approach is to prohibit synthetic aperture mode for small squint angles. Any of these mechanizations can be simulated at the cost of additional hardware.

Over the past two years Link has completed the system design of a SAR DRLMS system capable of simulating these effects. The least significant bit in the computation of the vertices corresponds to .05 arc seconds, or about 5 feet at the equator, less elsewhere. This insures that the full precision of the DMA data base is preserved. Care was also taken to ensure that none of the accuracy in the DMA data base will be degraded in other ways. The new real time data base uses the geodetic coordinate system, the same one used by DMA. This will eliminate the loss of accuracy caused by the transformation to the real time data base and greatly simplify and reduce the cost of real time data base generation. Moreover, world-wide flight and modification of the data base become much simpler.

The system is capable of handling five million feature vertices per second. In addition, a great deal of detail can be added by using the

Figure 4a RADAR IMAGE OF MOVING TRAIN. FOR INTERPRETATION, REFER TO FIGURE 4b. PHOTOGRAPH MADE BY APG-63 RADAR ON F-15 AIRCRAFT. (COURTESY OF HUGHES AIRCRAFT COMPANY.)

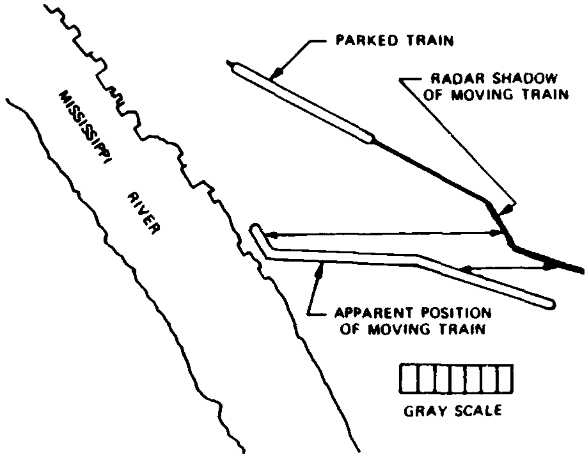

Figure 4b ILLUSTRATION OF DISTORTION CAUSED BY MOVING TRAIN

Synthetic Signature Generator. Vertices produced by this generator are not counted in the five million vertices per second capacity of the system. By using the Synthetic Signature Generator it is possible to produce images with several thousand objects per square mile.

One would expect that the higher resolution of SAR would increase the required size of the on-line data base. In fact, the size of the data base is smaller for the SAR DRLMS than for the previous generation DRLMS. This improvement is attributable to a more efficient method of storing the data and also to an algorithm that compresses the elevation data.

Although the Link SAR DRLMS will have significantly greater capabilities than the present one, the amount of hardware and the cost will be comparable to present systems. This advance was achieved by introducing various innovations and simplifications in the basic algorithms through a thorough study of the computational requirements. These led to architectural changes resulting in more efficient hardware utilization. Finally, a great deal of the credit for improved cost performance should be given to the use of VLSI and VHLSI advances in semiconductor technology.

To ensure that all these goals are reached, Link made extensive use of computer emulation of the system. The images generated by emulating the hardware were then compared to actual SAR photographs.

SIMULATION OF MALFUNCTIONS

SAR systems have all the failure modes encountered in real-beam radars. In addition, one may also encounter problems caused by equipment extraneous to the radar. For example, a problem in the inertial navigation system of the aircraft may produce a mapping distortion. This can occur when a velocity error exists in the navigation system. An offset in the aircraft's velocity will produce an azimuth distortion of the image. (An object located at one o'clock relative to the aircraft may appear at two o'clock.) The pilot can recalibrate and correct this error, but only if he is able to recognize the problem. Therefore, training is essential.

CONCLUSION

Present DRLMS systems cannot satisfy the training requirements of SAR. Changes must be made to both the data base and the hardware, but these changes are feasible; the overall cost of these requirements should not increase the cost of the simulators, because advances in semiconductor technology and system architecture more than compensate for the new requirements.

ACKNOWLEDGEMENTS

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SIMULATION VS STIMULATION IN ELECTRONIC WARFARE TRAINERS

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ABSTRACT

The design of an EW trainer involves a decision to simulate EW functions via computer software or to incorporate actual EW hardware within the trainer and stimulate it with required signals. This paper compares the requirements and relative advantages of software simulation vs. hardware stimulation in EW trainers. Aspects discussed include cost of hardware and software, computer load, trainer fidelity to real-world conditions, documentation and data requirements, interaction among EW units, testing requirements, and trainer modification. Both approaches have particular advantages and problems in each of these areas. In conclusion, the choice of simulation or stimulation, or mixture of both, in a given trainer should be based on careful study of particular circumstances and requirements.

INTRODUCTION

Electronic warfare trainers are designed to provide a student with training on electronic warfare equipment acting in an EW environment. In a typical trainer the environment consists of a number of radar emitters scattered throughout a war gaming area, emitting signals that are received by the student's ownship. The EW equipment in the trainer may include radar receivers and analyzers, chaff and flare dispensers, jammers, and so forth.

Many trainers involve training on specific EW equipment, such as a particular model of radar warning receiver or jammer. When such specific equipment is included in a trainer the design question arises: should the trainer simulate the equipment via computer software or should the trainer include actual equipment that is stimulated to produce the desired effects?

This paper examines the question of simulation vs stimulation, particularly with regard to radar-based trainers, and draws on experience with EW trainers developed by AAI Corporation for A-10 and F-16 aircraft flight simulators. Both trainers include the AN/ALR-69 Radar Warning Receiver and other EW equipment. The A-10 EW trainer includes an actual ALR-69 unit stimulated with video pulse trains, while in the F-16 trainer the ALR-69 is simulated entirely by computer software.

TRAINER CONFIGURATIONS

A modern training simulator for electronic warfare consists of several major functional components, as illustrated in Figure 1. A threat environment is generated and continuously updated by several related functions. A mission generation module defines the environment and places the trainer's ownship within the environment. A threat tactics module defines the signal generation modes of the threats, thus defining the types of signals to be generated. Further processing defines exact characteristics of the threat signals. Ownship countermeasures such as jamming, chaff, flares and maneuvering may be made to affect the threats' signal generation modes.

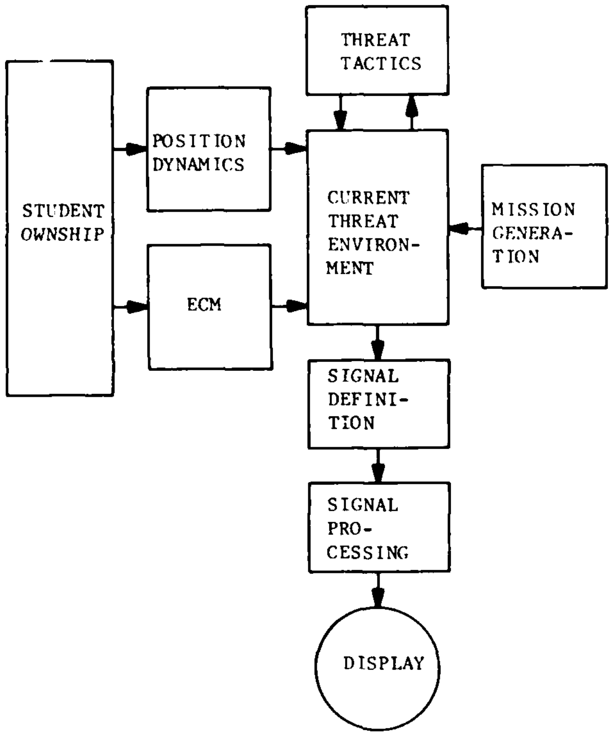

Figure 1. EW Trainer Configuration

The signal processing functions are then performed. Threat signals are analyzed according to the algorithms employed by the equipment associated with the trainer. Processing may be performed by actual EW equipment or may be simulated by computer software. This signal processing may be simple or elaborate according to equipment characteristics and trainer requirements. Outputs from the signal analysis are used to drive display hardware consisting of display screens, indicator lights, and speakers.

Figures 2 and 3 compare implementations of the basic functional design in Figure 1. The definition of the threat environment, and all of its associated activities, must almost necessarily be implemented in computer software. Even if some functions may be performed by digital hardware circuits, this hardware is merely performing logical functions that assist in the threat simulation. The real choice comes in the area of signal processing equipment. If it is to be simulated as in Figure 2, computer software defines the signal characteristics, simulates the signal processing functions and triggers hardware to drive the displays. If a stimulation is used as in Figure 3, the threat environment definition software directs pulse generators to generate pulse trains which are sent to the signal processing hardware. This hardware then performs whatever signal processing is appropriate and generates output to drive the display hardware.

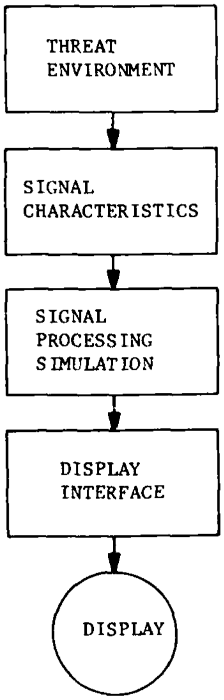

Figure 2. Software Simulation

In reality, nearly every trainer includes both simulation and stimulation techniques to some degree. A stimulation-oriented trainer will include a simulation of the threat environment and computer-controlled generation of threat signals. Furthermore, a simulation trainer must include some signal generation if only to drive display hardware or produce audio tones. The real question centers around the number and type of functions to be implemented by simulation or stimulation.

A discussion of the relative merits of simulation versus stimulation involves a number of considerations such as the cost of hardware and software, trainer fidelity to real world conditions, documentation and data requirements, testing requirements and trainer modifications.

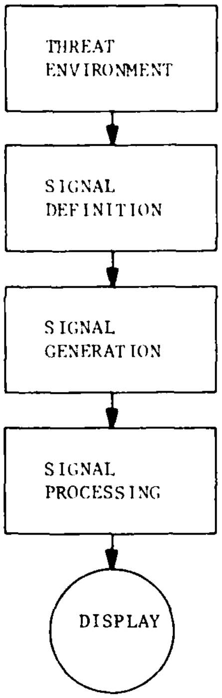

Figure 3. Hardware Stimulation

COST

If a hardware stimulation is being considered, the cost and availability of the EW hardware must be taken into account. Advanced EW equipment may be very expensive and its inclusion into the trainer may increase its cost significantly. Even if the EW hardware is provided as Government Furnished Equipment the overall cost to the customer must include the cost of the equipment. The availability of the equipment must be considered as well. If few of the units are manufactured, if all of the units are committed to other purposes, or if the units are out of production, it may be difficult to obtain units for inclusion in the trainers. The cost of maintenance and updating facilities for the EW equipment must also be taken into account.

The cost of support hardware and software in the trainer can be considerable as well. A complex EW environment requires a bank of signal generators for stimulating the EW equipment. Special effects such as scan patterns and range attenuation are produced by further hardware. All of these signals must be coordinated and interfaced with the EW equipment. The design, testing and manufacture of this hardware can run to sizeable expense, especially if the hardware configuration is large and elaborate.

A hardware stimulation also requires special software to control the signal generation hardware. When a threat enters the environment, a signal generator must be selected, loaded with pulse generation data if necessary and turned off when the threat leaves the environment. Special hardware effects are also controlled by software. The cost of design, development and testing of this software must be included into the special costs of a hardware stimulation.

The cost of a software simulation must be weighed against the cost of a hardware stimulation. As described earlier, a modern training simulator relies heavily on a computer to perform a number of supervisory and simulation functions. The computer generates and controls the threat environment and may interact with ownship and visual systems. The addition of a software simulation of EW equipment may not involve an extremely large further effort. However, as will be discussed later, development and testing of simulation software can pose major difficulties. And if specific EW equipment is being simulated, it is likely that the actual equipment will undergo revisions. The cost of changing the software to simulate these revisions can be quite large.

Software simulations hold a definite production cost advantage in trainers where many units are to be produced. Once the original simulation has been developed, additional units are produced merely by copying the software onto the mass storage devices of the new units. This is a trivial part of copying general simulation software to the new system.

Producing new hardware stimulation units requires more effort and expense. Not only must the EW equipment be procured and installed, but the signal generation hardware for each new unit must be manufactured and tested. Each new unit thus incurs significant new production costs.

Simulation and stimulation therefore both involve their own special costs. The relative costs of each vary from trainer to trainer, depending on the equipment configurations and numbers of units involved.

DOCUMENTATION AND DATA REQUIREMENTS

Software simulation and hardware stimulation both have their special data requirements. A software simulation requires extensive documentation on the EW equipment being simulated. A realistic trainer must be based on detailed specifications of all displays produced by the equipment, including threat indications on display screens, patterns of flashing lamps, audio tones, and so forth. Processing of various emitters must be described in sufficient detail to imitate the same results as produced by the actual EW equipment. In the case of a signal processor analyzing a dense threat environment, the designers of a simulation will require a large amount of threat data and sufficient functional documentation to develop software processes that handle the threats in the same manner as does the EW hardware.

A realistic software simulation should not only generate the major functions of the EW equipment, but should also reproduce subtle and anomalous effects found in the actual EW units. Complex EW hardware may produce unexpected effects in extreme or unusual combinations of circumstances. In normal operation the equipment may exhibit unwanted side effects on its displays, and hidden bugs in the EW equipment software may alter the basic standard specifications. An ideal simulation would reproduce all of these effects. However, some of these effects may have little or no training value and thus may not be required in specifications for the trainer. For other effects, no definite information may be available, rendering these effects impossible to simulate with any realism.

Considering the extent of the data that could be required for a realistic software simulation, it is essential that the specifications for the simulation describe the behavior to be simulated and the data available on this behavior. In the absence of adequate data, the software designers must either ignore the behavior or make their own guesses about specifications.

Hardware stimulation may likewise require a large amount of data and functional description. On the hardware level, timing diagrams, pulse widths, bus protocols, etc., must be specified exactly since input signals are fed into EW equipment itself. These specifications may seem straightforward, but problems may develop in actual interfacing with the EW hardware. The EW hardware may not perform exactly as described in the specifications, or it might have requirements not clearly stated in the interfacing protocols. Solving these kinds of problems will require further research to discover modified or hidden requirements.

The functional requirements of the inputs must likewise be specified carefully. EW equipment that performs elaborate and discriminating signal analysis will probably require highly realistic inputs. The designers of the stimulation equipment will thus require complete data on all of the signals to be input into the EW equipment. In the absence of explicit input parameter data for particular cases, it may be necessary to "reverse-engineer" the input data from the signal analysis processes used by the EW equipment. This may require detailed and precise information on the exact algorithms used within the EW equipment. At times this data requirement may be more exacting than for a software simulation design.

However, given the correct inputs, a hardware stimulation should by its nature produce all of the intended and anomalous effects generated internally or by the inputs. Not only will the major and minor display effects appear realistically, but special peculiarities and overload behavior will perform the same as in field units. Fidelity to real world phenomena is thus more attainable, as the EW equipment is presenting realistic displays to the trainee. Once again though, the realism of the output depends on the realism of the stimulating inputs.

INTERACTIVE EFFECTS

An EW trainer becomes particularly complex when it contains several pieces of EW equipment interacting with each other under power management or some other configuration. The interactions between the units can be particularly difficult to simulate, especially in the areas of subtle and anomalous effects which may be poorly understood. When the actual EW units are installed in the trainer and connected together, they automatically produce all of the subtle interactive effects that may be extemely difficult to reproduce in a software simulation.

On the other hand, if the additional EW units are quite simple or require extensive additional signal inputs, a software simulation may be simpler and more cost-effective. However, a software simulation interacting with hardware is subject to difficulties both in software development and in hardware interfacing.

TESTING

Simulation and stimulation trainers each have particular testing requirements. Testing of a hardware stimulation is presumably more straightforward, as the EW equipment is expected to produce a set of well-known results. As was noted earlier, the major and minor displays, anomalies and pecularities should be documented beforehand and observable during testing. However, if unpredicted results appear during testing, the origin of the problem may be difficult to pinpoint. The chain from input data specification through signal generation to signal analysis and display contains a number of separate links, each quite distinct from the others. The nature of the problem may make it difficult to determine whether the inputs have been generated incorrectly or whether the EW equipment is exhibiting a heretofore unknown anomaly. If the output results are not according to specification, it may be that the inputs are not sufficiently realistic for processing by the EW equipment. More elaborately realistic inputs may be required to produce the correct results. On the other hand, an unexpected output from the EW equipment may be a correct result that has not previously been documented. Unusual signals or combinations of signals may produce results that have not been observed prior to the testing of the trainer. In this case, the testing personnel will have to re-evaluate the test criteria and revise them accordingly.

A software simulation can be more difficult to debug and test. All of the output effects originally specified for the trainer must be tested and evaluated. Since the effects are being artificially generated, they do not automatically display the realism associated with a stimulation. Thus disagreements may arise during testing as to whether the simulated effect is acceptably realistic. Furthermore, the full range of secondary and subtle effects of the actual EW equipment are rarely, if ever, programmed into the simulation. Unless the list of required effects has been carefully specified beforehand, testing the simulation may give rise to disagreements over whether particular effects that have been omitted are actually necessary. Unfortunately, many such effects are not readily specified beforehand and can be defined and judged only upon inspection of the simulation itself. Unforeseen anomalies may arise during testing of a software simulation as well. In a well-structured software program the source of such anomalies can be identified fairly readily, but it is more difficult to determine whether they properly belong in the simulation. The simulation designers can claim that the anomaly is a necessary consequence of a realistic simulation, while the testing personnel deny that the EW field units exhibits such behavior. Only an examination of actual equipment operation can determine whether the behavior really occurs.

MAINTENANCE AND UPDATES

Hardware stimulation and software simulation both require continual maintenance and updating once the trainer has been installed. EW equipment included in the trainer will require periodic or emergency maintenance, probably by trained personnel. Such maintenance must be provided for either at the trainer site or at the depot level. In addition, the EW equipment will probably undergo revisions in the field. In this case the equipment in the trainer must be modified if it is to be kept current with the field units. Such modifications are typically easy to make on modern military electronics equipment, as they usually involve little more than the replacement of printed circuit boards. This modification can be performed as part of a program of revisions to field units. Even if the revision of the EW equipment is simple to perform, a revision to the EW equipment may have consequences for the rest of the trainer. Any significant alteration of input requirements may require changes to the signal generation processes of the trainer. The EW revisions may require improved or altered signal modeling, entirely new inputs or altered timing of existing inputs. Changes may be required in signal hardware or even in the simulation software and involve far more effort than the EW equipment modification itself.

Modifications to a software simulation are typically more difficult to perform as the hardware revisions must be studied, modeled, implemented in software and tested. The software changes must go through the entire design and development process and are subjected to the same difficulties in testing as were discussed earlier. This is particularly true if the EW equipment revision results in significantly altered outputs or new anomalous behavior. Data on the new requirements must be procured and studied, even though documentation on the revision may be incomplete or difficult to obtain. The effects of the revision must be evaluated and modeled and included into the simulation software. The original software typically does not provide for such modifications, so integrating them into the original software may not be a simple matter. Finally, testing of the modification is subject to the difficulties discussed earlier, particularly if the operational effects of the revision have not been extensively documented.

However, ordinary maintenance of a software simulation is much easier. Once the trainer is in place, the EW software will not require any maintenance unless hidden software bugs are noticed. Any maintenance on the computer CPU or peripherals takes place as part of normal computer operation and is not specifically chargeable to the EW simulation software.

CONCLUSION

Hardware stimulation and software simulation both have their advantages and shortcomings in EW trainers. A hardware stimulation includes actual EW equipment that already comes with a full range of realistic output behaviors, both intended and anomalous, that can be used directly for highly realistic training on the EW equipment involved. If it is part of a larger system, the EW equipment will interface with other components of the system without further development effort, and revisions to the EW equipment can be made relatively easily as part of a general field update program.

Actual EW hardware may present some problems, however. The EW equipment itself may be extremely costly or unavailable for a number of reasons. The software and hardware required in the trainer to produce all of the required inputs may be difficult to design and expensive to produce, and modifications to the EW equipment may have ramifications in the trainer that extend beyond the EW hardware itself.

A software simulation can prove to be less costly to design and produce if exact realism is not required or if many units are to be built. Since a modern trainer performs many functions via a computer, the addition of an EW equipment simulation module may involve only a moderate additional effort. A software simulation also bypasses the elaborate signal generation hardware required by EW equipment stimulation.

A software simulation has difficulties of its own. Trainer realism can be most difficult to achieve, and may be impossible to define and assess. Furthermore, modifications to the simulation require a full design and development process.

Neither approach has an overwhelming advantage over the other, and both have their merits when used in the appropriate situation. A generic trainer involving no specific EW equipment and providing only generalized training should obviously use a software simulation. Any trainer in which EW is secondary or in which moderate realism is necessary is also a candidate for the software approach. On the other hand, a trainer that relies heavily on detailed training on specific EW equipment should probably use hardware stimulation to achieve greatest realism. Furthermore, the greater the complexity of the EW system involved, the greater the advantage of stimulation. Even here, however, recent advances in computer hardware and software techniques have made highly realistic software simulations possible. Thus each trainer design should be considered separately and the approach of simulation versus stimulation chosen according to the particular requirements of the trainer.

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APPLICATIONS OF A GENERIC SHIP PROPULSION MODEL FOR ACOUSTIC SIGNATURE SIMULATION IN SONAR TRAINERS

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ABSTRACT

This paper describes a generic model for use on a sonar trainer that simulates the propulsion systems (including engines, turbines, shafts, and propellers) for most vessels in use today without predefining the specific vessel types. These vessel types include surface ships, submarines, torpedoes, and decoys which the instructors can create or alter by modifying a set of table driven model constants without the necessity of changing the basic structure of the model. The model provides for realistic simulations of propulsion mode transition dynamics and allows for interruptions of transitions already in progress. The model is suitable for sonar classification training, and further, is adaptable to a variety of training systems which would require a high fidelity target radiated acoustic signature simulation.

INTRODUCTION

Modeling ship propulsion systems such as engines, turbines, shafts, and propellers for simulating target radiated acoustics in sonar trainers has traditionally been done by using unique models for each type of ship. These traditional approaches result in significant modifications and added cost to the computer software when changes to the vessel are required.

A Navy surface ship sonar trainer (NTEC device 14E27A) currently in development, will avoid these modification problems with an approach that allows the instructors to define the specific vessel characteristics. The fidelity of the simulation can be adjusted by the instructor because of the generic structure of the model. Thus, the instructor can provide the proper level of realism that is desired for each vessel type. By involving the users of the system directly in the development of the trainer's capabilities, the sonar trainer will be more responsive to the system user's needs.

Typical propulsion systems are described, and the overall model structure which simulates these systems is developed. The instructor interaction in controlling the simulated propulsion systems, as well as in fine tuning for fidelity, is explained.

TYPICAL VESSEL PROPULSION SYSTEMS

A sonar trainer will usually employ many different types of vessels in the acoustic simulation of targets in the ocean enviroment. The most important of these vessel types are surface ships, submarines, torpedoes, and decoys. An accurate simulation of the passive acoustic signature of each vessel is an important component to the task of sonar classification training. Since the propulsion systems are a prime contributor to the acoustic signature of a vessel, it is important to have a high fidelity acoustic simulation of these system elements.

Vessel propulsion systems include many different types of components including the following (see Figure 1.):

1. Engines (both diesel and gas/steam turbine)
2. Shafts/propellers
3. Electric generators
4. Electric motors
5. Miscellaneous equipment such as pumps, reduction gears, clutches

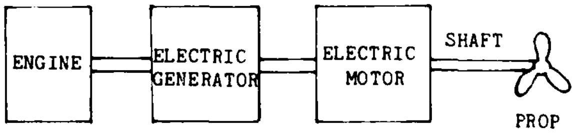

Figure 1. Engine/Shaft Drive Train Components

Acoustically, the first four elements in the list above are usually the major contributors to the acoustic noise generated by a vessel when it is moving. The miscellaneous equipment is either transient in nature or is acoustically related to one of the four main components.

A vessel will generate two basic types of acoustic energy, tonal and broadband. Tonal sound is concentrated into narrow frequency segments (or harmonic groups of segments), such as the whine of a generator (see Figure 2.). Broadband sound is basically continuous over a wide range of frequencies, such as the hiss of steam (see Figure 3.). For sonar classification purposes, the tonal sound is much more important than the broadband. Therefore, the propulsion simulation concentrates on the elements that produce primarily tonal acoustic energy in the vessel. Consequently, the steam generator (if used) is not an important component in the acoustic model of the vessel's propulsion systems, even though it is very important for actual propulsion. This type of broadband noise, however, is included in general broadband radiated noise levels which provide for training in sonar detection of vessels, and to realistically obscure the classification tonal components.

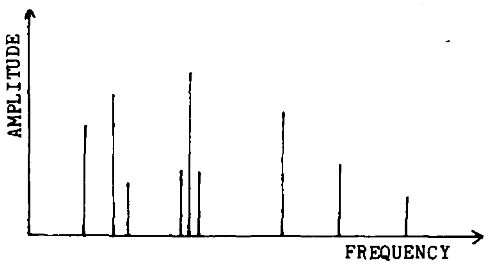

Figure 2. Tonal Sound Spectrum

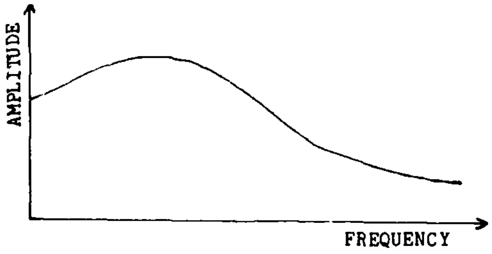

Figure 3. Broadband Sound Spectrum

BASIC MODEL STRUCTURE

Since there are a large number of vessel types that are of interest today for a sonar trainer, modeling the propulsion systems for each one of them would be very complex and cumbersome. A better approach, used in the 14E27A sonar trainer, is to develop a generic propulsion model that can be configured to simulate the important features of any particular vessel type.

A vessel will typically have multiple engines, shafts, propellers, motors, and generators. The propulsion model allows for up to four shafts and propellers which will accomodate even the largest battleships and carriers in use today. The model makes the following simplifications:

1. Each propeller for a multiple shaft vessel will have the same characteristics (turns-per-knot, number of blades, diameter).

2. Each shaft for a multiple shaft vessel will be considered as an independent engine/shaft drive train. No implicit interaction is allowed between different drive trains.

3. Each drive train will consist of an independent set of the following components:

   a. Engine
   b. Electric Generator
   c. Electric Motor
   d. Shaft and Propeller

   Note that some vessel types may not use all of these components.

4. Each drive train will have a limited set of internal interconnections, referred to as a configuration, as follows:

   a. Engine is off-line (disconnected), shaft is off-line
   b. Engine is directly (mechanically) driving the shaft
   c. Engine is off-line, an electric motor is directly driving the shaft
   d. Engine is driving an electric generator, shaft is off-line
   e. Engine is driving an electric generator, an electric motor is directly driving the shaft

   Note that some vessel types may not use all of these configurations.

5. Only fixed blade propellers are modeled. There is no provision for variable pitch props. In addition, only forward propeller thrust is available since the model does not allow for the propellers to be reversed.

Even with these simplifications, the model provides a great deal of fidelity and flexibility for virtually every type of vessel of interest for sonar classification training purposes. A particular set of configurations for each engine/shaft drive train in the vessel is called a propulsion mode. For many vessels, there may be very few modes used in practice, especially for merchant type surface ships. In contrast, a diesel submarine will usually have many propulsion modes available. The model uses these modes along with other data to control the RPM of all the propulsion system components. Since the RPM of acoustically significant machinery is very important in the sonar classification analysis of a vessel, the model must realistically control each component's RPM in the engine/shaft drive train.

INSTRUCTOR INTERFACE

The sonar trainer instructor needs to control the motion of the various vessels in the training scenario. This is done by changing the ordered speed, course, and depth (if applicable) for the desired vessel. When new ordered values are entered by the instructor, the propulsion model should respond realistically to them. However, for many vessels with multiple propulsion modes available, there is not always a unique propulsion mode defined for a given set of ordered values. In this case, the instructor might (but not always) want to select the particular mode that is desired for the vessel.

"Favorite" Mode

The model is designed to calculate a favorite propulsion mode for the ordered speed and depth of the vessel. This is the most probable propulsion mode that would be used for the ordered speed and depth, and therefore acts as a default mode for the instructor.

Available Mode List

The model also generates a list of available modes for the ordered speed and depth of the vessel. These modes are all valid at the ordered speed and depth, with some more likely to be used than others in reality. For example, a two shafted vessel can run with one or two propellers turning. Typically there is a speed range for the vessel where either mode is valid (mode overlap). If the ordered speed was in this speed range, then both modes would be in the available mode list to allow the instructor to select from among the options.

MODE HIERARCHY

A structured hierarchy of modes and algorithms is used to control the propulsion model. These are organized as follows from the highest level to the lowest:

1. Final Mode
2. Commanded Mode
3. Ordered Mode List
4. Engine/Shaft Configuration
5. Transition Algorithms

Figure 4. illustrates the hierarchy of these modes and algorithms as well as the instructor interface modes and the RPM adjustment calculations.

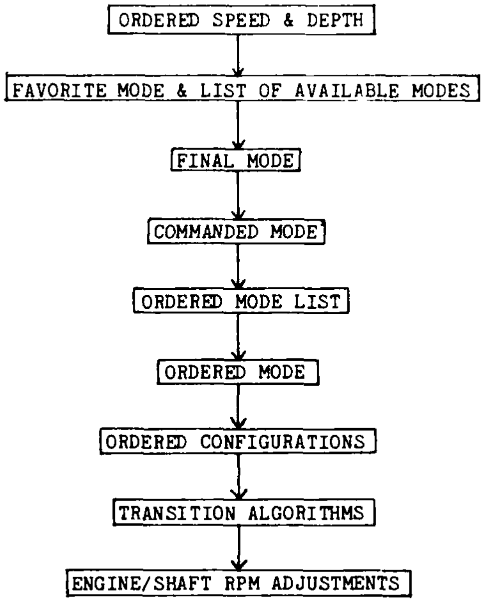

Figure 4. Mode Hierarchy Diagram

This modular sequence of control modes, as will be shown below, allows the model to be both generic and adaptable to different fidelity requirements.

Final Mode

The instructor can select the desired propulsion mode from among the available mode list or accept the favorite mode default. The mode that is eventually selected either by the instructor, or by default, is referred to as the final mode. It is this mode along with the ordered speed and depth that will trigger the dynamic behavior of the propulsion model. After all mode transitions are concluded, then the vessel will remain in the final mode. Of course, it is quite possible that the final mode will be the same as the current mode in which case there will be a relatively simple transition in the RPM of the engines and shafts.

Commanded Mode

In some types of vessels, most notably diesel submarines, it is possible to select a propulsion mode for a particular ordered speed and depth that cannot be used immediately. For example, if a diesel sub is submerged below the snorkle depth and the final mode uses a diesel engine in one of its configurations, then the model cannot start a transition immediately since the engine cannot yet be used. In this case, an intermediate mode that is valid at the current depth is automatically specified as the commanded mode before the final mode is eventually used. However, for most cases the commanded mode is the same as the final mode.

Ordered Mode List

Using the commanded mode and the current propulsion mode, the model initializes an ordered mode list (see Figure 5.). This list defines a sequence of modes that will be used by the transition algorithms and a minimum mode duration time for each ordered mode. The last mode in the list is always the commanded mode. This mode list is designed to add realism for complex mode changes where a vessel would not directly transition from the current propulsion mode to the commanded mode, but would, instead, switch through several transient modes before finally reaching the commanded mode. This is an important feature to prevent unrealistic transitions that would create negative training in sonar classification. Note that if the commanded mode is not the same as the final mode, then the model will cycle through two ordered mode lists. The first will be for the intermediate commanded mode transition and the second will be for the final mode transition.

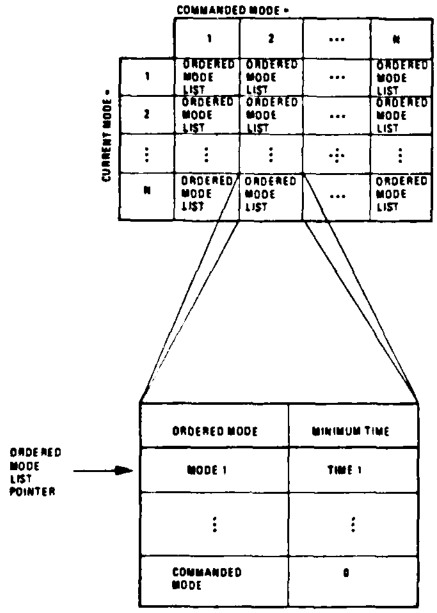

Figure 5. Ordered Mode List Table

An additional important feature of the ordered mode list is that it permits instructor initiated interruptions of transitions already in progress. For example, if the instructor inputs a new set of ordered values for a vessel, then a mode transition will be initiated. For some types of vessels, this transition process from the current mode to the final mode will take tens of minutes to complete. During this period, the instructor may decide to change the ordered values for this vessel again before the final mode has been reached. If this occurs, then a new transition will start using the last mode fetched from the ordered mode list (as the current mode) and the new final mode. This provides a realistic response to the new ordered values since the transient modes in the ordered mode list are all equally valid as current or final modes. If the transient response for a mode change was simply described in detail, then it would be very difficult to decide in the model what the proper response should be if new ordered values arrive during a mode change.

Engine/Shaft Configurations

Using the ordered mode, the configuration for each engine/shaft drive train is determined (see Figure 6.). These new configurations are called the ordered configurations and are used with the current configurations (based of the current propulsion mode) to define the engine/shaft transition algorithms (see Figure 7.). Each engine/shaft drive train is handled independently using a fixed set of 25 transition algorithms.

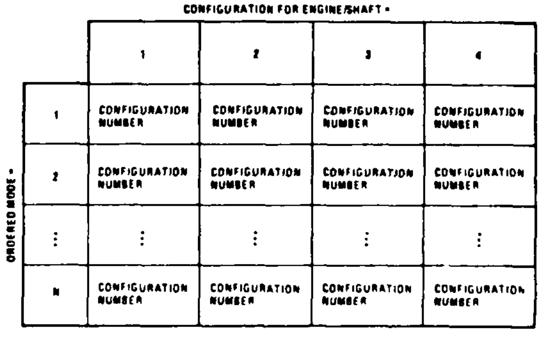

Figure 6. Engine/Shaft Configuration Table

ORDERED CONFIGURATION

CURRENT CONFIGURATION	1	2	...	5
1	ALGORITHM NUMBER	ALGORITHM NUMBER	...	ALGORITHM NUMBER
2	ALGORITHM NUMBER	ALGORITHM NUMBER	...	ALGORITHM NUMBER
⋮	⋮	⋮	⋮	⋮
5	ALGORITHM NUMBER	ALGORITHM NUMBER	....	ALGORITHM NUMBER

Figure 7. Engine/Shaft Algorithm Table

Transition Algorithms

Each of the 25 algorithms consists of a series of engine and shaft RPM adjustment equations and if-then-else logic statements. There are a total of seven equations and logic statements used to form the elements of the algorithms. The largest algorithm uses six of these equations and logic statements. Using this simple mechanization, the mode transition dynamics can be modeled with very few basic equations. These basic equations directly control the engine and shaft RPMs and are generic to all vessel types. Only the coefficient constants of the equations are unique to a particular vessel type. These characterizing coefficients are a part of the complete set of coefficients which specify a vessel type, and are defined and fine tuned by the training instructors. Coefficients are changed during non-instructional sessions whenever new information, such as from at-sea experience, is available, or as other realism considerations suggest the need.

Engine/Shaft RPM Calculations

The engine and shaft RPMs are adjusted using simple digital exponential time response filters of the form:

$$rpm(n+1) = (1-K)*(\text{ordered RPM}) + K*rpm(n)$$

where K= time constant coefficient,
n= last computational iteration,
n+1= this iteration

The ordered RPM is calculated from the ordered speed and the vessel's turns-per-knot value which is based on the ordered configurations. The filter prevents discontinuities in the RPM of the shaft or engine when new ordered values are received. It also realistically models the mechanical inertia of the rotating machinery since they can respond only so fast to a new RPM setting.

Miscellaneous Effects

The generic propulsion model modifies the calculated values for the engine and shaft RPM to simulate such effects as long term RPM wander, turn count masking, sea state RPM instability, and shaft bowing (inboard/outboard RPM differential) in turns. Each of these effects is modeled to add realism to new maneuvers of a vessel. Some of these clues, such as shaft bowing, are very important to sonar operator training since they help predict the position or motion of a vessel from its acoustic signature. The model also includes the singing propeller effect, a distinct tonal characteristic, which can be very intense acoustically when it occurs.

SONAR SIGNAL STIMULATION

The 14E27A sonar trainer consists of two primary sections, the actual ship sonar equipment and a hardware sonar signal stimulator. The stimulator produces the actual electrical waveforms like those normally produced by the hydrophone or sonobuoy sensors. These simulated waveforms then drive the actual sonar equipment based on the results of various models in the trainer. The signal used to stimulate the sonar equipment consists of two main components, tonal and broadband.

Tonal Stimulation

The tonal signal for a particular vessel as received by the actual sonar equipment consists of many different spectral components. As described earlier, these "line" components (as seen on a spectrum analyzer) are produced by engines, propellers, motors, and other miscellaneous ship equipment. A particular piece of equipment may produce a single line, or it may generate a harmonically related set of lines. This effect is created in the 14E27A sonar trainer by the use of hardware line family generators. The line family generator allows the software to specify the frequency, line width, and amplitude of a single line or a group of harmonic lines. The RPM of the engine and shaft along with the propulsion mode are used to calculate the parameters for the line families.

Broadband Stimulation

The broadband signal for a particular vessel consists primarily of flow noise and propeller cavitation. The flow noise calculation is usually based on the vessel's speed. The propeller cavitation calculation uses the propeller RPM to determine if cavitation is occurring. Using these propulsion model outputs, the broadband signal generator parameters are selected to simulate the desired vessel.

SHIP MOTION

The generic propulsion model is also used to compute parameters for the ship motion model in the 14E27A trainer. This model is used to compute the position of all vessels in the training scenario. Since the new position of a vessel is dependent on the thrust from the propulsion system, the ship motion model needs to receive this dynamic data from the propulsion model. While some inputs such as the turn rate control of the vessel are handled directly by the motion model, other inputs such as the depth control of the vessel are used by both the motion and propulsion models.

The motion model will compute a root mean square RPM for all of the actively turning propellers and then compute a new vessel speed by using the turns-per-knot value and the mean RPM value. This allows the ship to respond in a realistic fashion to changes in the propulsion of the ship. For example, if the propeller RPM increases then the vessel will gradually speed up until it reaches the desired speed. In general, the vessel's motion will lag the propulsion changes due to the vessel's inertia.

MODEL MODIFICATIONS

One of the most important features of the generic propulsion model is the ease with which modifications can be made to the vessel types. Since all vessel unique parameters are organized as tables of constants, it is very easy to fine tune the fidelity of a particular vessel type by altering these tables. For example, it may become known that a particular vessel type will not transition directly between propulsion mode 3 and mode 5, but will instead transition through an intermediate mode 7. This enhancement can be included by simply adding mode 7 to the ordered mode list for the mode 3 to 5 transition element. All of the proper responses will then occur in the subsequent control logic for this new enhancement.

A new vessel type can be added to the system by creating a whole new set of parameter tables and then adjusting the constants until the desired fidelity level is achieved. If the new vessel type is similar to an existing type, then it is possible to copy the existing vessel type's data tables to the new vessel type and then make the desired modifications. This is useful where the new vessel type may only have a slight but important acoustic difference from a previous vessel type. This occurs frequently in submarines where a new production run of a given submarine class will sound slightly different that others in the same class.

CONCLUSIONS

The generic propulsion model has been shown to possess several technical and cost advantages over the traditional approach of simulating each vessel type with a unique model. It also allows the instructor to fine tune the acoustic signature fidelity of the vessel types to the desired level. The generic propulsion model's structure has been demonstrated as being adaptable to new vessel types and allows enhancements to existing types.

ABOUT THE AUTHORS

Mr. Ronald A. Roane is a Senior Systems Analyst Engineer with Honeywell Training and Control Systems Operations (T&CSO). He has been involved with math modeling on the F-15 and F-16 Simulated Aircraft Maintenance Trainers and on the surface ship 14E27A sonar operator trainer. Prior to joining Honeywell, he was involved with the research and development of real time signal processing algorithms for passive sonar detection applications at Rockwell International's Marine System Division. He received a Bachelor's Degree in Engineering from the University of California, Irvine.

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A LOW-COST DRIVER TRAINER (LCDT) FOR A TRACKED VEHICLE

by
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ABSTRACT

A videodisc-based driving procedures training system is under development by General Dynamics Electronics Division for the United States Marine Corps that will provide training for drivers of the new LVT-7A1 tracked landing vehicle. This new system, to be delivered in March of 1984, will provide training and practice to new drivers in correct vehicle operation before they drive an actual vehicle. The system is designed to train 750 students each year in classes of 30 students each. The LCDT consists of a minicomputer with a master control console, five instructor consoles, and five student stations that replicate the driver's compartment of the LVT-7A1.

INTRODUCTION

The LVT-7A1 is an upgraded version of a previous Marine Corps Tracked Landing Vehicle put in service in 1971. The significant portions of the upgrade include a new engine and transmission, as well as a new instrument panel and other mechanical changes. The principal use of the vehicle is transporting troops or cargo from a landing ship stationed off-shore to the beach with minimum risk. In this application, the vehicle carries 25 troops and a crew of three. In an effort to reduce the high maintenance costs caused by the failure of vehicle drivers to follow correct operating procedures, a driving procedures simulator is being developed by General Dynamics Electronics Division for delivery in March of 1984.

The major purpose of the trainer is to train new drivers in proper vehicle operating procedures. The trainer will be used in conjunction with classroom instruction and actual vehicle driving periods and will train 750 students each year in classes of 30 students each. It is not intended to replace actual vehicle driving time, but to train for normal as well as emergency and failure shutdown procedures that must be followed to prevent compound vehicle damage. These procedures can not be taught effectively in the classroom due to lack of real-world conditions, or on the vehicle because of the potential danger to vehicles or personnel.

The major components of the training system are the simulation computer and the five trainee stations with associated instructor stations. Figure 1 is a block diagram of the overall training system.

The simulation computer is a low-cost minicomputer of the SEL 32/27 type which contains and executes the software that runs and controls the training system. The computer system consists of the central processor, and 80 MB removable media disc drive, a tape unit for system rebuild and program archival use, a 200 CPS printer, and a master control terminal.

The computer software, written in FORTRAN 77, is the result of over four man-years of development. It simulates the vehicle responses by modeling vehicle dynamics including engine, transmission, braking, steering, and traction as a result of student inputs and vehicle operating environment. The instructor has the option of changing the operating environment by specifying the simulated outside temperature or by introducing vehicle malfunctions at particular locations during the training session. The procedures to be followed by the student for the various driving conditions as well as those to be followed under malfunction conditions are monitored by the computer software for later review and print out by the instructor, if desired. Student performances that are monitored include the number of times the student exceeds the maximum speed in a gear, the number of stalls, the number of times the vehicle is in the wrong operating mode, and others for a total of 16 parameters.

The five student stations replicate those controls and gauges in the driver's station that are critical to the correct operation of an actual vehicle. These controls include the steering wheel, gear selector, hand and foot throttle, water/land mode selector switch, cold-start switch, and ramp control handle. Figure 2 is a diagram of the student enclosure. The various gauges include the transmission oil temperature and pressure, engine oil temperature and pressure, engine water temperature, air filter restriction, battery voltage, engine RPM, vehicle speed, and compass heading. Figure 3 shows the vehicle control panel. The fire warning and fire suppression system is also simulated so that the student can receive instruction in vehicle fire procedures.

Each student station also has a voice and vehicle sound synthesis system. The voice synthesis system will command the student in much the same way as an actual training instructor using voice commands for such things as "Take the right fork", "Stop the vehicle", "Enter the water", and "Return to the beach". The voice synthesis system is completely solid-state and can play back up to 64 seconds of prerecorded voice commands. The sound synthesis system reproduces the various vehicle sounds necessary for training including the engine, transmission, bilge pumps, personnel ramp, water jets, and tracks for a total of 15 sounds, all under computer control and coordinated with the student actions.

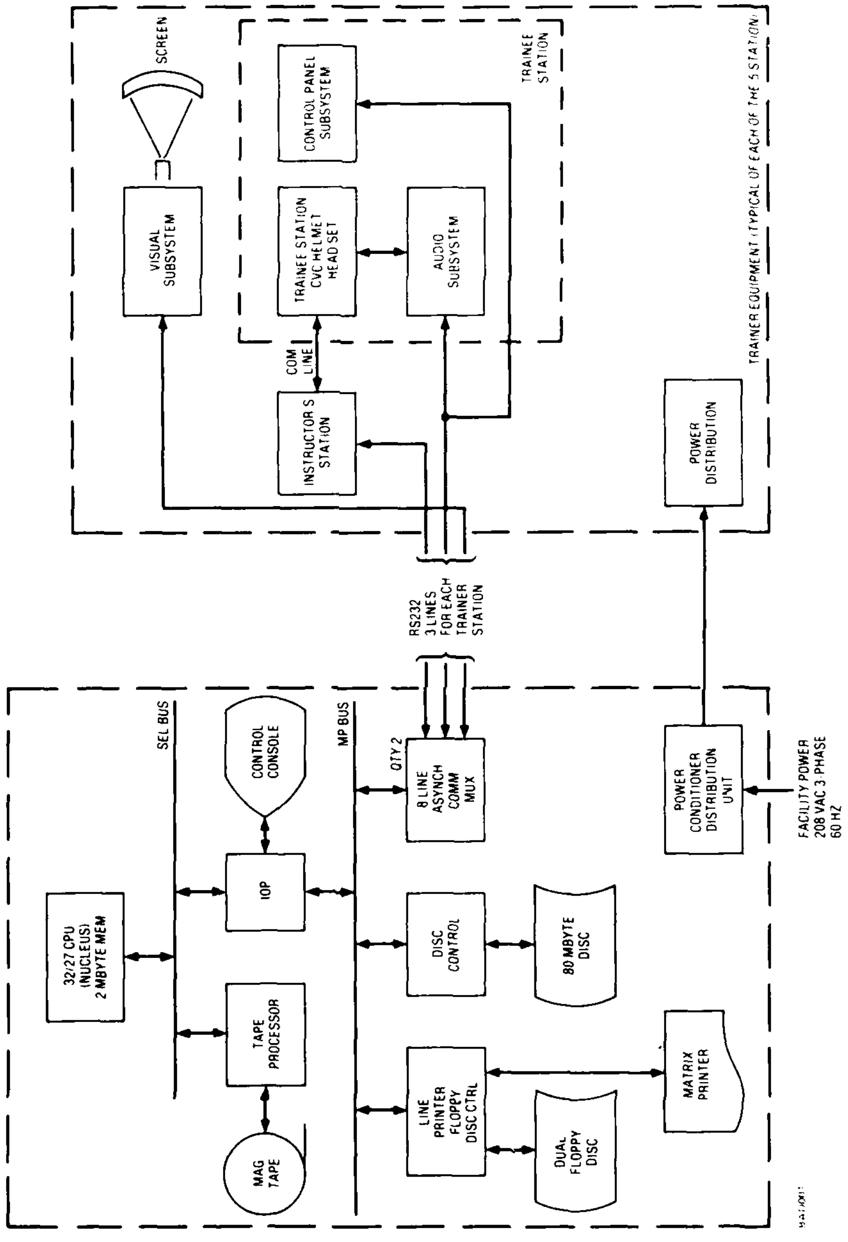


Figure 1. Overall LCDT System Block Diagram

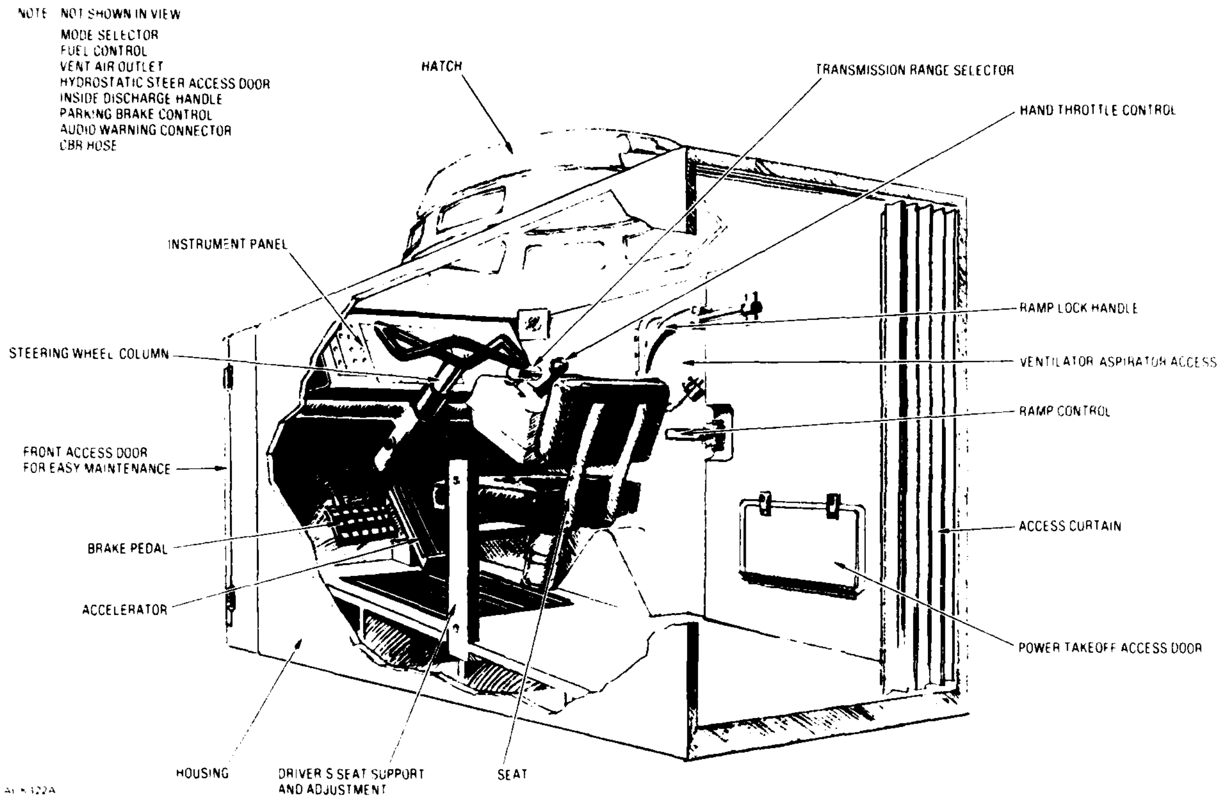


Figure 2. Realism Is an Important Objective in the Trainee Station

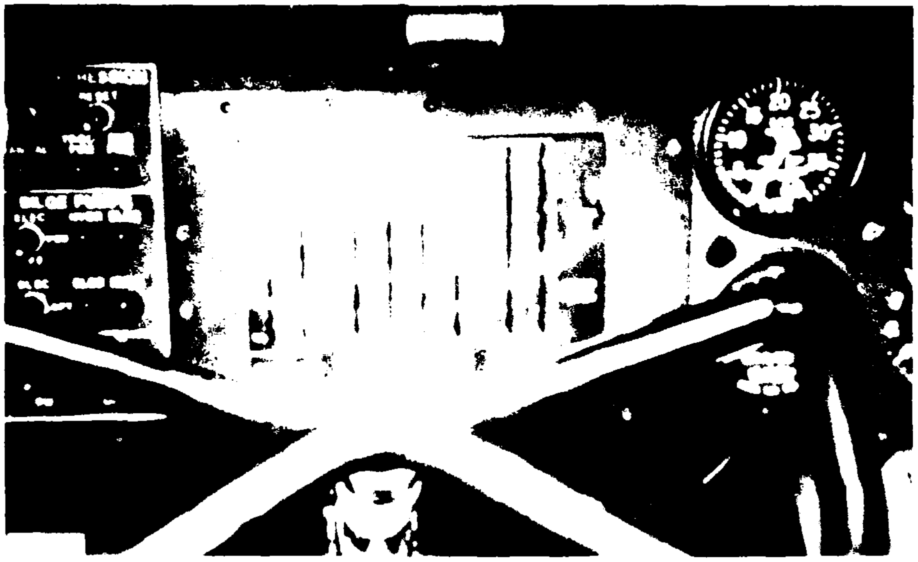


Figure 3. LVT-7A1 Control Panel

Another part of the student station is the visual system which shows the student pictures of the driving course on a 6.5-foot-diagonal projection TV screen. The source of the pictures is a videodisc that was produced expressly for the training system as part of the project. The videodisc is played back on an industrial-quality player under computer control. The video from the disc is processed by the visual electronics hardware under computer control to generate a modified video image that shows the results of the student's steering the vehicle to the left or right of the correct course. The speed of the video presentation is controlled by the computer in response to student manipulation of the throttle, gear selector, and brake. The visual screen also shows computer-generated advisory messages and instructions to the student.

Associated with each student station is the instructor's console which is a standard computer terminal connected to the trainer computer via serial link.

The audio, visual, and procedure monitoring portions of the trainer will be discussed in greater detail in the following paragraphs.

AUDIO SUBSYSTEM

As described previously, the audio subsystem is responsible for generating the voice commands and the vehicle sounds sent to the student as feedback for his actions. Figure 4 is an overall block diagram of the subsystem. The voice commands are the same as those which would be given by an instructor training the student.

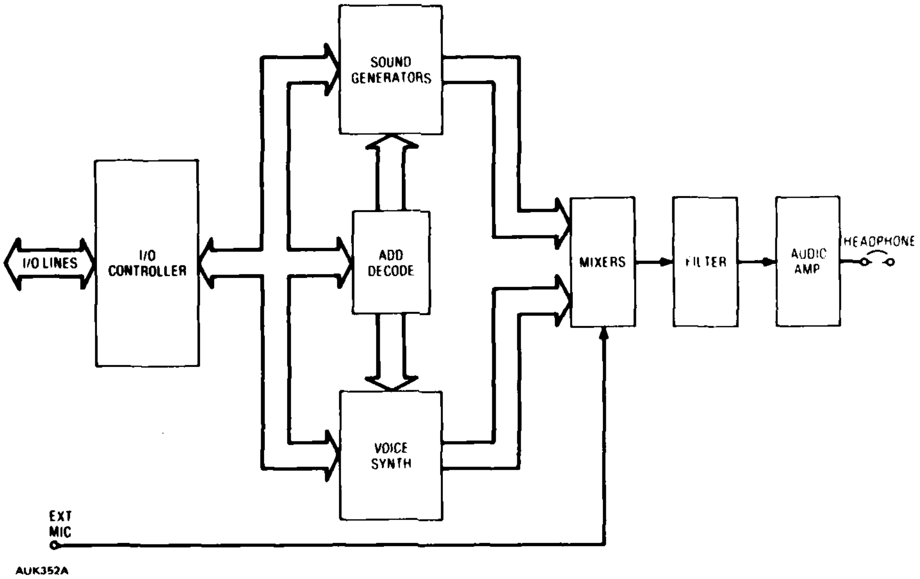


Figure 4. Audio Subsystem

These commands must be easy to understand and natural sounding for effective training. To generate these voice commands, an instructor speaks the desired commands into the speech digitization hardware. This hardware converts the speech into digital data using the Continuously Variable Slope Delta Modulation (CVSDM) technique at a clock rate of 16 kHz with an input low-pass filter cutoff frequency of 5 kHz. The digitized speech is then saved on disc for later use. At the start of the training lesson, this speech data is sent from the trainer computer to each individual student station for use during the training lesson, and is stored in solid-state dynamic memory. When a voice command is required, the trainer computer sends a command to the student station that defines which voice command to speak. The voice hardware then converts the digitized voice data back into natural-sounding speech and sends it to the trainee through his headset.

The sound synthesis subsystem must reproduce the simulated vehicle sounds in a correct and realistic manner because they are cues to the trainee indicating correct or incorrect vehicle operation. These sounds include the engine as it is started under normal and freezing conditions, as it runs under various loads and speeds, and as it stops. The transmission sounds that must be generated include the sounds in each of the four forward and two reverse speeds. Other vehicle sounds that must be generated are the engine cooling fan, plenum doors opening and closing, ramp raising and lowering, ramp hitting deck, hydraulic and electric bilge pumps, audio warning tone, water jet noise, and track noise. The malfunction sounds that are simulated include engine overheating with radiator hissing sound and the transmission gears grinding.

The sounds are generated using 16 commercially available sound generator ICs. Each IC can generate three individually-controlled frequencies with noise and a modulation function. The outputs of several ICs are mixed together and filtered to form more complicated sounds. The most complicated sound, the engine, requires six frequencies, two modulation functions, and two noise components to duplicate the actual vehicle sound. The least complicated sound, the hissing sound from the radiator, requires only a single noise component. The software in the trainer computer monitors the simulated vehicle operating conditions and outputs the control words to the sound synthesis system which defines the actual frequencies and amplitudes to be generated by each IC.

Since the vehicle sounds are such an important feedback cue to the student, it is necessary that they be as correct as possible. The first step in the sound synthesis process is recording the actual vehicle sounds. This was accomplished by recording a vehicle under known operating conditions. These conditions were chosen to isolate and reduce interaction between sounds to the greatest extent possible. First, the sounds that are independent of the engine operating such as the horn, ramp opening and closing, ramp hitting deck, bilge pump, and starter motor were recorded on a high-quality tape recorder located near the sound source. The absolute amplitudes of these sounds were then recorded using a sound-level meter at the driver's station. The same procedures were followed for the sounds of the engine running at various RPMs, but with the vehicle stationary. The procedures were again followed for the engine cooling fan and the plenum door opening and closing. Finally, the vehicle was driven over actual terrain to record and measure the sounds of the transmission in the various gears, as well as the track and the water jet sounds.

The recordings of these sounds were then digitized, stored on a magnetic disc, and analyzed using an FFT analysis program which extracted the principal frequency components. These frequency values were then used as inputs to a sound development program which reproduced the sounds using the sound synthesis ICs. These synthesized sounds were then compared to the actual sounds using audio analysis techniques. The more complicated engine sound, which had several components that changed as a function of engine RPMs, was analyzed at several recorded RPMs to determine the relationship between the amplitude and the frequency of the components. Once this relationship was determined, the sounds at the intermediate RPMs could be determined so that a continuous spectrum of sounds can be generated during the training session. Sound generation in the trainer required that the software generate the various data words required by the sound synthesis system so that the sounds would be correct and natural.

VISUAL SUBSYSTEM

The visual subsystem is responsible for providing the scenes of the driving course that match the operation of the simulated vehicle by the trainee. To add realism and acceptance by the students, the visual system provides a simple interactive steering approach that keeps the student busy during the simulated driving so that malfunctions are not the only thing that the student must respond to. The major components of the visual system are the videodisc player and videodisc, the visual electronics, and the projection TV system. Figure 5 is a block diagram of the visual subsystem.

The visual subystem uses a videodisc to store the visual scenes. There are four different types of driving situations portrayed on the videodisc: stall test, land driving, water driving, and surf operations. The stall test is a simple, straight-ahead driving sequence that is part of the preoperational tests on the vehicle each day. As part of the training, the instructor can select the normal stall test or the stall test that simulates and shows a vehicle fire in the engine compartment. The land driving portion is a 3.6-mile sequence that requires the student to demonstrate correct operation of the engine, transmission, steering, and brake as the vehicle is driven over various types of terrain. As part of this sequence, the student must also follow the hand signals given by a ground guide. The water driving portion requires that the student demonstrate correct water operating procedures including water entry and exit as well as turns, stopping, and backing up in the water while operating the vehicle in a protected jetty area. This sequence also requires that the student follow a more complicated set of ground-guide hand signals and maneuvers. The surf operations portion is a six-minute sequence that exposes the student to the conditions and procedures required when entering and leaving the surf from the beach. The sequence starts on the beach, goes through the surf zone, turns parallel to

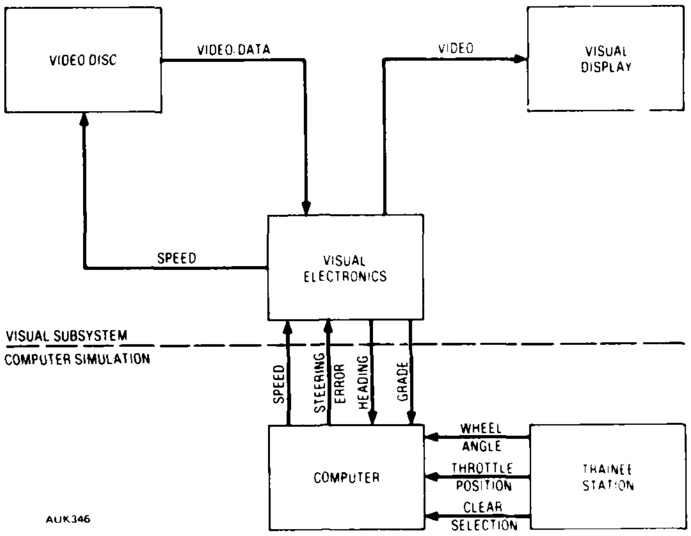


Figure 5. Visual Subsystem

the beach for about 100 meters, and returns to the beach through the surf zone.

The quality production of these sequences was important to the acceptance of the trainer by the instructors and the students. Both film and video were used to take the pictures of the various scenarios. The land portions were filmed using a 35-mm step-frame camera that was connected to a speedometer output shaft on the right-hand track. A new frame of film was taken whenever the vehicle went 1.5 feet forward, thus providing a maximum simulated vehicle speed of 30 mph when the film is converted to video on a videodisc. The use of the freeze-frame capability of the videodisc allows the trainee to go as fast or as slow as desired and still provide a correct visual presentation. The water sequences were shot using video since there is no distance-traveled indication to control the film camera. However, the sequences were shot using a constant, known engine RPM so that the simulation program would have a reference from which to speed up or slow down the videodisc to portray the student's actual speed.

The two cameras were mounted on a specially-constructed camera mount which was welded to an actual vehicle just ahead of the driver's station so the same relative view would be retained in the simulator. The focal lengths and, thus, the angles that each camera covered were set to be the same and to match the field of view that would be portrayed from the trainee's position onto the projection TV system.

The visual electronics system has three purposes. The first is to provide the interface between the trainer computer and the videodisc player. The second is to provide the interactive steering capability. The third is to generate warning and advisory messages.

The data from the trainer computer provides the controlling information for the videodisc player and tells it to search to a particular video frame, to step forward or back to the next frame, or to play the disc at normal speed. The interface electronics formats the data received from the trainer computer and sends the data to the videodisc player. The electronics also reports videodisc player status information to the trainer computer.

Implementation of the interactive portion of the visual electronics system requires that data be recorded that defines the direction that the camera system was pointing at the instant the picture was taken. It is also desirable to record the inclination of the vehicle so that the simulation program would know when the vehicle was going up or down a hill to accurately simulate the vehicle speed and sounds during a training session. This data logging took place during filming by using vertical and heading gyros from an aircraft navigation system. The readings of these gyros were converted to digital data as the pictures were taken and were recorded on each film frame and each video frame in the active image area. When the film and video are put on a videodisc and later played back, special circuits in the visual electronics will recover the data and send it to the simulation program for incorporation into the vehicle model solution. This method eliminated the need for the training program to store and retrieve data that describes the course heading and grade for each video frame. Any scenerio changes in the driving course that might have rquired a change in the course data were handled automatically by the editing process since this data was actually part of the film or video. The data recorded was 12 bits of heading data for a resolution of 0.079 degrees and 8 bits of inclination angle information for a resolution of 0.351 degrees. Figure 6 shows the location of the data bits within the active video area. This portion of the picture is blanked so that it is not visible to the student.

The interactive steering portion of the visual electronics receives trainee steering error data from the trainer computer and uses this data to rotate the visual scene from the videodisc right or left, depending on the error made. When the student's error is large and the

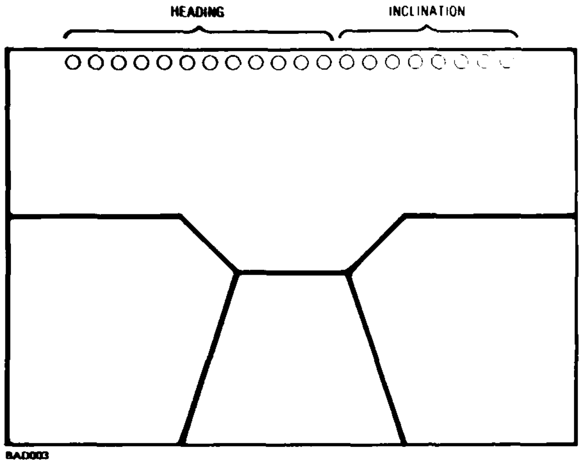


Figure 6. Data Bits in the Film or Video Frame

amount of rotation is such that there is no data from the videodisc for the scene, the visual electronics generates synthetic video for that portion not on the videodisc. Figure 7 shows the shifting scene and the computer-generated color when the shift amount is large. Thus, as the student drives around the course, the correct path must be driven and maintained or the scene will shift off the screen in the direction of the error made and the student will see nothing but synthetically-generated color. This shifting is accomplished by synchronizing to the video from the videodisc, generating new sync signals that are shifted from the incoming signals an amount determined by the student's steering error, combining these with the incoming video to generate the new shifted video, and sending these to the projection TV system. Figure 8 is a block diagram of the visual electronics portion of the system. The visual electronics system also generates computer-controlled warning and advisory messages and sends them to the projection TV for display.

The various driving scenes and messages are shown on a commercially-available, high-brightness, 6.5-foot-diagonal-screen projection TV system that is eight feet away from the trainee's position. To provide the student with a straight-on view of the screen while maintaining the correct student-to-screen distance required that the optical path be folded using a flat mirror and that the image from the projection TV system be reversed electronically.

DRIVING PROCEDURE MONITORING

Monitoring the student's driving procedures is an important part of the training program. The goal of the training school is to graduate drivers from the program who have knowledge of and are able to demonstrate the correct vehicle driving procedures. To grade the students

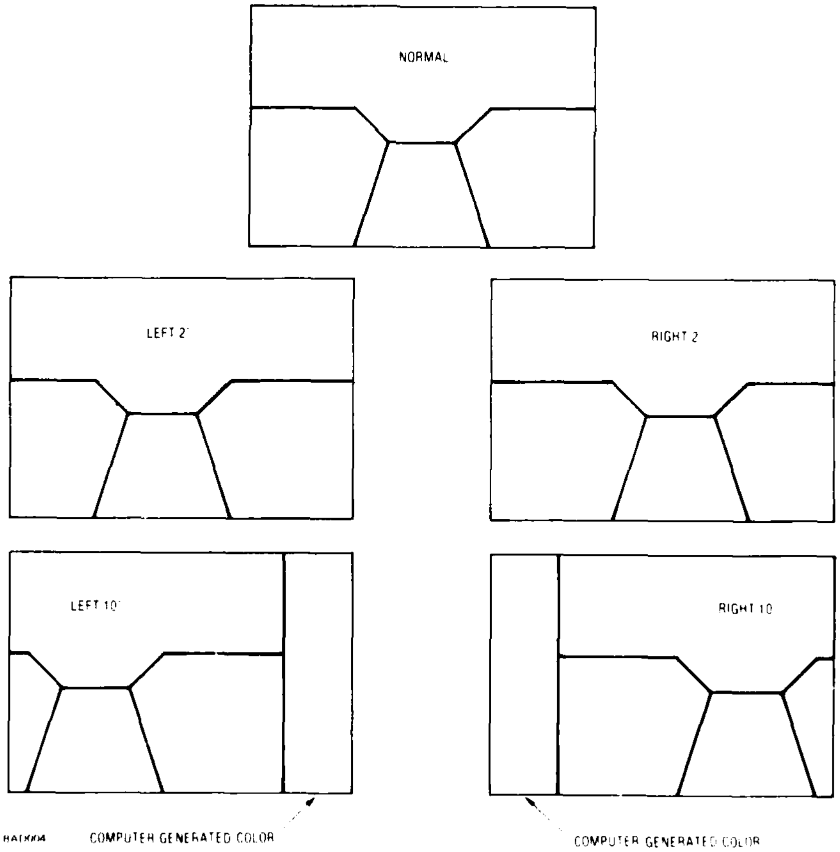


Figure 7. Examples of Scene Rotations

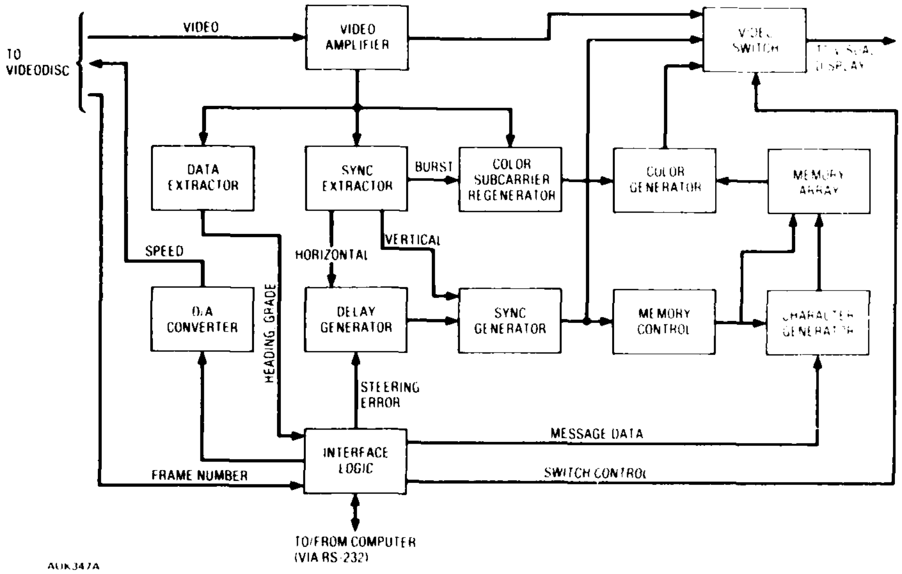
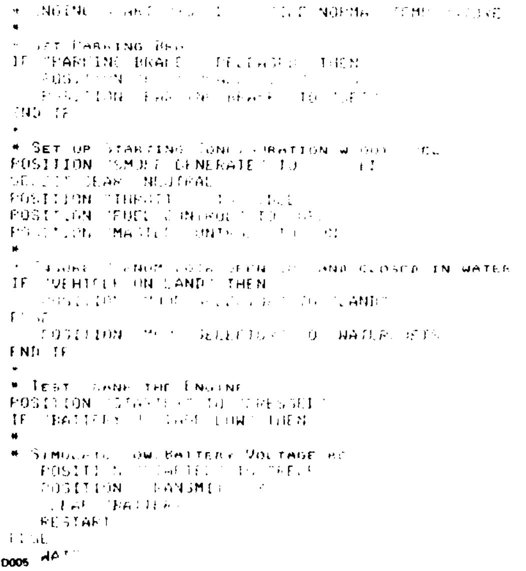


Figure 8. Visual Electronics Detailed Block Diagram

on their performance, the computer program must know the correct procedures to use as a standard. It would also be desirable for the training course instructors to be able to make changes to the driving procedures monitored by the program so that any changes in the actual vehicle operating procedures would be reflected in the simulated driving course. To accomplish these two goals, an English Language procedure file system was developed that expressed the actions to be performed by the student in real vehicle terms and conditions. Thus, anyone familiar with the operation of the actual vehicle could read the procedure file to determine if the actions and responses were correct without having knowledge of computer programming. Any changes to the procedures are simply entered by modifying the procedure file using a text editor. This procedure file is then read, parsed, and analyzed by the monitoring program during the course of the training session to test the correctness of the student's actions and performance. Since the procedure file read and changed by the course instructor is the same as that used by the program to monitor student performance, there can be no translation errors between the desires of the instructor and the student's actions checked by the program. Figure 9 is an example of the engine start procedure file for normal temperature.



```
* ENGINE [illegible] NORMAL [illegible]
*
* SET PARKING BRAKE
IF "PARKING BRAKE" [illegible] THEN
   POSITION [illegible]
   POSITION [illegible] BRAKE" TO "SET"
END IF
*
* SET UP STARTING CONFIGURATION W[illegible]
POSITION "SMOKE GENERATE" TO [illegible]
SELECT GEAR NEUTRAL
POSITION "THROTTLE" [illegible]
POSITION "FUEL CONTROL" TO [illegible]
POSITION "MASTER CONTROL" [illegible]
*
* [illegible] AND CLOSED IN WATER
IF "VEHICLE ON LAND" THEN
   [illegible] LAND"
ELSE
   POSITION [illegible] SELECTOR" TO "WATER [illegible]
END IF
*
* TEST CRANK THE ENGINE
POSITION "STARTER" TO "PRESSED"
IF "BATTERY [illegible] LOW" THEN
*
* SIMULATE LOW BATTERY VOLTAGE [illegible]
   POSITION [illegible]
   POSITION [illegible]
   [illegible] BATTERY
   RESTART
ELSE
WAIT
```

8AD005

Figure 9. Partial Engine Start Procedure File

CONCLUSIONS

When installed in March of 1984, the LCDT will provide the desired procedures training on the LVT-7A1 vehicle for the Marine Corps.

The technology used in this driver trainer is directly applicable to other vehicles that require driving procedure training.

ABOUT THE AUTHOR

Mr. JOHN ABRAHAM is a Principal Engineer with General Dynamics Electronics Division. He is currently responsible for the visual subsystem of the LVT-7A1 Driver Trainer as well as other videodisc-based training projects. He holds a master's degree from the University of Southern California in Electrical Engineering. He has worked in the area of videodisc-based systems for the past three years and in training systems for the past 12 years.

MERCHANT SHIP SIMULATORS

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As recently as 14 years ago, the various tasks involved with sailing merchant ships was reviewed and emphasis was placed on those considered appropriate for simulator training. Following this move, development was started by several organizations throughout the world on ship simulators. This paper presents the story of the work that led up to the completion of two large ship simulators. The size of these simulators plus motion to simulate heavy weather and a 360° horizontal field of view led to many interesting design experiences. The problems, errors and successes that were encountered during the design, development and final construction of these devices should be of importance to future planners of marine simulators. The mathematical modeling of ship and systems is of importance. Decisions concerning the bridge instrumentation, performance measurement, and instructor control are based on training requirements. Of maximum importance is the visual input to the trainee. The fidelity of the simulator is judged by this presentation.

1. Introduction

The Merchant Marine Industry, obviously a senior service, has for centuries, been a major mode of heavy goods transportation. Yet this important industry was the last to make use of computer-driven simulation for training.

Epic changes in the seafaring industry during the past twenty-five years demanded the implementation of innovative training techniques. Today's deck officer commands ships ten times and more the size of yesteryear's vessels. One natural gas carrier is capable of providing the average city with energy for months. The increased risk in terms of lives, effects on environment and capital loss is much greater than ever before. These high technology vessels call for a wide array of new and specialized shiphandling and safety techniques, which impose new demands and responsibilities on the ship's officer. Traditional onboard methods of training, accumulated with years of experience, must to some extent, be laid to rest. The high quality training now required must be accomplished by real-time computer simulation. This need was dramatically demonstrated during the early 1950's when radar proved to be less than useful and sometimes dangerous because of operator error. It was at this moment that simulators began their slow move toward acceptance by the maritime industry. These early simulators provided training ashore and afloat covering what turned out to be the most important use of radar, its ability to provide information for collision avoidance. The first rudimentary attempts of radar simulation rapidly grew to an industry which is now well entrenched and providing excellent training equipments. It is inconceivable that any one should be sailing today without adequate radar training. In fact, the U.S. law so-states that you must have an endorsement on your license as a radar observer on a periodic basis.

2. Background

The first really "exciting" period in maritime simulation began not with complicated electronic simulation, but what could be described as small boats. It was ascertained during experiments at Grenoble, France that an accurately scale down version of any specific vessel would in fact, render very satisfactory results for training in handling that particular vessel. These experiments, which eventually led to regular courses being offered in these small boats, were the precursor of the more complicated, more exotic ship simulators that we know today. Obviously, there were deficiencies to the Grenoble type of training. For example, it's impossible to scale time. (I am sure that as we age, we would all like to slow it down). Therefore, the length of time it takes to complete a maneuver using these model vessels is drastically reduced compared to the quarter million ton tanker or bu[illegible] that you are attempting to mimic. Another disadvantage was you could never accurately repeat any particular exercise or event so that you could clinically study it for possible improvements. Further, it was difficult to grade the students, and instructor opinion formed the basis for evaluation. While the Grenoble facility and others like it are still providing valuable training, the limitations outlined did, in part, influence the move toward computer-driven simulation.

The first computer simulation attempts as far as the maritime is concerned, could be credited to the Dutch. Their facility at Wageningen and Delft were the first commercially successfully computer-driven simulated shiphandling installations. The devices provided a useful visual scene plus proper instrumentation and responses keyed to a mathematical model of the particular vessel for which training was being provided. This model controlled all of the elements of the simulation, so the responses were in were in time and quality an accurate representation of the ship.

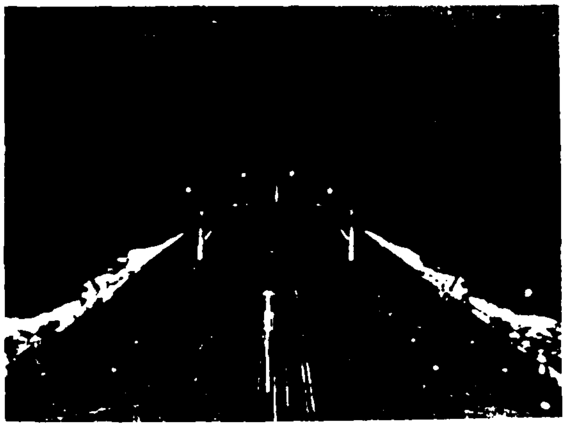
These early simulators, while a break through in the state of the art, had limiatations. One of their obvious deficiencies was a poorly defined visual scene. The visual technique the Dutch chose to use was a point light source. In this system, the point light source illuminated a three-dimensional model board which produced a shadow-like image on the screen that resembled an approach to a port. The model board rotated back and forth as the heading of the vessel changed. To simulate range change, the model board moved in and out with respect to the point light source. This technique provided a wide field of view, however, it was limited in approach range because of the mechanics of the system. With the early models, you could not go much closer than one mile to the shore or object of interest whether it be at the pier, single point mooring, or whatever.

Even with all of their limitations, these simulators in Holland were an exciting and successful breakthrough. Immediately demand for training time on them was high. A number of important decisions regarding training of officers to handle the new and imposing VLCC's were made using these devices. As a result, VLCC masters were now required to spend time on a simulator before they were given the new command. In this way, it was possible for them to experience the vessel's handling characteristics and gain a feel for its dynamics in advance of the ship's trial runs.

But this was only the beginning with respect to simulation. Plans were already being made for simulators in other countries. For instance, the Computer Aided Operations Research Facility (CAORF) was conceptualized about this time. Another entry in the field; Marine Safety International, envisioned a simulator design approach that would give them a marketable tool for training of deck officers. In Japan, work on electronic ship simulation of one form or another had been underway for some time by I.H.I. and Mitsubishi and within some of the maritime schools.

Dr. Kensaku Nomoto of the Osaka University, Department of Naval Architecture, designed a simulator built by the students that was a hybrid configuration. By using computer-controlled special effects such as; sea scape, clouds, sky, generated by an analogue such as a transparency rotating on a motor controlled base, he was able to produce a color enriched background. The other contacts (sometimes called target ships) were a series of models that were placed on a turntable that could be controlled in rotation. A zoom lens equipped video vamera projected the model's image through a color TV three gun system on to the screen. The simulator, driven by an old Hitachi analogue computer, performed well even though it was a very simple bridge configuration with equipment consisting of the helm, engine order telegraph, RPM, Rudder Angle Indicator and radio communications.

Meanwhile, ship simulator activity was underway in the U.K. These developments concentrated on a pure nocturnal scene using spot projectors to display ship, shore and navigation lights. The Decca Company with Pat Hansford's "sealing wax and string" model of a nocturnal simulator showed much promise. While the limited field of view of 110° left much to be desired, the reasonable cost of the device made it attractive. The National Maritime Institute, the source of funds and direction for the project, eventually developed five of these devices.



Each had a very tidy bridge, small but configured to have all the essentials of any well ordered ships bridge. The early models had a flying spot scanner radar simulator that later was replaced by a digital landmass system. It can be said that this simulator was a useful tool.

3. Current Technology

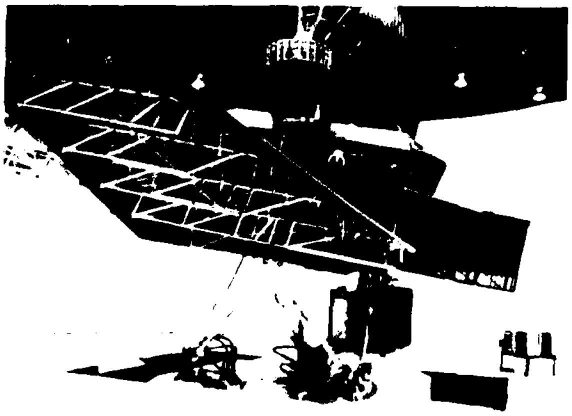
With each new requirement for ship simulation, higher demands were made on the fidelity of the simulation itself. A wider field of view, two points abaft abeam, more realism in the scene, more flexibility, better math models of own ship, all of these requirements were laid on as a result of a perceived need. Almost all of these new devices were intended for training. Therefore the bridge layouts, the instructor controls and the visual systems were designed to support a training mission only.

However, in the United States, the Computer Operations Research Facility (CAORF) was beginning to come on line. Its mission, different than one of strictly training, was to determine some of the long required answers to the problem of maritime personnel and the handling of

Projection of the nocturnal scene is accomplished utilizing a series of computer-control-led projectors. Each projector is capable of projecting a spot of light which can be varied in position, intensity and color (white, red, green or yellow). In the present configuration, either simulator is capable of generating a total of fifteen ships in a full 360° night scene. This capability can be expanded.

Each year many ships are damaged or lost due to heavy weather. The simple expedient of reducing speed and reorienting the ship's course with regard to wave motion is well known. A master's range of experience necessary to make maneuvering decisions in heavy weather may be limited. Yet, if he is forced to maneuver such as in collision avoidance or at an imperative junction point, he must rely on this experience and whatever visual input is available. A great deal of thought and discussion went into the need for motion to provide realistic simulation of all relevant aspects of handling a ship in heavy weather. These include the external influences acting on the ship motion in both longitudinal and lateral direction, in yaw, roll and pitch; the effects of wind and current varying in speed and direction with time; the effect of waves varying in direction, time and size. It was necessary to consider water depth and effects of landmass. However, no studies or operations research on motion in marine simulation had been done which could act as a guide. Thus, the inclusion of a 6° motion base was strictly a practical decision recognizing that costs to retrofit at a later date would be extremely expensive.

In motion simulation, the human threshold of response to acceleration measures from .003 to .045 m/sec^2. About ten times this value and more can be obtained in the wheelhouse for the simulation of roll and pitch motions of a small ship (30,000 DWT) in a heavy sea. Even the small values of acceleration due to heave can be sensed. The system installed will provide the primary three degrees of motion with $\pm 20^\circ$ roll, [illegible] pitch, and 18" of heave. Rotational motion (yaw) is readily detected through the visual scene when yaw is present in the exercise.



Considerable interest has been stirred in the industry by our decision to proceed with a motion base on the simulator. It is felt that much can be learned concerning heavy weather shiphandling and the effects of prolonged exposure to motion using this controlled environment.

At present, the constraint to improving simulator fidelity is the inability to project a higher quality scene. This means the apparatus between the scene data store, be it film or computer, is incapable of reproducing even a small degree of the quality available from this store. Considering computer-generated image (CGI), it can be argued that high resolution is within the state-of-the-art as far as the computer is concerned. Therefore, the quality breakdown must be beyond that point or between the projector device and the resolving surface or the screen.

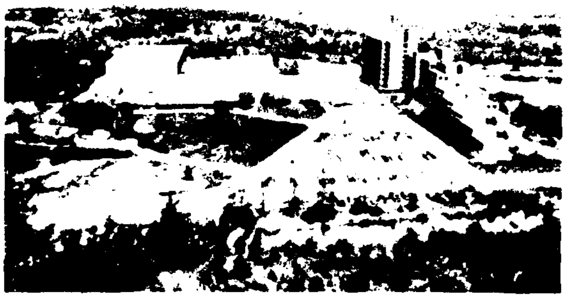
Many innovative approaches have been evaluated, but in the end, all of the computer-generated systems end up using a series of video rasters end on end to achieve a wide-angle field of view. As each "swatch" subtends approximately 44° horizontally, it is necessary to have eight or nine video projecting elements to achieve a 360° field of view. Much of the problem of poor fidelity stems from the matching of these rasters and from the use of the NTSC 525-line standard. The use of commercially available three-gun projectors does not enhance the situation. Usually low cost, they are also low output. Although there has been an attempt to use a film base system for daylight projection it has been less than a tremendous success; and therefore can be classed along with the other approaches in use at the present time, which can be described as useful but not the ultimate answer.

What then is the answer to the maritime wide-angle field of view requirement? Where are we going, and when? In 1983, the first glimmer of a breakthrough came when the laser was finally used in a video projection system by Dwight Cavendish of the U.K.

His system is the first that promises a commercially successful laser device for video projection. His device could be the basis of the next major step in a seamless, wide-angle video picture. The system consists of a blue-white ion laser beam that is split into its blue-green-red components through optical prisms. Each of these separated beams is directed through crystal lattice modulators that are energized from the RGB drive of the video stream.

ships at sea. Now with the advent of CAORF, the long costly process of designing vessels could easily include the important man-machine interface. This meant it was possible to evaluate control functions and predict their effect. In other words, simulation now gave the designer and the researcher a means by which data that had previously had to wait the trial test, could now be assembled and verified safely and accurately.

With the number of simulator facilities now coming on line, there was a quickening of interest in their use for ship handling training. At the present moment, there are over fifteen such simulators operating in the world today. One facility that has two such simulators is the Maritime Institute of Technology and Graduate Studies (M.I.T.A.G.S.).



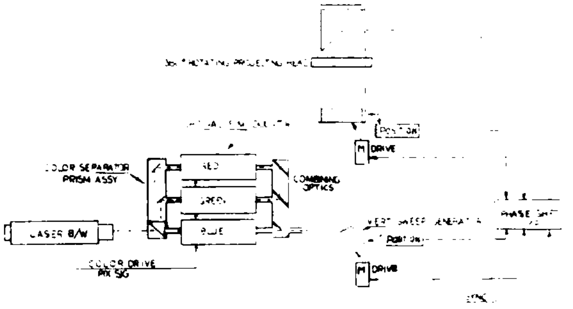
M.I.T.A.G.S. is the largest simulator based maritime training facility in the world today. The range of these training devices includes a tanker loading simulator, cryogenic cargo simulator, steam turbine simulator, a radar simulator that includes eight own ships, an electronic navigation trainer/simulator, and two total environment ship simulators. These ship simulators provide a 360° field of view. The bridge is designed to allow complete flexibility in equipment layout. The size is thirty-six feel by twenty-four feet (36'x24') and will allow the training of a complete bridge team.

In addition to the basic instruments normally found aboard ship, the instrumentation includes the following: a full chart room layout with Decca, Loran-C, Omega, Transit Satellite Navigation, and all the necessary radio communication, bow and stern thrusters, anchor controls and indicators, alarm panels for both enginerooms and navigation systems.

At present, fourteen ship math models are available. Some of these are 160,000 deadweight ton (DWT) tanker, 80,000 DWT tanker, a Lash, Seabee and Ro/Ro vessel, two container ships, twin-screw and diesel, a 21,000 DWT break bulk freighter, and an LNG vessel of the Quincy design. These math models reproduce the behavior and characteristics of the individual vessel and are able to demonstrate all the dynamic forces acting on the vessel during the navigation of shallow waters, narrow and restricted waterways, or while passing other vessels close at hand, and while operating in heavy weather in open seas.

The heart of any ship simulator for training purposes lies in the ability to convey to the trainee the visual realism either in a night or day environment. This aspect of simulator capability must be carefully considered based on the techniques available. At MITAGS, our resolution requirement of one minute of arc precluded the use of current state-of-the-art visual techniques. This requirement was based upon the premise that the primary input device for the watch officer was his eye, and a watch officer's natural response to an initial sighting or radar contact is to attempt further identification of the contact with binoculars. Of course, this is not possible with current computer-generated imagery (CGI) or video/model board systems (VMB) and therefore, computer-controlled synthesized (CCSI) imagery was selected. In CCSI scene generation, the image is projected onto a hyperspherical screen located fifty feet from the optical center of projection. This distance is beyond the ability of the eye to range by separation and restricts ranging to object association.

Because statistics presently show that over seventy percent of the casualties that result from a breakdown of judgmental skills occur at night, we have restricted ourselves to a pure nocturnal scene. Another factor which weighed heavily in favor of delaying acquiring a daylight visual capability was the poor quality of the projected scene using the current techniques. Limited light level and the need to match together several rasters for a wide angle field of view did not satisfy our needs. We have a project underway at this time that will provide a 360° continuous seamless picture. This work is based on recently developed laser techniques, which will be covered in the following paragraphs.



The output of these modulators is again reunited into a coherent beam which produces the horizontal scan through the action of a rotating polygon mirror. The points or facets of the polygon are as it rotates, the start and the end of each sweep. Another mirror device driven at the frame rate frequency produces the vertical deflection of the beam. These two devices are locked together through a comparator to the sync signal of the video stream.

At M.I.T.A.G.S. work is being done on a modification of this type of system to allow for a 360° projection system. This envisions vertical scanning as opposed to horizontal scanning at a frame rate of 60 cycles. However, the aspect would change from the 3 x 4 of the ordinary raster to a 30° included angle vertically by 360° horizontally. The Cavendish rotating polygon mirror system would be maintained, but it would now displace the laser beam in the vertical. The oscillating mirror for providing the vertical framing would be eliminated, and a rotating projection head would take its place. For a two minute of arc separation between the vertical scan lines, it would be necessary to rotate the head at 3600 rpm and have a scan rate of 10,500 cycles per second. While these numbers are imposing for mechanical devices, it's not an impossibility, and the work done to date, has shown promise.

In the past, much effort has been expended trying to establish the minimum visual input that would be considered useful for a day or night ship simulator. While this effort may have been useful, it is certain that when a modestly priced yet effective computer-controlled wide-angle visual scene is available, it will be warmly welcomed by all.

About the Author:

Max Carpenter is currently Director of Special Projects at the Maritime Institute of Technology & Graduate Studies and is responsible for research using the extensive simulator facilities of the School. Formerly Executive Director of MITAGS, this new position allows him to devote more time to the expanding and upgrading of the simulator systems of this unique facility. For twenty-five years, Mr. Carpenter has been involved with design engineering which includes simulators, marine electronics and other related equipments. His diverse interests stem from career experience which includes Electric Boat Co., Engineering Research Corp., IT&T, Kelvin-Hughes, Ltd. and Singer/Link. He is currently President of the International Omega Association (since 1978) and has guided its growth into a truly international organization. He holds membership in the Institute of Navigation, the International Marine Simulator Forum and the Nautical Institute. He has co-authored several books on radar navigation.

THE NAVY'S SHIPHANDLING RESEARCH AND DEVELOPMENT MODEL

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ABSTRACT

The U.S. Navy has undertaken a shiphandling trainer design and development project for the purpose of upgrading existing training. Naval officers at all career levels have had fewer opportunities to acquire and practice shiphandling skills because of a considerable reduction in underway steaming time. A functional design has been generated that describes several design alternatives ranging from expensive, full mission, high fidelity, bridge simulators to smaller part-task devices that train principles and concepts. The Navy has determined that a relatively small, less expensive part-task trainer may meet most of the requirements for training basic and intermediate level shiphandling skills in the areas of shiphandling: alongside, in restricted waters, in open ocean, during mooring and anchoring, and for tactical operations. A model device has been developed that allows the Navy an opportunity to evaluate each of the proposed trainer subsystems under consideration for final engineering design. Major subsystems include a computer generated imagery (CGI) visual display, computer aided instruction (CAI), and a situation display that affords immediate and delayed performance feedback during and after training exercises. Future research using this model will provide important information concerning subsystem training effectiveness and the fidelity requirements for major areas of shiphandling training.

INTRODUCTION

Conning officers, who are responsible for the safe maneuvering of ships require a specialized set of cognitive skills. Traditionally junior officers have been provided both the time and opportunity to develop these skills on-the-job while underway. Unfortunately, as the Navy's high technology operational systems have increased in complexity, the training responsibilities of commanding officers has taxed schedules and facilities to their limit. More of what a naval officer does at sea has been devoted to tactical and engineering requirements leaving a limited amount of time for training and practice of the skills of shiphandling. In addition, continuing high fuel costs and shortages have reduced total underway time, which had been used for practice and training of shiphandling skills.

To maximize training effectiveness for the time and resources that are available, the Navy has initiated a program to provide quality shiphandling training for all officers who require it. This paper briefly describes the program and then explores in some detail a research project aimed at developing one component of the shiphandling training system - a part-task device.

Training Problem

Several years ago the Naval Training Equipment Center (NAVTRAEQUIPCEN) began to closely examine the training requirements of Navy shiphandlers to determine ways for enhancing the quality and increasing the opportunities for shiphandling training (Hanley, Bertsche, and Hammell, 1982).[1] As a first step, a problem analysis was undertaken that resulted in a shiphandling job and task analysis of the Surface Warfare Officer (SWO). Supporting skills and knowledge elements were derived which were compared to those addressed in existing Navy shiphandling training programs. Current programs were compared to the training demand for officers serving in seagoing commands who were expected to handle the ship as part of their job. An estimate of the total training demand was made to understand the magnitude of training need and the qualitatively different types of training necessary to address most shiphandling training requirements.

Training demand was estimated by surveys of the major school and operational SWO commands. In addition to the total number of Surface Warfare Officer billets (approximately 12,000), several other factors were examined to help identify existing training requirements including:

Types of Training Required. The numbers of officers within basic, intermediate, and advanced skill levels were estimated. These skill groupings are consistent with career development paths described in NAVPERS 15197A ("Unrestricted Line Officer Career Guidebook"). Numbers were derived from counting the number of active Navy ships in service and estimating the number of officers who regularly conn a ship. This method provided conservative estimates of training requirements.

During 1981 it was estimated that approximately 750 basic, 1250 intermediate, and 767 advanced officers would be available for training based on a 50 percent availability of officers assigned to seagoing commands. These large numbers of trainees would require initial training and periodic refresher training.

Training Opportunities. A survey was made of Navy officers for time spent at sea under instruction and actually conning a ship. Additionally, training opportunities at shore facilities were surveyed. It was clear from the analysis that additional training sites and media must be developed to supplement existing Navy training efforts. In either area, opportunities for training were found to be extremely limited. Existing training facilities ashore were few, and equipment limited in its availability to school and operational commands. At-sea opportunities for training have been reduced because of a fleet wide reduction in steaming time.

Location. The dispersion of fleet units across major U.S. ports on either coast requires the distribution of training capabilities in many locations rather than several central ones. The Surface Warfare Officer Schools in Newport, Rhode Island, and San Diego, California; the Fleet Training Centers in Norfolk, Virginia, and San Diego, California; the Naval Academy, Reserve Centers and a number of major naval bases are all potential offerers of initial and refresher shiphandling training.

Shiphandling Training System

As a result of the training analysis, and subsequent media selection process, a shiphandling training system has been derived. The media chosen for delivering training ranged from simple audio-visual aids to a very complex, full bridge simulator which incorporates a 220-degree horizontal field of view visual scene. A number of similar shiphandling simulators are in existence today. The level of visual fidelity which they provide is necessary for the training and practice of intermediate and advanced shiphandlers. The cost to the Navy for these simulators, however, may prohibit their acquisition. In addition, there is some question as to whether basic shiphandling trainees can benefit fully from a high fidelity simulator with a limited number of instructional features.

To fill the gap which exists between audio/visual media and full bridge simulators, the NAVTRAEQUIPCEN has recommended that a relatively low-cost, part-task device be developed which will be used to teach basic shiphandlers the concepts and principles necessary to gain shiphandling cognitive skills. The part-task shiphandling device which is described in detail below, is the first of its kind to incorporate visual imagery, computer-assisted instruction and a plan position indicator in the same device. In order to determine the efficacy of this type of approach and also to examine some of the research issues which must be answered, a preprototype model of the part-task device is being developed by the Human Factors Research Laboratory of NAVTRAEQUIPCEN.

PART-TASK SHIPHANDLING TRAINING DEVICE MODEL

The model (Figure 1) called PARTT-SHIP will be used as a research tool to establish the degree of training effectiveness resulting from its current design. The goal of the PARTT-SHIP program is to demonstrate the training effectiveness of a low cost shiphandling training capability which can be distributed to training locations where need is demonstrated. As a research tool, the PARTT-SHIP design is flexible and reconfiguration is possible to examine the unique contributions of its major subsystems to the total training effect. Each subsystem is explained in the following paragraphs.

Computer Generated Imagery (CGI)

A computer generated imaging subsystem is provided that displays a 150-degree (75 degrees either side relative to ownship's forward longitudinal axis) horizontal field of view (Figure 2). The vertical field of view is 22.5 degrees, 5.6 degrees up and 16.9 degrees down. The scene is full color including ownship's bow and various day and nighttime images.

Plan Position Indicator (PPI)

A "birds eye" view CRT display of an exercise area is provided during exercises (Figure 3). Ownship is at the center of the screen. Land edges, piers, channel edge, etc., are shown in solid and dashed line format. The display is capable of supporting instruction in docking, anchoring, tug handling, and restricted waters navigation through a series of specialized display enhancements. A series of vector functions representing ownship's predicted, actual, and historic movements aid instruction in the concepts and principles of shiphandling.

Computer Aided Instruction (CAI)

Giving the student a means for individually operating the model device will allow the instructor to focus on the quality of instruction and the needs of the student. Automation of this sequence reduces instructor burdens for mechanically controlling training. A dedicated CAI plasma display introduces the student to exercise objectives; gives tutorial by way of "help" functions prior to exercise run, scores performance and displays feedback to the student. Subject areas are under the direction of the instructor and he controls every portion of the training sequence from an instructor console, should he desire.

Training scenarios have been designed to simulate the real world demands of maneuvering a single screwed Navy combatant (FFG-7) in a channel although any ship can be modelled. Variable wind and current effects are simulated in an ecologically valid manner to increase the difficulty of training scenarios according to the stage of training and skill level of a student.

PARTT-SHIP Functional Description

The PARTT-SHIP model is enclosed in a training carrel with approximate dimensions of 10 feet wide, 6 feet high, and 6 feet deep. It accommodates three students comfortably at the control panels. Students alternate as conning officer, auxiliary control panel operator, and helm operator. Auxiliary panel and helm operators are seated while the student acting as conning officer is free to move about the carrel. In addition to the trainer, the carrel contains a small chart table and a chart storage facility. Trainees not conning the ship operate the trainer under the direction of the student acting as conning officer. In its current con-

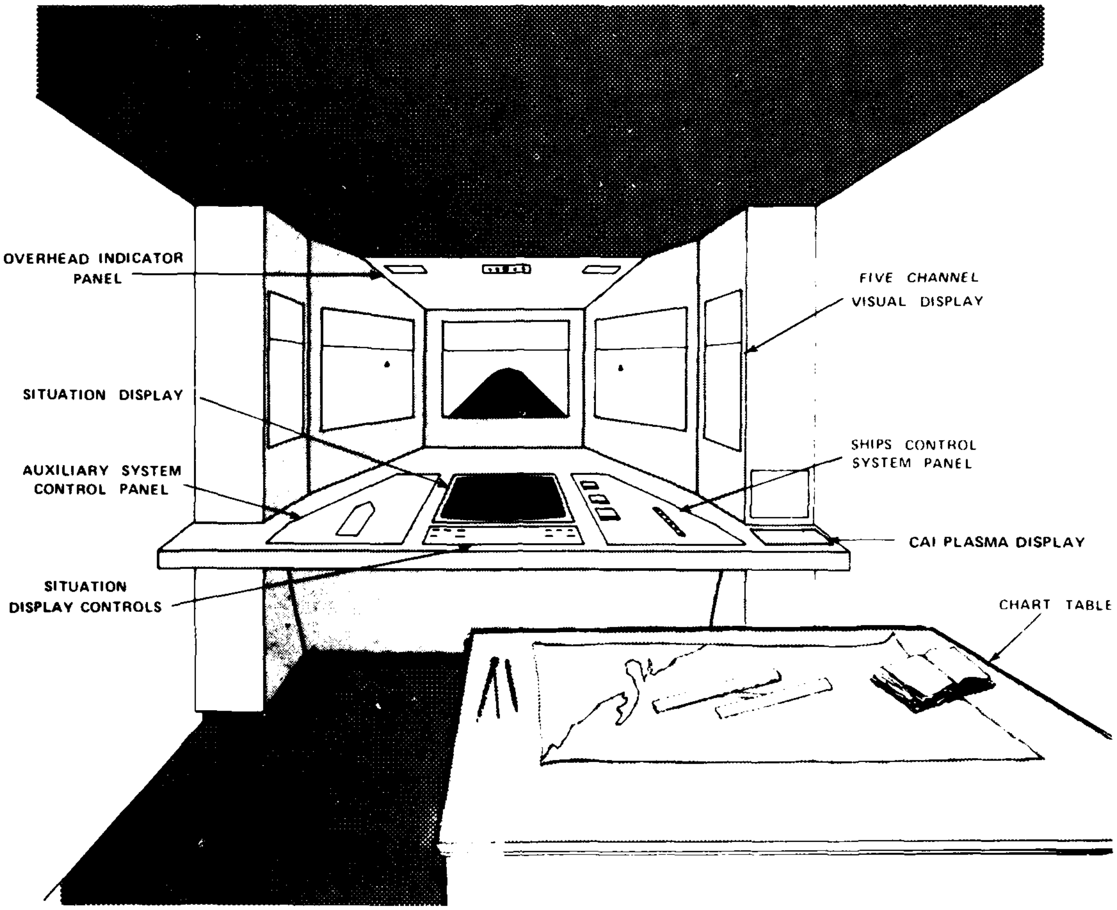


Figure 1. PARTT-SHIP Device

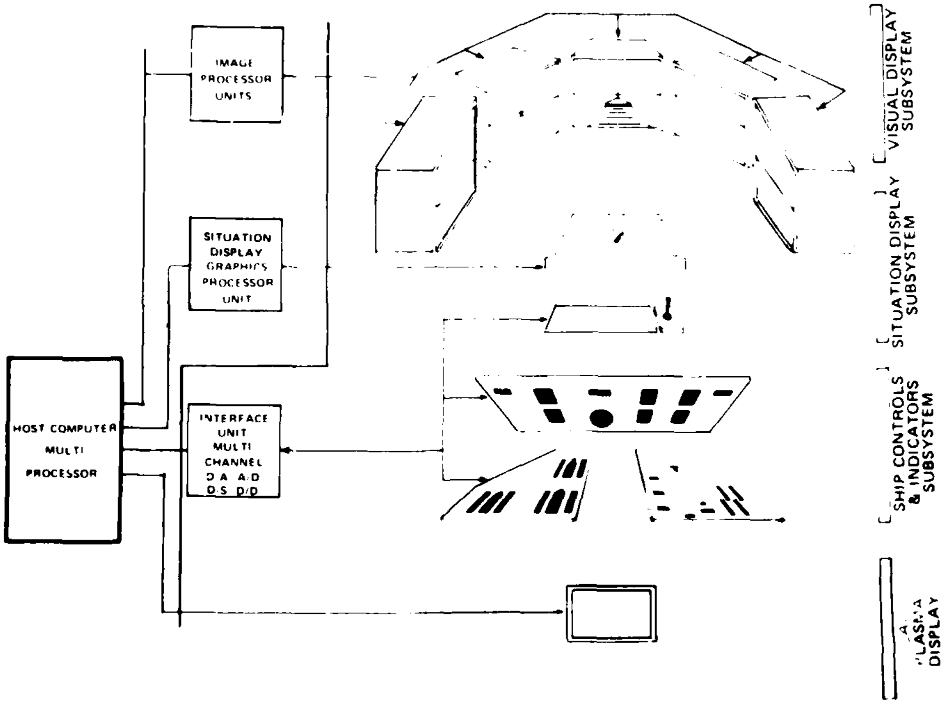


Figure 2. PARTT-SHIP Subsystems

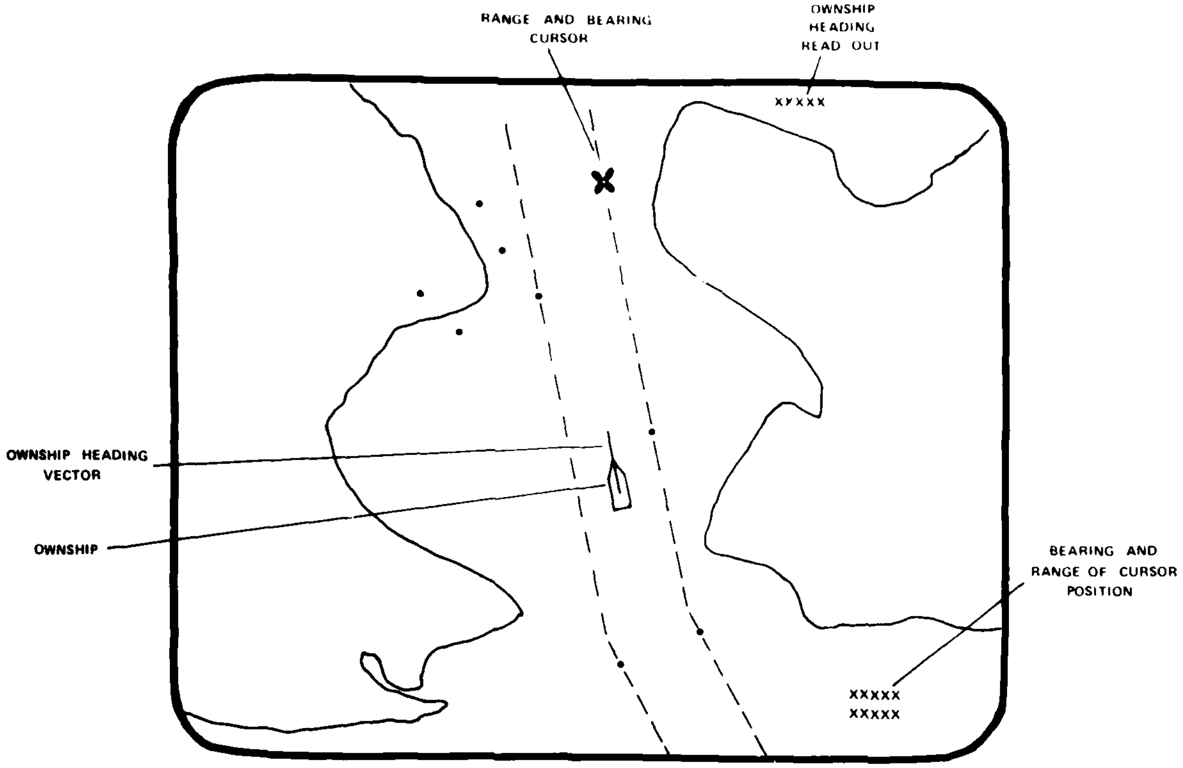


Figure 3. Typical Plan Position Indicator Display

figuration the instructor manually controls a fixed sequence of assigned instructional steps that are dependent upon the students achieving a preset criterion level of performance. Practice exercises are selected by the instructor and each simulator exercise scenario is initialized automatically. The trainee may run, freeze, or terminate the exercise scenario. Performance measures are automatically recorded by the PARTT-SHIP device and can be displayed as instructional feedback following exercise scenarios. In a production mode, it is anticipated that many of the functions currently performed by the instructor could be automated.

The device provides a real time, dynamic simulation of a selected ownship and exercise area. Generic stylized ship controls are provided which allow the trainee to control the ship's rudder, engine, propeller pitch, auxiliary propulsion units, anchors, and servicing tugboats. The status of these controls and ship performance parameters are displayed on generic indicators. The principal display for the trainee is computer generated imagery in the five-CRT configuration that comprises a 150-degree horizontal field of view. This is coordinated with an enhanced plan position indicator (PPI) representation of the geographic area that provides a "birds-eye" view of the exercise and ownship's position. The situation display also presents the future course of the ship based on external sources acting on the ownship and an estimated prediction of the ship maneuvering response to various trial rudder and engine commands. The visual system uses computer generated imagery (CGI) technology that generates images of simple aids to navigation, docking structures, and ownships bow for day conditions. Night conditions consist of lights on traffic ships, and cultural objects/land for night conditions. The training device may be operated with either or both the situation display and visual display systems.

The FFG-7 model includes auxiliary propulsion unit characteristics, autopilot, passing ship interactions, anchor effects, tug effects, wind, and current effects. Figure 2 is a simplified system diagram of the PARTT-SHIP hardware configuration that has been developed for the demonstration model. Major subsystems are:

- CAI controls and display systems
- Ship control and indicator subsystem
- Situation display subsystem
- Visual display subsystem

The model is driven by a host computer multiprocessor that controls the functions of image processing units, radar graphics processors, and a multichannel interface unit.

Situation Display. The situation display is provided to allow the student an enhanced navigation and maneuvering display in place of a traditional radar. The PARTT-SHIP model is not a radar trainer. The PPI display is a situation presentation format that was chosen over a traditional radar display because of its increased training capability through special instructional features.

The display includes distinct symbols for anchors, tugboats, piers, and other navigational aids. Channel boundaries show areas and motion vectors that can be displayed on the PPI to aid

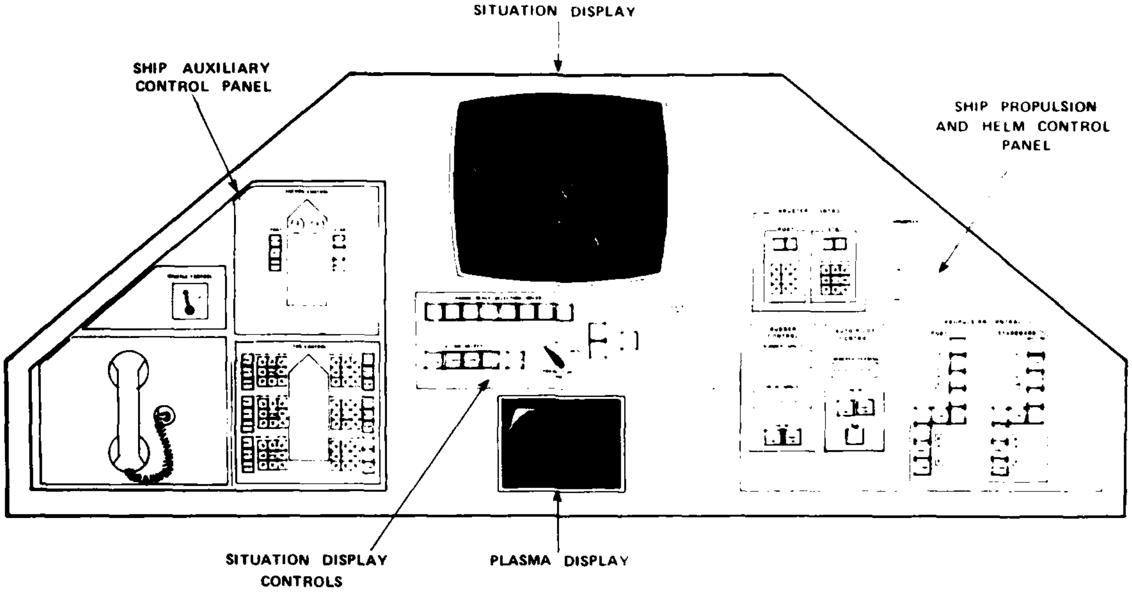
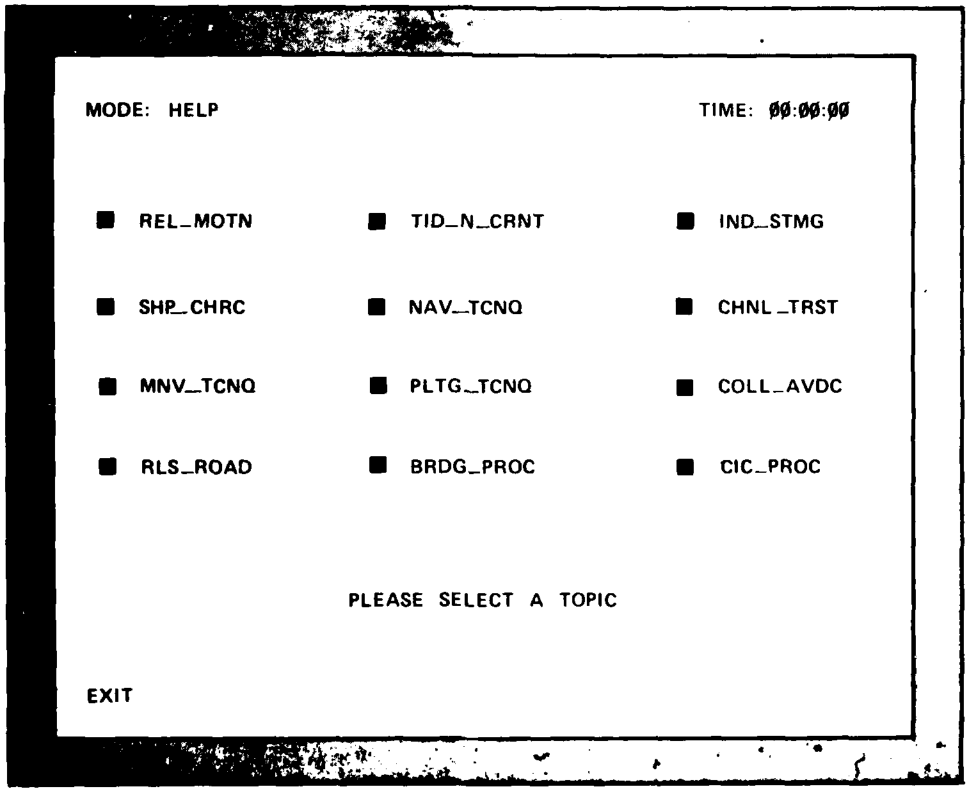


Figure 4. PARTT-SHIP Bridge Control Panel



MODE: HELP

TIME: 00:00:00

PLEASE SELECT A TOPIC

Figure 5. Plasma Console Showing an Example of a Tutorial "Help" Menu

the student in negotiating various restricted waters situations. A special set of vector functions are included as part of the PPI capability that will display past ownship track information, a predictor steering feature, and a scenario freeze capability. The trainee may choose to examine his historical performance or up to 3 minutes of the ships predicted future course. These functions are carried in fast time while the scenario is in run or is frozen. Traditional radar features (i.e., range and bearing) can also be displayed. Using a PPI representation, the student is less apt to attempt mastery of radar operations since operation of the PPI situation display is simplistic. Operating device controls demand little attention from the trainees to increase the probability that the student attends to the principles and concepts of shiphandling rather than the mechanical operation of the trainer.

Bridge Controls. The generic bridge design includes a number of stylized controls and indicators that were included to reduce the amount of familiarization time necessary within the trainer before training can begin (Figure 4). The controls are simple pushbuttons which simulate the function of real world bridge equipment. The stylized generic nature of the controls and indicators make the training device applicable across a wide variety of ship classes and ship types without sacrificing face validity. The goal of the design was to make the operation of the trainer straightforward and simplistic. This minimizes the necessary task demands for operating the device so that students can pay attention to the important information being displayed in the visual scene, situation display, and computer aided instructional display.

Gaming Area. The nature of computer generated imagery (CGI) systems is such that reprogramming of new gaming areas or switching from one gaming area to another can be done rapidly and inexpensively. Any number of major U.S. Navy ports or other ports of interest may be called upon for instructional purposes limited only by computer storage capacity and data base availability. Special features of each gaming area are accurately programmable since the environmental equations that model each data base are sophisticated. The effects of bank, cushion, shallow water, passing ship, current, wind, bottom composition, and a number of other environmental parameters are designed into the hydrodynamic equations that control the portrayed motion of ownship through the gaming area.

CAI Functions. A computer aided instructional capability has been designed for use before, during, and after exercise run. No shiphandling trainer presently uses a CAI feature, so its effectiveness will be closely monitored in this project. These functions are used to: explain the operation of the trainer, exercise objectives, and performance feedback information to the student. Additionally, CAI functions have the capability of interrupting a training scenario to question the trainee concerning various exercise scenario features with which the student should be familiar or should be anticipating during the exercise run. This feature cues the trainee so that he may direct his attention to important features within the exercise. It is also a means by which the instructor can judge how well the trainee is absorbing the instructional materials.

Before exercise run, a PARTT-SHIP "help" feature can be called upon for a brief tutorial of principles and concepts related to the scenario. The trainee need only touch the appropriate area on the plasma "help" display for a number of various menus to appear within which the student can select (Figure 5). Several levels of branching have been designed so that the student can access the level of instruction required for his particular entry level skills and knowledge. The tutorial structure is flexible yet easy to follow.

TRAINING EFFECTIVENESS EVALUATION

Design of the PARTT-SHIP model was a product of front-end analysis that included user inputs and expert analyses in the areas of training, operation, and engineering. Many design steps were taken to maximize potential training benefits to Navy shiphandlers. However, as in any development the validity of design must be examined through actual use. To avoid the incorporation of unneeded model features into the final engineering design, a series of model evaluations have been conducted.* Goals of the evaluations are to experimentally test the training effectiveness of the PARTT-SHIP design and to collect expert shiphandler evaluations of training potential for the existing model. Information gained from evaluations will be used to improve the final engineering design specification.

Two questions have been posed concerning the PARTT-SHIP model:

1. Can basic and intermediate level shiphandlers receive comparable training with the part-task trainer as with a full-scale shiphandling simulator?

2. What features of PARTT-SHIP are necessary for good training, i.e., CGI, PPI, and CAI?

A training effectiveness evaluation (TEE) has been conducted to answer these questions and is described below.

Comparative Evaluations

Two experiments were planned to investigate the measurable training gains of the model. Each was designed as a before and after study to compare entry level shiphandling skills of junior Navy officers to skill levels demonstrated after training. Figure 6 is a diagrammatic representation of planned treatments and control groupings. The simplified block diagrams and drawings below each capability represent the configurations that will be compared. An example of one treatment is the "PARTT-SHIP

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*Note: At the time of this writing, the evaluations were just beginning. Preliminary results of the study will be distributed. In addition, final results may be obtained by writing to the authors.

EXPERIMENTAL DESIGN

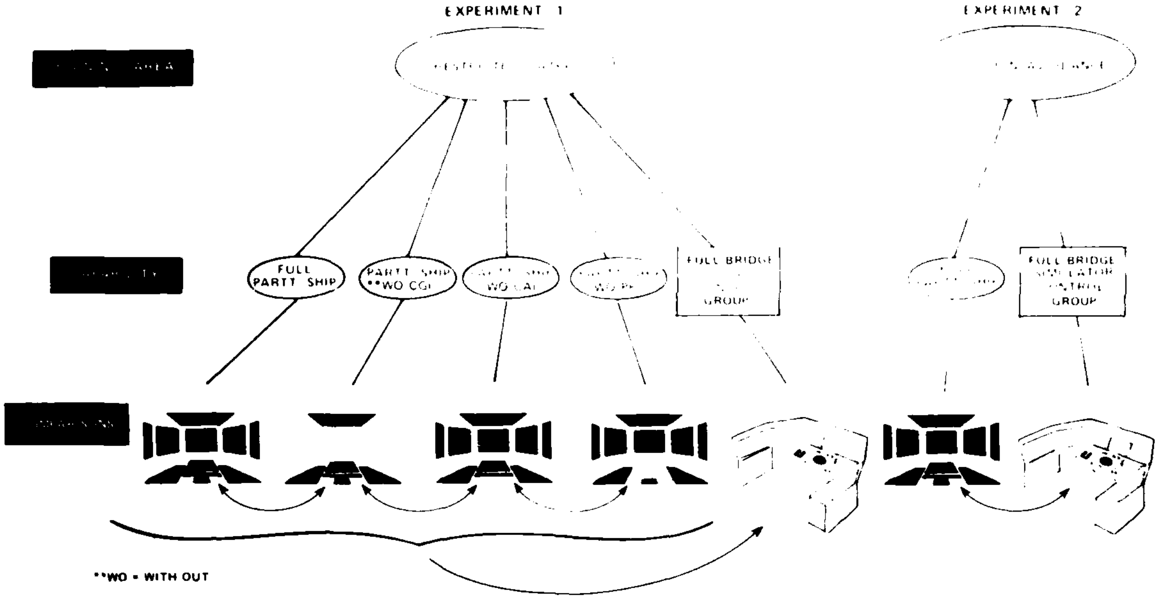

Figure 6. TEE Experimental Design

without (wo) CGI" (PARTT-SHIP without computer generated imagery) shown for Experiment 1. It can be seen that the CGI display screens are not included in that drawing.

Experiment 1 investigated the training effectiveness of the PARTT-SHIP model for restricted waters shiphandling. Subjects in this experiment were junior Surface Warfare Officer students from Surface Warfare Officer School (Basic).

The principal comparison was between training conducted on a full-mission bridge simulator and that conducted on the PARTT-SHIP model. Entry skill levels of students trained on either device were balanced along with scenario difficulty, scenario length, training objectives, instructors, and total time of training. This allows a direct comparison of final posttraining skills and training gains between training devices. Comparisons were also made between pretest and posttest performances within control and treatment groups to examine the total training gain.

Three other comparisons were planned to test the effectiveness of reduced PARTT-SHIP configurations. Reduced designs were accomplished by removing the CGI, CAI, and PPI subsystems one at a time and to test their individual effects. A separate group of trainees was instructed with each reduced version of the trainer. Each treatment (PARTT-SHIP) group was compared to one another and to a control group trained on a full-mission simulator.

Experiment 2 was a separate but similar experiment run with other groups of trainees within the area of collision avoidance but without the reduced trainer comparisons.

Qualitative Evaluation

Each experimental subject and all Navy personnel taking part in demonstrations of the model have filled out a device rating questionnaire. It was designed to record and quantify opinions of the model's training potential.

Research Hypotheses**

Expected findings from experimental efforts can be summarized in several specific hypotheses.

Hypothesis 1. Principal comparisons between treatment and control groups will show no difference. This would mean that the PARTT-SHIP model approaches or equals full scope bridge simulation training capabilities within the areas tested. This outcome was expected because of the similarity of functional capabilities in each device. Primary physical differences exist for the size of the bridge area and the fidelity of the bridge controls and control panels. Visual scenes are essentially the same. Training displays were the primary functonal difference.

Hypothesis 2. When comparing "reduced" versions of the PARTT-SHIP model to one another and to training on a full-mission simulator, removal of any one subsystem (i.e., CGI, CAI, or PPI displays) was expected to affect the speed of learning and therefore the total training effect. No a priori rankings of the training effectiveness of any one subsystem was predicted.

**Whether these hypotheses have been supported or refuted will be discussed in the additional pages distributed at the conference.

Hypothesis 3. Although performance gain was expected to be equal between control and treatment groups within either training area, subjects trained on the PARTT-SHIP model may have experienced a performance decrement during simulator posttest. This could have occurred since a degrading in performance between part- and full-task trainers was found by Williams, Goldberg, and D'Amico, 1980,[2] in a simulator study of Chief Mates shiphandling behaviors. Although training gains were equivalent for students training on a full-scope (full-task) simulator and a reduced bridge (similar to the PARTT-SHIP model), Chief Mates having trained on the reduced bridge experienced significant deficiencies in performance when transitioning to the higher fidelity full scope simulator for more training and testing. Although those subjects differed somewhat from the Navy population (i.e., junior Navy officers), it is reasonable to assume that such a deficit may occur in the PARTT-SHIP experiments during posttest.

Hypothesis 1 is not contradictory to Hypothesis 3 although the former predicted no difference between treatment and control groups while the latter predicted a possible difference. Hypothesis 1 was concerned with training effectiveness with respect to device types as measured by pretest/posttest comparisons. Hypothesis 3 predicted that subjects from treatment conditions, who were trained on the PARTT-SHIP device, may have experienced performance decrements on a full bridge simulator posttest following training. Hypothesis 1 was, therefore, a comparison of training gain within devices as measured on each device while Hypothesis 3 was concerned with measures of training effectiveness as measured by the simulator alone. These predictions were not mutually exclusive.

CONCLUSIONS

High accident rates over the last few years prompted the Chief of Naval Operations in 1979 to make the area of shiphandling training a high priority objective for improvement. The shiphandling training program under development at NAVTRAEQUIPCEN will go a long way towards meeting that objective. Special emphasis is being given to the numerous research questions which must be answered concerning the part-task device preprototype, especially since it is the first of its kind. Will it be training effective? Which elements of the device are most important? What will be the opinion of experienced shiphandlers about the efficacy of the device? The results from the current study will hopefully provide the answers necessary to make the part-task approach an effective and efficient element of the total shiphandling training system.

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REAL-TIME CGSI-SINGLE PIPELINE PROCESSOR

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ABSTRACT

Non-real-time feasibility was demonstrated in 1982 for a hybrid visual/sensor simulation approach which merges two technologies, Computer Generated Imagery (CGI) and Computer Synthesized Imagery (CSI) to form Computer Generated Synthesized Imagery (CGSI). This approach holds promise as a cost-effective, attainable method of providing real-time, high detail imagery for visual and/or other sensors, such as FLIR. Because of the high potential payoff from the development of this hybrid approach, a current program is aimed at demonstrating feasibility of this CGSI technology in real-time. CGSI uses a modular set of building blocks which may be configured to meet specific training and simulation requirements. The pipeline processor is the major element in a CGSI system. The pipelines accept control commands from the Field of View (FOV)/Controller module and input video data containing objects from the data base. The Pipeline Processor then outputs transformed objects to the scene-construction module and special-effects module. To control risks, a single pipeline is being fabricated and tested before the remaining modules and additional pipelines are fabricated. The feasibility demonstration of a single pipeline is scheduled for September 1983. The results of these tests will be included in the oral presentation at the conference, but unfortunately will not be available in time to meet the publication deadline for the written paper. A description of the test procedure is included here.

INTRODUCTION

Requirements

Sophistication of weapons systems is growing at a rapid pace. This sophistication takes many forms including increased operational capability through use of multiple sensor systems including FLIR (Forward Looking Infrared), Imaging RADAR, LLLTV (Low Light Level TV) in combination with out-the-window visual. Proper task loading is often necessary to train operators and maintain skills in the use of sophisticated weapon systems. The arguments against using operational assets include cost and safety. There is, therefore, a need for increased fidelity through simulation. Current approaches in visual and sensor simulation are inadequate for tactical training. Modelboard systems lack the ability to provide multi-spectral imagery, weapons effects, moving targets, large gaming areas, and wide fields of view. Present Computer Generated Imagery Systems lack scene content to support this type of training.

This paper addresses a new technique being developed to increase visual and sensor simulation system fidelity and capability. Honeywell's Systems and Research Center is presently under contract to the Naval Training Equipment Center and the Army Project Manager for Training Devices to develop this increase in visual system capability and fidelity. The system under development will merge the attributes of an optical disc technology approach, Computer Synthesized Imagery (CSI), and Computer Generated Imagery (CGI). CSI provides high quality imagery, but does not provide free movement within a gaming area. CGI provides the necessary freedom of movement, but with highly stylized or cartoonish imagery. This hybrid concept of Computer Generated Synthesized Imagery (CGSI) utilizes optical disc photographic imagery (CSI) overlayed onto a CGI background. In addition to displaying individual objects in a scene, the system is capable of displaying groups of objects, imagery as seen from various sensors (e.g., FLIR and LLLTV) and adding smoke and other special effects. Initial non-real-time feasibility of this hybrid system has been demonstrated (1). Additional work is necessary and is being pursued to provide a real-time capability (i.e., a minimum update field rate of 60 Hz). Detailed design of a limited system was completed in April 1983 (2). CGSI uses a modular set of building blocks which may be configured to meet specific training and simulation requirements. The pipeline processor is the major element in a CGSI system. The pipeline processors change a stored image to scene conditions (screen coordinates) by changing image position, size, rotation, warp, and intensity. The Pipeline Processors then output transformed objects to the scene-construction module, pixel by pixel, based upon range. The pipelines will operate as single, large object processors; as multiple, small object processors; or as special effects processors.

A top-level system specification for each subsystem has been prepared. These specifications contained two key elements - performance and I/O requirements. After the specifications were reviewed and approved by both the Government and Honeywell, the detailed design effort began. Each subsystem was designed as a unit, with individualized hardware and software. This detailed design of the pipeline has been completed. The pipeline processor subsystem is the most complex subsystem. Therefore, to control risks, a single channel is being fabricated and tested before the remaining modules and additional pipelines are fabricated. The feasibility demonstration of a single pipeline was performed in early September 1983.

The CGSI system has been selected for a competitive fly-off to provide next generation visual and sensor simulation technology development for the U.S. Army. Technology being developed under this Army contract builds on a feasibility demonstration contract received from NAVTRAEQUIPCEN. This joint Navy/Army/Air Force effort will first demonstrate the real-time feasibility of the CGSI concept. The U.S. Army requirements are for the AH-64 Apache helicopter combat mission simulator. Visual requirements encompass weapons effects and delivery, wide field of view displays to support nap-of-the-earth flight, multiple viewpoints, multiple sensors and multiple magnifications through a telescoping systems. The Apache requirements are felt to be one of the most demanding in the simulation industry today. The system described here could provide a capability to meet these requirements. The CGSI system has potential application for providing air-to-ground capability in the U.S. Navy's F/A-18 Hornet fighter/attack aircraft simulators and for filling low level contour training requirements on the CH-53 D/E and CH-46 helicopter simulators. One of the extremely attractive features of this approach is the potential for utilizing CGSI to retrofit existing CGI systems to increase performance. The Air Force's interest in this development results from the need for high fidelity simulation for air-to-ground attack missions. The Air Force Human Resource Laboratory (AFHRL) has provided funding support for the CGSI feasibility demonstration.

CGSI System Overview

The single pipeline is an integral part of the entire CGSI system. Therefore, a brief functional overview of a real-time CGSI system will be given here in order to provide understanding of the single pipeline in its proper context. Figure 1 is a functional overview of a real-time CGSI system. The functional blocks are separated into an off-line non-real-time data base construction module and a real-time processing system. A brief description of each module follows.

The data base consists of two very different types of data - the object library and the gaming area. The object library contains images of objects and surfaces in different spectral bands, and transmissivity masks of special effects. The gaming area data base provides the information necessary for placing the contents of the object library in the gaming area. The objects in the library may be either stationary or capable of movement. The vehicle simulation computations determine the locations and viewing

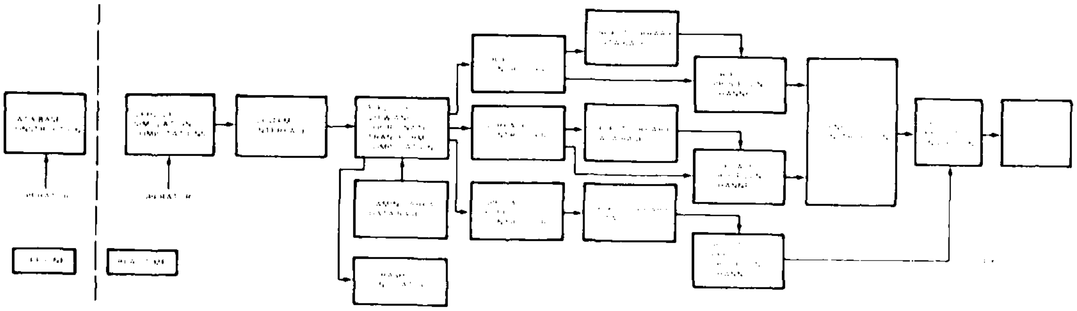

Figure 1. CGSI Functional Overview

direction of the visual or sensor system for the primary vehicle. The FOV processor determines the presence of objects, surfaces, and special effects in the scene under construction. The output of a transformation matrix converts the real-world coordinates to screen coordinates. The controllers fan out and process the control functions generated during the FOV computation. The processed control functions are passed to the object/surface/special effects processing channels. The object, surface, special effects (OSSE) library stores the images used to construct a scene. The controllers command the selected images which are passed to the processing channels. The individual processing channel pipelines process one object, surface or special effect per channel. All the processing channels operate in an identical manner. The object, surface, special effect channels change a stored image (normal perspective) to scene conditions (screen coordinates) by changing image, position, size, rotation and warp. Image intensity is modified based upon range and object type. The scene construction module takes the individual image from each processing channel, separates the image from the background, and assembles the scene based upon range. The high frequency edges generated by assembling a scene from individual images are smoothed, matching edge and internal frequencies. The translucent special effects are added after the generation of the scene. The special effects module adds the special effects based upon range. Special effects, such as smoke or dust, may occur ahead of or behind images in the scene. The intensity masks are stored in the object library and processed in the special effects processing channel.

OSSE Processing Channels (Pipelines)

In this section, the functional overview, shown in Figure 1, is expanded to provide a generic hardware overview for a single pipeline and scene construction and special effect components (Figure 2). The system is modular; a small system may contain only several OSSE processors and a large system may contain several hundred OSSE processors. It is the intent of this design to allow the system to produce any type of imagery, visual, IR, MMW (Millimeter Waves), SAR (Synthetic Aperture Radar), radar, etc. Current funding includes simulation of visual and IR imagery.

Each object, stored group of objects, surface or special effect is individually processed by an OSSE processor and used to construct a scene in the scene construction module and special effects module. Depending on the size of an OSSE image, the OSSE processors handle from 1 to 16 OSSEs per channel. In this section the path of an image (one full image or up to 16 small images) will be traced from the image storage media to the image display subsystem. The processing of the image during its flow through the pipeline is under the control of a Field of View (FOV) controller. All OSSEs are processed in the same manner at the beginning. Depending on the function, major changes occur in the scene construction modules and special effects modules. Nontranslucent objects and surfaces (trees, rocks, bushes, tanks, etc.) are combined in the scene construction module. Realistic color or true color can be applied. Realistic color is generated via lookup tables and uses one pipeline, while true color uses three pipelines, one each for red, green and blue.

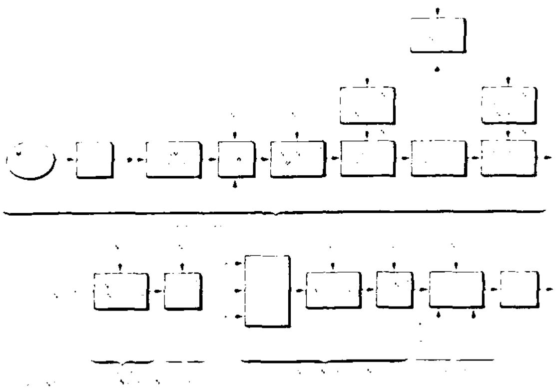

Figure 2. CGSI Configuration Elements

A/D Conversion. A high speed A/D module converts the analog video imagery to digital data. The module operates near 8 MHz and provides 8-bit, or 256 gray shade, output.

Frame Buffer. The frame buffer is controlled by the OSSE controller; it is used to store images that are not changing. This includes distant 2D objects and all surfaces and special effects. The warping process may compress data resulting in loss of resolution in the transmitted imagery if the image is rotated beyond 50 or 60 degrees. To limit rotations to + 45 degrees, a high speed memory design is used which can be accessed in both the X and Y axis. As a result, one image may be rotated a full 360 degrees without degradation through line and column memory access.

Frame Buffer Switch. The frame buffer switch allows the imagery to be held in the frame buffer for repeated use of 2D objects, surfaces and special effects. After an OSSE is stored in the frame buffer, the optical disc may be used to apply imagery to other channels. For dynamic 3D objects, the frame buffer allows the imagery to be taken directly from the optical disc without any delays. The frame buffer switch is controlled by the OSSE controller.

Intensity Modifier. The intensity modifier modifies the intensity of a scene in both global and local manners. Global changes use a LUT. As an example, these changes may be associated with range; that is, an object at a distance is more saturated and bluer than the same object at a very short range. Local modifiers multiply, on a real-time basis, each image pixel by an LUT value. The LUTs contents are a function of position within the frame. The intensity modifier introduces only pixel delays.

Y Axis Processing. The algorithm for distorting an object operates in two passes. Before explaining the Y axis functions, an overview of the warping function is presented. The warping algorithm contained in the pipeline operates in two passes; first the Y axis and then the X axis. The field microprocessor determines the offset (starting location), the magnification (change in line length) of the first line in each axis and selects the field memory buffers. The line microprocessor determines the delta offset and delta magnification of each line. The field microprocessor operates in a 16 millisecond cycle and the line microprocesor in a 63 microsecond cycle. The pixel processors operate on the pixel streams in a 100 nanosecond cycle or 10 MHz. During the first pass of the Y axis, each line in the row may be distorted in one or more of the following manners: Linear, perspective, curved, lens correction or multi-object (2).

Three Field Buffer. The three field buffer allows the Y axis processed image to be read into two field buffers, one for odd pixels and one for even pixels. The third field buffer allows either odd or even fields to be processed in the X axis processor.

X Axis Processing. The techniques used in the X axis could be identical to those used in the Y axis which includes the following functions: Linear, Perspective, Curved, Lens Correction, and Multi-Objects. In addition, for potential applications where perspective distortions in the real-world are not identical in the X and Y axis, the X axis processing could use algorithms which differ from the algorithms used in the Y axis. This case could occur with dome projection display systems or Synthetic Aperture Radar (SAR) imaging systems.

Line Rate Converter and Synchronizer. If the system requires other than 525 line video, a line rate converter changes the line rate of 525 lines to, for example, 875 or 1024 lines by changing the pixel clock rate. The line rate converter does not add lines or pixels; it only changes the rate at which the pixels are clocked in and out. In converting a 525 line system to 1024 line, for example, only 1/4 of the 1024 system is covered by a single 525 line input. The line rate converter is a first-in/first-out buffer (FIFO) that synchronized and positions the 525 line, 10 MHz imagery to and within the 1024 line, 40 MHz imagery.

Realistic Color. The CGSI approach has been developed to provide monochrome; realistic color; or full, true-color capability (See Figure 3). True color is provided through the creation of three spectrally distinct data bases - each full-color photograph is digitized and stored separately using optical quality red, green and blue filters. When a full color image is displayed, the red, green and blue object images are independently processed and delivered to the red, green and blue channels of the color display system used. One can see that full color is bought for a price: three times as many processing channels are required relative to the number needed to generate a monochromatic version (e.g., IR) of the same object image. Near-perfect color is achievable in a much more economical manner. Most OSSEs contain only shades of one or two colors; i.e., consider green leaves, brown branches, blue water, camouflaged targets. Look-up table manipulation techniques permit the generation of realistic (as opposed to true) object and surface color on the basis of mapped grayshade imagery. The realistic color approach allows the CGSI system to generate terrain, vegetation and object colors with one-third the processing required. To obtain realistic color, each object is stored as a spectrally mapped image. Associated with each image is a red, green and blue LUT conversion that assigns up to 256 colors to gray shade levels of the image. The 256 colors that are achievable may be 256 shades of one hue - for example, shades of green to create a high fidelity color image of a bush - or 256 distinct hues. The process is thus precisely controllable, and provides adequate color capability for combat mission training simulations.

SINGLE PIPELINE TEST PROCEDURE

A single CGSI pipeline design has been completed as described above. The feasibility demonstration is scheduled for September 1983. A test plan has been developed to verify the operation of this single pipeline and will be described here. The objectives of this demonstration are to verify the speed and accuracy of a single pipeline, to provide contractor in-plant testing of a single-pipeline, and to provide real-time warping of 2D objects and 3D objects for both the visual and IR spectral regions. Figure 4 gives a system block diagram for the single pipeline feasibility demonstration.

Measurements of speed will include both throughput lag and update rate. Figure 5 gives the nominal design timing for the CGSI systems. Throughput lag (transport time) is defined as the time between the receipt of positional informa-

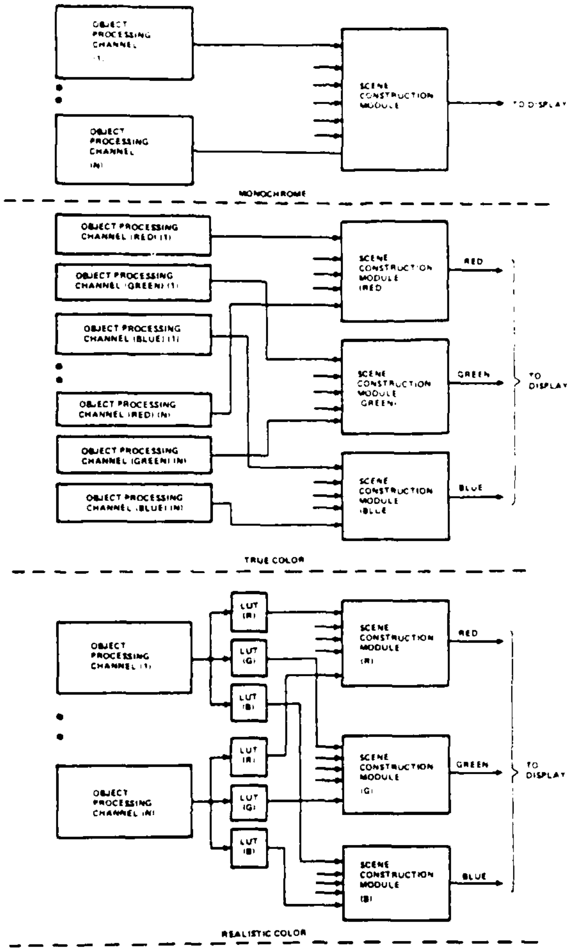

Figure 3. Color Hardware Configuration

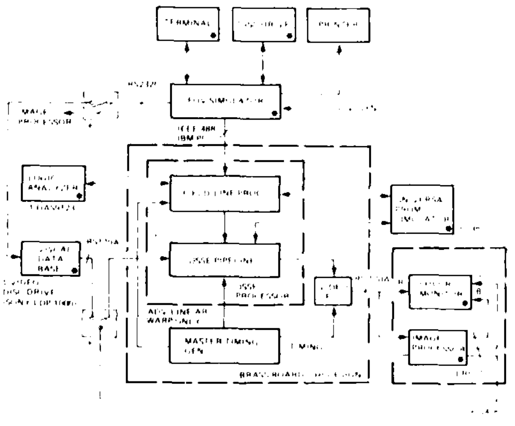

Figure 4. Single Pipeline Feasibility Demonstration

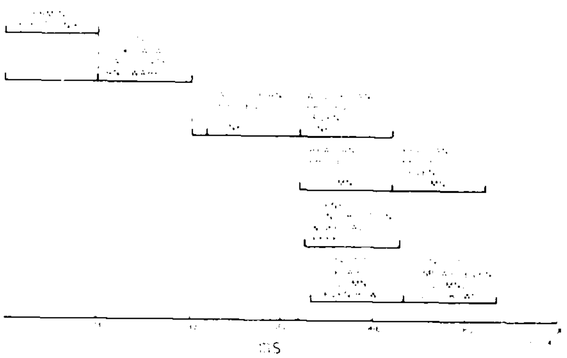

Figure 5. CGSI System Timing

tion from the vehicle simulation computer to the completion of the picture scan. Based on use of a specific test pattern, the delay from receipt of positional change information at the FOV computer to a change in output pixel value will be measured with a logic analyzer. Update rate is defined as the rate at which vehicular position may be changed. The design target update rate is 60 Hz. The operator will start the simulation, causing the object to be displayed and move. Motion will occur because the FOV simulator outputs coordinates to the "pipeline" via the IEEE 488 interface at a 60 Hz rate. Delta values will be applied at each update by the simulation program to make the object move on the screen. Proper rate of motion will be verified by having the image processor sample frames out of the pipeline. These frames will then be analyzed off-line to verify that the pixel(s) are in the expected location(s) for the particular frame sample times.

Measurements of accuracy will include both measurements of screen location and timing. Screen location is defined as the absolute location of the object within the FOV as expected from commands transmitted to pipeline by the FOV computer. The test object will be translated in x,y, magnified, compressed, and rotated independently and in combination. The output of the pipeline is fed back into the image processor (See Figure 4). The image processor will enable non-realtime simulated imagery to be compared to real time pipeline imagery such that the monitor will display the object in three colors as follows: R=pipeline modified object, G=image processor modified object, B=background. The image processor and trackball will be used in combination to find differences between these images. Differences will also show up obviously as yellow on the color monitor. All differences shall involve 1 pixel or less. The timing of an object relative to the horizontal sync signal shall be controlled to ensure object to object alignment at the scene construction module. The operator shall select an object which consists of a single pixel located in a known time slot on a known line. An oscilloscope shall be used on the pipeline output video to measure the location of the single output pixel relative to the line sync and the master sync.

The image stability will be tested. Image stability is defined as the constant location of an object from frame to frame in time. The operator will select an object to be sent through the pipeline. The image processor will be used to periodically sample a group of three frames. The image processor will be used off-line from the test with the pipeline to measure the location of the pixel matrix in each sample frame. The matrix location shall vary by no more than +/-1 pixel from the average (nominal) location across all of the sample frames. In addition to the above quantative tests, the following qualitative demonstrations will be observed. The image quality shall be photographic quality with minimum degradation resulting from processing. The capability of warping/displaying 2D and 3D objects for both visual and IR will be observed. The capability to interface the pipeline to a video disc player will be demonstrated. Realistic motion of objects will be assessed.

SOURCE OF DIGITIZED IMAGERY FOR A SINGLE PIPELINE

A point which may seem obvious to some, but is worthy of emphasis, is that a single pipeline can process any type of digitized data. It is immaterial what region of the spectrum (visual, IR, RADAR, MMW) is represented by the imagery or what the original source of the imagery was (real-world object, physical model of object, non-real-time CGI).

Current funding provides for simulation of visual and FLIR using the CGSI pipelines. Qualitative analysis indicates that other imaging sensors such as SAR and MMW could also be handled by CGSI pipelines.

Figure 6 emphasizes the fact that the source of the digitized imagery is variable. The CGSI pipeline can warp and properly inset any digitized image into a

Figure 6. CGSI Composite With Different Image Sources

scene. Figure 6 is a CGSI synthesized composite scene which illustrates three alternatives. It shows a real helicopter image which has been properly inserted into the mid-ground of a forest scene. It is obvious that in the real-world, it will not always be possible to photograph target objects at close range from various aspect angles. One alternative is illustrated in the foreground. A model tank has been constructed, photographed, digitized and properly inserted into this same scene. In addition, computers are capable of generating highly detailed, realistic objects in non-real-time. This non-real-time CGI (computer generated imagery) could provide input to the CGSI pipelines as illustrated in the sky. The fixed wing aircraft is a non-real-time CGI image. In some cases, non-real-time CGI may provide a viable alternative for feeding a CGSI pipeline.

The critical point to emphasize here is that the single CGSI pipeline has been designed to be a highly flexible, modular building block for providing high fidelity visual and sensor simulation to meet a wide range of training simulation requirements.

MULTIPLE PIPELINE CONFIGURATIONS

As the CGSI concept moves into physical realization in a real-time demonstration, its application to real-time training visual and sensor systems become practical and advantageous. Such application is clearly warranted whenever high object fidelity or high data base flexibility is required, although other instances of favorable application exist.

This CGSI development is unique for a research effort. Critical considerations are being designed into the system from the ground up. These include reliability, maintainability, integrated logistics support as well as development, production, and support cost issues. CGSI is being designed as a system that works and will continue to work in a cost effective manner in an actual training environment. This is an extremely ambitious undertaking. However, if these critical considerations are not designed into the system initially, extensive redesign would be necessary in order to provide a capability for answering real training problems in the field.

<u>System Analysis</u>. Based upon the identified training mission requirements, CGSI systems configuration development becomes an iterative sequence of refinements/trade-offs involving the various CGSI building blocks previously described. The elements to be considered in addition to the training mission requirements are considerations of reliability, maintainability, integrated logistics support as well as development, production and support cost issues. Table 1 gives a listing of CGSI system building blocks and the configuration rules for developing a large CGSI system.

Table 1. Configuring a CGSI System from Building Blocks

o	SELECT DATA SOURCE	1) VIDEO DISK 2) WRITE-ONCE VIDEO DISK 3) MAGNETIC STORAGE 4) GRAPHICS
o	SELECT PROCESSOR	1) OSSE 2) OSEE/W/TRUE PERSPECTIVE 3) GRAPHICS 4) CGI
o	MAKE 525 OR HIGHER RESOLUTION DECISION.	1) 10 MHZ, OR 2) 40 MHZ FOLLOW-ON CARDS (ADD LINE RATE CONVERTER)
o	MAKE B/W, TRUE VS REALISTIC COLOR DECISION	(ADD COLOR LOCK-UP TABLE (LUT))
o	IS ITERATIVE SCENE DEVELOPMENT REQUIRED?	(ADD ITERATIVE RANGE AND IMAGE MEMORIES)
o	IS CHANNEL IR, VISUAL B/W, OR VISUAL COLOR?	1) IR SMOOTHING, VISUAL SMOOTHING
o	SELECT NUMBER OF SPECIAL EFFECTS CHANNELS.	
o	CONFIGURE TIMING CONTROL, FIRMWARE, AND SOFTWARE TO MATCH.	

These trade-offs take two forms: 1) balancing training effectiveness versus cost, and 2) trading off technically limiting parameters to achieve optimum system performance. The training effectiveness trades are primarily related to number of OSSE channels required. When the training mission analysis has defined the characteristics and count of the objects to be presented, an obvious but simplistic approach to configuration would be to provide a channel per object. This, however, would produce an excessively large and costly system when alternatives exist with either no or minimal training impact. The number of OSSE channels required can be traded off against: 1) Off-line development of composite scene views (clusters), 2) On-line iterative composite scene construction, 3) Area of Interest (AOI) displays, multiple resolution displays, 4) Realistic versus true color. (True color channels can be mixed with realistic channels if required for selected critical objects), 5) Training Cue Fidelity (This trade area is the most subjective but provides the most opportunity for ingenuity of approach), 6) Availability (For very large visual systems, system reliability becomes a training issue because of significant failure rates and/or extended repair times). Numerous alternative implementations and trades exist beyond these six in configuring a CGSI system. Trade alternatives exist in the purely technical realm also. An example is transport delay/update time. While the nominal transport delay of an OSSE process is related to a 512 X 512 image area, smaller image definition (say 256 X 256) will yield shorter transport delays by reducing the field processing time.

As an example, a CGSI configuration for a small visual system could provide potential applications for periscope training or hand-held missile or gunnery applications. Figure 7 shows a non-real-time CGSI scene of a view thru a periscope which could be provided in real-time by a small CGSI configuration. Figure 8 depicts a CGSI configuration capable of providing this image. Figure 9 shows a non-real-time CGSI scene of a AH-64 flying among the trees which could be provided in real-time by a large, robust CGSI configuration. Figure 10 depicts a CGSI configuration capable of providing this imagery level with all sensors supported for team training.

Design. The system analysis trades result in specific design requirements related to configuration. In assembling the required configuration from the CGSI building blocks, the modularity and configurability of the CGSI components together with standardized inter-card and inter-channel interface minimize new design. Correlated hardware, software and firmware components also ease the configuration process. Despite this modularity, every new application will require unique responses.

Life Cycle Support. A key element of any trainer application is the life cycle support requirements of the system. This normally includes maintenance and spare issues. Increasingly, especially for software intensive applications, this has meant the enhancement or redirection of a trainer for new training requirements related to new tactics, new equipment (Avionics, Visionic Weapons Systems), and new personnel qualifications. Historically, visual systems have had extensive data base maintenance costs and infrequent but extensive hardware/software upgrades. CGSI promises significant improvements in all of these areas: 1) Maintenance - On-line BITE, and extensive isolation are included. 2) Spares - Few card types minimize replacement cost as well as lowering stores inventory. 3) New Training Requirements - Common building blocks permit multiple use of CGSI systems and

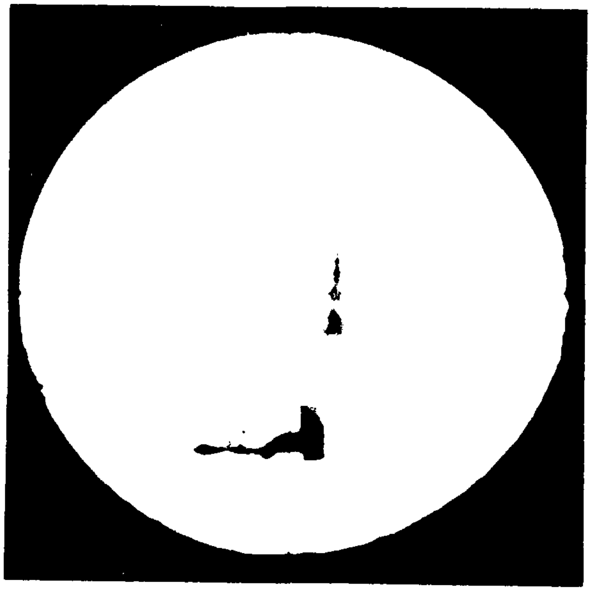

Figure 7. CGSI Simulated Periscope Image

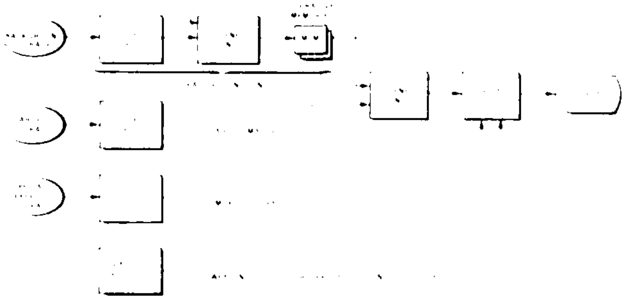

Figure 8. Small CGSI Configuration

Figure 9. CGSI AH-64 Simulated Image

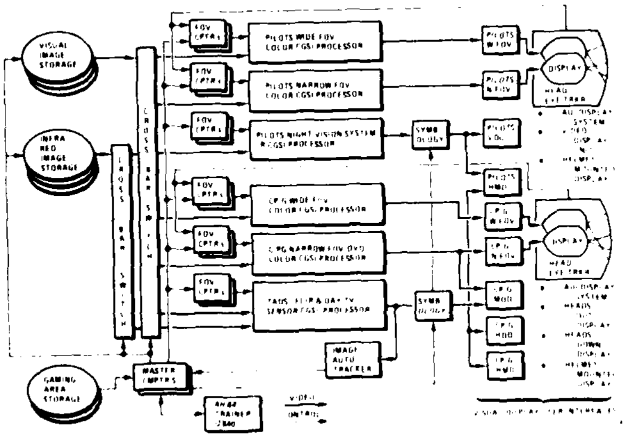

Figure 10. Large CGSI Configuration

incremental expansion to higher fidelity simulation. 4) Data Base Maintenance - Rapid specific area simulations through Defense Mapping Agency (DMA) data and straight forward data definition. Rapid target compliment updates are accomplished through actual imagery equipment for replacement applications or the addition of similar like components for new applications.

Adaptability. Beyond the new visual trainer application, CGSI is adaptable to a wide range of trainer and simulator applications. 1) Stimulators - Stimulation of operational equipment or equipment under evaluation is made possible by insertion of high fidelity video stream data to trackers. 2) Part Task Trainers - A modular approach provides limited simulation applications for limited training goals. 3) Team tactics trainers - Systems providing coordination training involving multiple vehicles and/or ground personnel are easily configured. 4) Existing CGI visual retrofit - Typical CGI systems of today exhibit inadequate target fidelity and very limited background fidelity or a serious compromise of both. CGSI can be used to supplement such systems requiring higher fidelity.

CONCLUSION

CGSI is a viable approach to visual and/or sensor simulation in multiple applications ranging from the very small to the extremely large. It is clearly warranted when high object fidelity and/or high data base flexibility is required. It can readily support multiple sensors in integrated operation including special effects from multiple viewpoints. It is capable of providing specific area simulations with full freedom of motion for both own ship friendly vehicle and hostile targets, and supports Trackers and Weapons, with high Gaming area flexibility and large environment variations. The next critical milestone in this CGSI development is the demonstration of a limited multiple pipeline configuration (4 pipelines) integrated with all of the modules outlined in the block diagram in Figure 1. This demonstration is scheduled for April 1984.

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A LASER IMAGE GENERATION SYSTEM FOR HELICOPTER NAP-OF-THE-EARTH FLIGHT TRAINING

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ABSTRACT

The training effectiveness of the camera-modelboard visual system for low-altitude, nap-of-the-earth (NOE) flights, particularly for helicopters, is well established. Traditional camera-modelboard technology, however, has a number of inherent limitations which have been overcome by using a laser image generator instead of a TV camera as in the current generation of camera-modelboard systems. The first full-scale Laser Image Generation (LIG) visual system, developed by Singer-Link under the AH-1S Cobra Helicopter Flight Weapons Simulator contract, will be delivered to the U.S. Army in the near future. This new visual system offers improvements in many areas, some of which are discussed in this paper, together with the visual system technology involved and performance parameters achieved on the AH-1S simulator.

INTRODUCTION

The effectiveness of helicopter weapons system and flight trainers employing modern flight simulation technology depends greatly on the ability to provide the pilot-trainee with a suitable visual environment in the simulator. This is particularly true for low-altitude, nap-of-the- earth (NOE) flight training, where sufficient scene content and high scene detail are needed to provide the necessary out-the-window (OTW) visual cues. It is well established that these types of training cues can be adequately provided by visual systems employing television cameras that view terrain models. However, the traditional TV-based camera-modelboard visual systems have several drawbacks which have made them less attractive when compared to other maturing products for visual simulation.

One inherent limitation of the first-generation camera-modelboard image generator was in the camera pickup tube, which typically had "third-field" image lags of 20-25 percent. This resulted in image smearing when dynamic scene conditions were encountered. This effect typically occurs when the simulated aircraft attitudes are changing rapidly.

Another limitation was due to the limited detail response of image pickup tubes which reduces the percentage modulation of the scene details displayed to the student-trainee.

A third limitation was the degree of image tube sensitivity achievable in conjunction with the other requirements of resolution, signal-to-noise ratio, lag, etc., needed for simulator applications. Since great depth of focus is required in camera-modelboard systems, the optical probe coupled to the camera usually has a very small relative aperture and transmits very little light. The net effect is that a very high light level is needed to adequately illuminate the modelboard.

In short, although the traditional camera-modelboard visual system provides excellent OTW visual cues for NOE flight training, it has limited dynamic resolution, provides a somewhat "soft" picture, and consumes a great deal of energy.

To overcome these limitations while retaining the desirable features of the camera-modelboard system, an IR&D program was conducted jointly by the Link and Librascope Divisions of The Singer Company to develop a new image generator that uses a laser beam to scan a terrain modelboard. The IR&D program culminated in a feasibility model that was demonstrated to the U.S. Army. Subsequently, a decision was made by the U.S. Army/PM TRADE to implement the Laser Image Generator (LIG) on the AH-1S Cobra Weapon System Trainer production contract, with the first simulator scheduled for training by early 1984.

AH-1S COBRA PRODUCTION SIMULATOR

The AH-1S Cobra production simulator has two separate cockpit trainee stations, one for the pilot and one for the copilot-gunner (CPG). The pilot's station is equipped with two adjacent display windows, one front window and one side window, each with a 48° horizontal by 36° vertical field of view (FOV). The CPG's station is supplied with only a single front window display.

Two separate LIG systems, each with a modelboard, provide two image channels that are switchable to either of the two forward display windows. The exact channel-to-display allocation depends on the training mode selected by the instructor. When the integrated training mode is selected, the pilot and CPG stations operate in unison and the two LIG channels are available to both of the pilot's displays. In this mode, the front channel is repeated for the CPG station also. In the independent mode of training, the pilot and the CPG each operate, in effect, a separate simulator, and a LIG visual system is available to each trainee.

The visual system provides a gaming area of approximately 10.5 by 4.5 nautical miles with terrain features designed for the required Cobra helicopter training missions, including NOE flight and confined area landings.

LIG SYSTEM CONFIGURATION

An artist's conception of the Laser Image Generator is shown in Figure 1, and a simplified block diagram of the LIG system is provided in Figure 2. A single LIG channel will be discussed here to describe the system configuration and principles of operation.

The major difference between the LIG visual system and the conventional camera-modelboard system is the replacement of the television camera with a laser image generator consisting of a laser table, a laser transmission subsystem, and a laser scanning unit mounted on the gantry. Also, the bank of lights that is required to illuminate the terrain modelboard is replaced with a bank of photomultiplier tubes (PMT's) for image pickup. The AH-1S LIG system consists of:

1) A laser table light source
2) Laser beam transmission subsystem
3) Laser scanning unit
4) Optical projection probe with Scheimpflug tilt/focus correction
5) Gantry transport
6) 24-foot by 64-foot terrain modelboard scaled at 1000:1
7) Photomultiplier tube bank
8) Video signal processing
9) Special effects, including cultural lights
10) Color CRT infinity displays

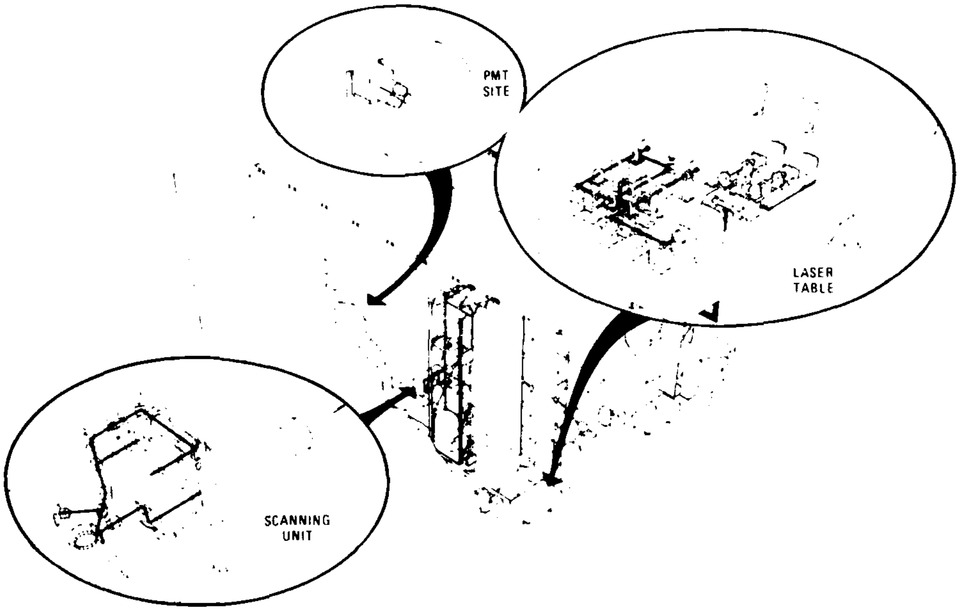

Figure 1 ARTIST'S CONCEPTION OF LASER IMAGE GENERATOR (LIG)

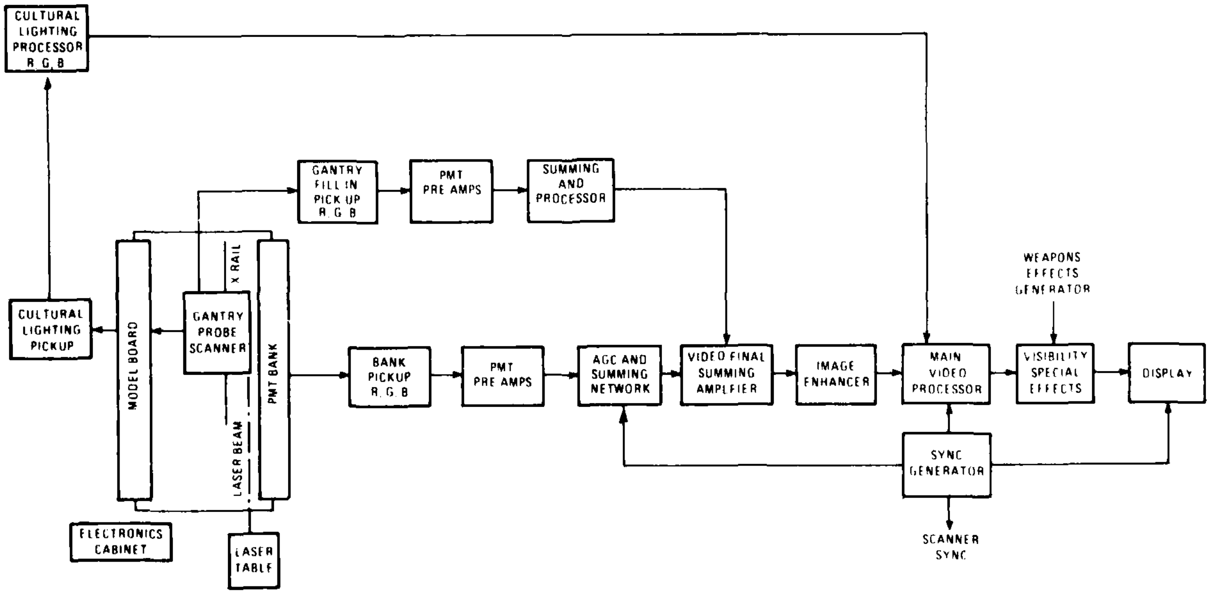

Figure 2 LIG SYSTEM BLOCK DIAGRAM (SINGLE CHANNEL)

PRINCIPLES OF LIG OPERATION

As in a TV camera-modelboard visual system, the LIG system generates a picture by viewing a scaled terrain modelboard. The source of illumination for the modelboard is the laser beam. As shown in Figure 3, the laser beam originates at the laser table and is directed along the rail on which the gantry is transported, traversing the modelboard in the long (X) axis. At the gantry location, the laser beam is transmitted up the gantry, along the short modelboard axis (Y). Here, the laser beam is relayed onto the gantry-mounted laser scanning unit which forms a scanning raster by deflecting the beam horizontally and vertically. The laser scanning raster is projected through the probe onto the modelboard, illuminating the area defined by the FOV, as seen from the trainee's eyepoint. The gantry positions the simulated eyepoint to the correct X, Y, and Z coordinates, while the probe optics provide the roll, yaw, and pitch of the simulated aircraft.

The scattered, reflected light from the modelboard is picked up by the bank of PMT's, each sensing the reflected light simultaneously with the others and generating an output electrical signal. The outputs from all the PMT's are then summed, producing a single time-varying video signal as the gantry duplicates the flight path of the simulated aircraft. This video signal is equivalent to the signal generated by the television image pickup tubes and preamplifiers of the conventional camera-modelboard system. The video signal is used as an input to the main video processor where the special effects, including sky, horizon, visibility, and weapons effects, are inserted. The signal levels are then properly scaled to drive the displays in the simulator cockpit. The display raster and the laser scanning raster are synchronized so that as the laser beam scans a picture element on the modelboard, the display CRT addresses the corresponding picture element in the display raster.

Cultural lighting is simulated by implanting properly scaled fiber optics in the modelboard as in conventional camera-modelboard systems. The signals from the fibers, however, are picked up by PMT's that are located behind the modelboard and away from the main PMT bank. The cultural lighting signal is separate from the model terrain information and can be processed independently. This processing flexibility permits cultural lights to be brilliantly displayed against a darkened terrain background under tactical night flight training conditions.

DESCRIPTION OF LASER IMAGE GENERATOR COMPONENTS

The Singer-Link LIG system development took full advantage of proven camera-modelboard hardware such as the servoed gantry system, the terrain modelboard, and the Farrand 60° Scheimpflug optical probe modified for laser projection. The major components that required design and development effort are those related to the laser image generation process. The new subsystems are the laser table, the laser beam transmission system, the laser scanning unit, and the PMT bank.

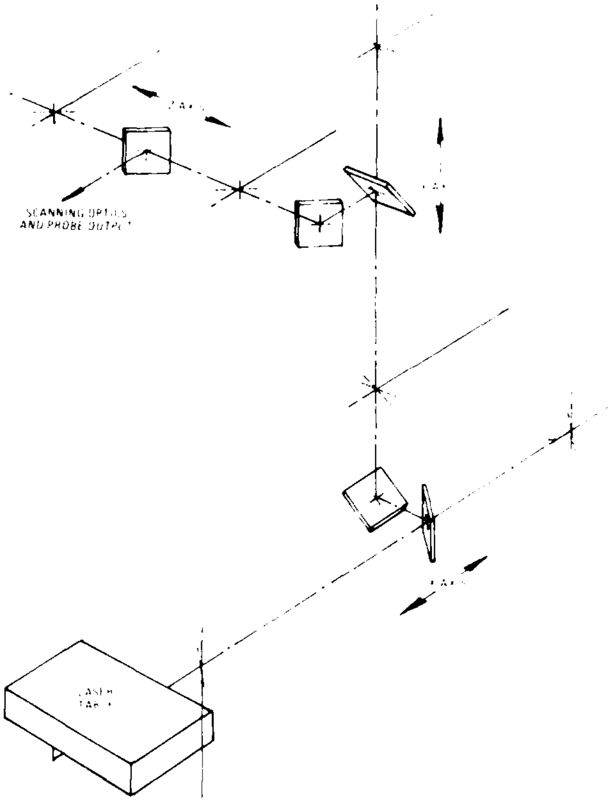

Figure 3 LASER BEAM TRANSMISSION SYSTEM SCHEMATIC

Laser Table

The laser table is an optical bench where three laser beams are combined to provide a single, concentric "white light" beam consisting of four major laser spectral lines with the following frequencies:

Blue	457.9 nm and 476.5 nm
Green	514.5 nm
Red	647.1 nm

Because it is not practical to mount the laser table directly on the gantry, it is located on the floor.

Two ion lasers are used to provide the needed colors. An argon laser generates the blue and green lines and a krypton laser supplies the red line. Each ion laser is equipped with a self-regulating light control system that monitors the laser output and maintains it at a preset level.

The optical arrangement for the laser table is shown in Figure 4. Notice that each laser beam is individually shuttered to permit easy alignment and maintenance. Three beam controller units are provided, one for each laser color. Each beam controller performs the

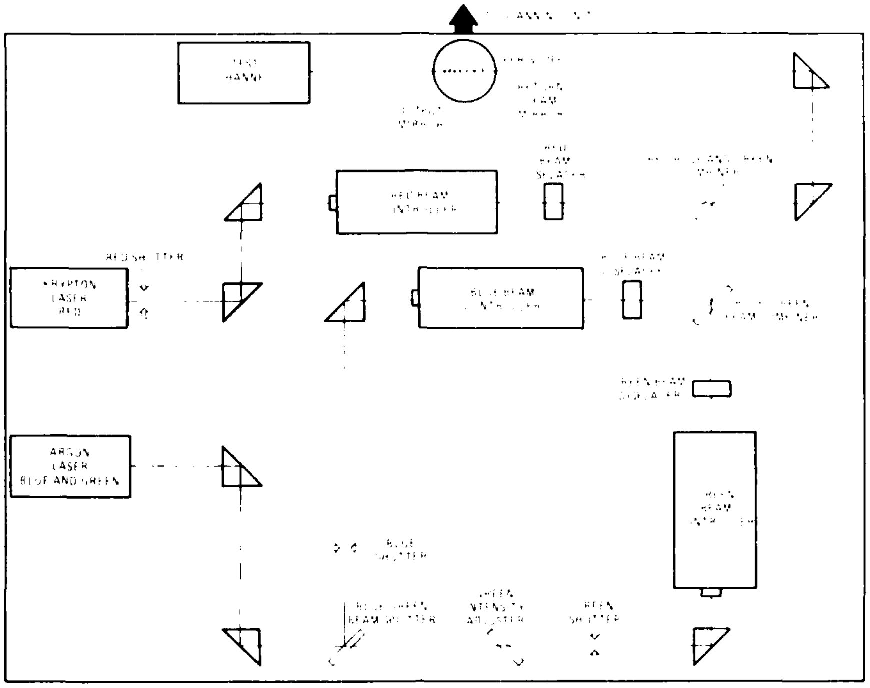

Figure 4 LASER TABLE OPTICAL LAYOUT

functions of expanding the beam to a suitable size for transmission to the gantry and provides adjustments for zoom, focus, and angular steering. The beam expansion is set up so that a beam "waist" is achieved for each color at a fixed distance from the table. The zoom adjustment controls the optical invariant of each color so that the three color beams will match in size and divergence. The focus adjustment shifts the waist of the beam along the transmission axis. It also compensates for the small residual spherical power in each optical path. The angular steering adjustment provides color convergence at infinity for the three beams. It is effected at the exit pupil so that the pupil position is not affected. With the colors converged at both the pupil and infinity, the color is converged for any gantry position.

The three beams of color are combined into a single coaxial beam before being transmitted through the periscope, where the composite beam is aligned in angle and translational displacement so that it matches the gantry rail alignment. Routine maintenance and alignment checks are greatly facilitated by the use of a built-in optical test channel. Figure 5 is a photograph of the production laser table.

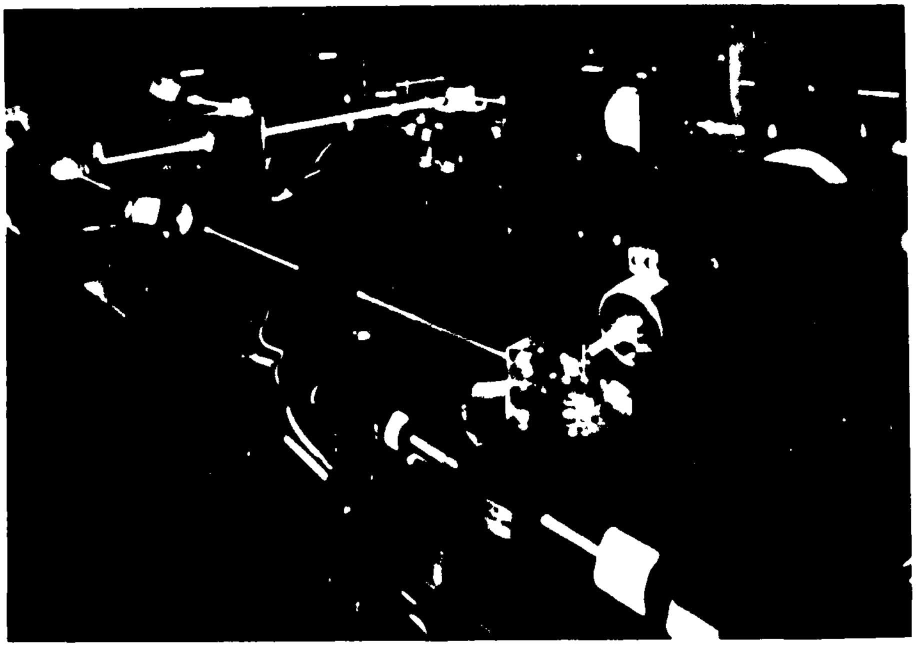

Figure 5 PRODUCTION LASER TABLE HARDWARE

Laser Beam Transmission System

One of the technical challenges met by the LIG system design was the design of a system to transmit the laser beam from the laser table to the moving gantry-mounted laser scanning unit. The resulting transmission system design accommodates all gantry motions expected under normal simulator operations and maintains correct laser beam pointing to within acceptable tolerances. The design accommodates a transmission path that varies greatly in length, depending on gantry position. The desired results have been achieved by expanding the laser beam from the nominal beam size of 1.3 mm to the chosen beam waist diameter and then routing the beam along the X-axis, up the Y-axis gantry tower, along the Z-axis, and into the entrance pupil of the scanning unit.

Expansion of the beam for transmission is done for several reasons. First, over a long transmission path, the laser beam diameter would increase as a result of diffraction dispersion, with the percentage increase a function of the beam diameter as well as the transmitted distance. Small beams expand very rapidly, large beams more slowly. For the chosen transmission beam size, variation in beam diameter over the total travel distance is less than 6 percent. This is well within the limits established by optical aperture design considerations and the system resolution requirement which is dependent on the spot size of the scanning laser beam. A second advantage of the expanded beam is that any lateral displacements of the beam caused by gantry motion are of a smaller percentage as compared to the increased beam diameter, so that motion-induced displacements of the beam have a smaller effect on beam movement at the probe exit pupil.

On the other hand, if the size of the transmission beam is too large, problems will be caused by wave front distortions which are exaggerated when the large beam is reduced back to the small size required to generate the scanning raster. In addition, a large beam reduction ratio would result in a large magnification of beam pointing angular errors introduced in the transmission process. Even at the chosen beam diameter and beam reduction ratio, the residual beam pointing error at the entrance pupil of the laser scanning device would be unacceptable without correction. A beam correction servo is incorporated into the design of the gantry-mounted scanning unit, as described below.

Laser Scanning Unit

The expanded laser beam is transmitted from the laser table and received by the gantry-mounted laser scanning unit. This unit generates the actual scanning raster prior to its projection onto the modelboard via the Scheimpflug optical probe. In preparation for scanning, the transmitted laser beam is reduced in diameter and the residual angular (pointing) errors are removed. As shown in Figure 6, this is accomplished by first routing the beam through a reducer which converts the beam diameter back to 1.3 mm and then using beam position sensors to detect beam pointing errors in two orthogonal directions. Each position sensor consists of a beamsplitter that diverts a small amount of laser light (less than 1 percent) onto the optical sensor (a silicon lateral-effect photodiode) via imaging optics. The error signals generated are used to drive two beam-steering-correction galvanometers, one for each of the two perpendicular axes, as a feedback system to achieve the calibrated null position.

The corrected laser beam is directed to the rotating head of the high-speed scanner where it is deflected by a polygon mirror, made up of 24 facets, rotating at approximately 76,000 revolutions per minute. Since air bearings are used for the rotating polygon, a support system consisting of an air compressor, holding tank, and vacuum pump is required, along with a small water cooling unit to remove heat generated. A fail-safe interlock system is provided to protect the high-speed scanner. The exit beam from the scanner facet provides the horizontal (or fast) sweep of the scanning raster. The vertical or slow sweep is provided by a galvanometer driven at the 60-hertz field rate, deflecting the relayed output beam from the high-speed scanner to provide the vertical sweep.

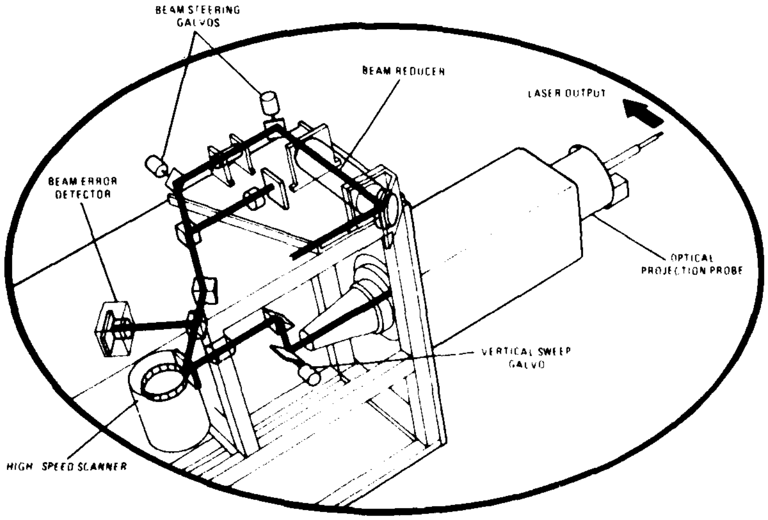

Figure 6 LASER SCANNING UNIT

A laser scanning raster is therefore formed at the entrance pupil of the optical probe, corresponding to the displayed field of view of a single window (scaled for 48 degrees horizontal by 36 degrees vertical). The scanning laser beam is projected onto the modelboard, illuminating only what is within the FOV, as seen from the simulated eyepoint. The production AH-1S laser scanning unit is shown in Figure 7.

Figure 7 PRODUCTION LASER SCANNING UNIT HARDWARE

PMT Bank

The light reflected by the terrain model is picked up by the PMT bank, which generates the video signal for electronic processing and display. The PMT bank consists of arrays of PMT sites, arranged as four rows by eleven columns and staggered as shown in Figure 8 to provide uniform signal distribution. Each PMT site contains a triad of 2-inch PMT's clustered in a triangular pattern. A red, green, and blue color filter is provided, one for each tube in the triad, to give a three-primary (red-green-blue) color system. Selection of the color filters, transmission optics, and modelboard paints, together with the chosen laser wavelengths, was originally made after comprehensive colorimetry analysis, supported by empirical results. The choice of colors has since proved to be very satisfactory on the full-scale production system.

Figure 8 PMT ARRAY AND MODULE

The AH-1S PMT bank design of 44 sites represents a reasonable compromise among performance parameters such as S/N ratio and signal uniformity versus the number of PMT sites required, which would directly impact hardware complexity and cost. Performance specifications were established for a S/N ratio of 40 decibels or better, and a design objective was set to have typically no more than a 15 percent signal amplitude variation caused by shadows. The PMT bank was designed to meet these requirements.

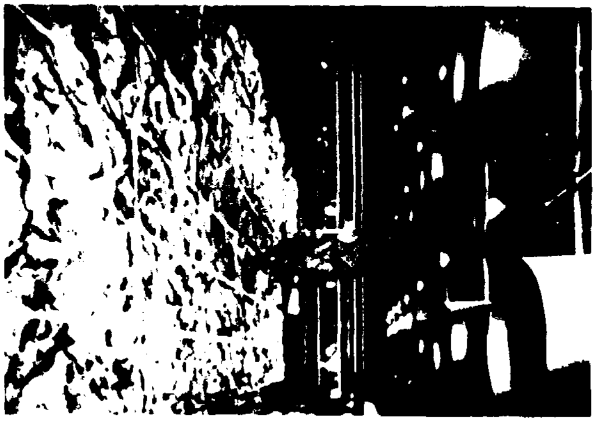

Figure 9 AH-1S LIG MODELBOARD/GANTRY SYSTEM

LIG PERFORMANCE RESULTS

The first production AH-1S LIG visual system has been undergoing system integration and test for some time and is being prepared for U.S. Army acceptance. Preliminary results show that all the performance specifications for the LIG are met, and often exceeded. The quality of the picture on the production unit is superior even to that achieved on the laboratory prototype. Although a formal reliability and maintainability (RAM) assessment and demonstration is yet to be conducted, experience accumulated on the new visual system so far indicates that significant RAM improvements over previous-generation camera-modelboard systems have been achieved. In addition, the test results show superior performance in many important areas, as discussed below.

Dynamic Resolution

Static limiting resolution measurements taken on the production LIG system show better than 6 arc minutes per optical line pair (OLP), only a slight improvement over the 7 arc minutes/OLP on previous camera-modelboard systems. However, image lag effects are absent in the LIG system, except for the negligible effects of very short decay time for the display phosphor. For the LIG, therefore, the dynamic resolution is the same as the static resolution, resulting in a dramatic improvement for dynamic scenes with fast-moving objects.

S/N Ratio

A S/N ratio of better than 40 decibels has been measured for each color channel, with the argon and krypton lasers operating at less then half the rated output power. This allows a two-fold increase in laser power to further improve the S/N ratio or operation at one-half power to prolong their useful life and increase reliability.

Picture Contrast

In addition to the improved dynamic resolution, the detail response of the image (or the modulation transfer function, MTF, of the system) is significantly enhanced, particularly in the low and middle frequency regions. This translates directly into a more vivid picture, remarkable for a TV system, which will greatly enhance the training value of the LIG-equipped simulator. The enhancement is achieved primarily because limitations previously posed by the camera pickup tube have been removed. With properly designed laser optics, the system resolution and MTF are now constrained by other system components, such as the optical probe and the display CRT.

Color Rendition

The subject of color rendition using only three discrete laser lines has been given much attention throughout the LIG development effort. Starting with the original colorimetry analysis, continuing through the feasibility model empirical verifications, and finally culminating with the production design, choices were carefully made in selecting every component that would affect the final color presentation. The end product offers an exceptional, high-quality color image.

Color Registration

Free of the difficulties associated with registering a color camera, particularly at the corners of the picture, the LIG offers a sharply registered picture. Color misregistration could result if the red, green, and blue laser beams become misaligned, but this does not happen under normal conditions because the optical system for the composite laser beam is a simple and stable design, and the optical elements are used primarily on-axis. The Farrand Optical probe, fully color-corrected, performs well for the selected laser frequencies, which are within its original design capabilities (broadband television camera applications).

Energy Consumption

The final significant improvement is in the reduced energy requirement for the LIG. Since the laser illuminates only what is within the FOV, no energy is wasted on lighting what the pilot-trainee cannot see, and power consumption is reduced by more than 80 percent. Compared to the previous camera-modelboard systems utilizing high-intensity lamp banks, the 80-percent energy reduction is quite attractive. Removing the lamp bank eliminates almost 200 kilowatts of power per modelboard, plus the corresponding reduction in facilities air-conditioning needed to remove the heat generated.

As examples of the picture quality provided by the LIG visual system, photographs of typical AH-1S display scenes are shown in Figures 10 and 11. A summary of LIG system performance specifications and preliminary test results is given in Table 1.

CONCLUSION

The first AH-1S Cobra simulator to be equipped with a LIG visual system will be delivered to the U.S. Army in the spring of 1984. The laser image generation visual system offers improvements over the traditional camera-modelboard system in many areas, including a more vivid picture (higher detail modulation), freedom from picture smearing caused by image lag, improved picture registration, and significantly reduced energy consumption. The LIG system provides very high scene detail and modeling fidelity. It offers an attractive solution to those training needs where visual cues of this nature are required for effective training.

ABOUT THE AUTHOR

Mr. Hin Man Tong is the Director of Visual Systems at Link Flight Simulation Division of The Singer Company. He is responsible for the visual product line within Link's Government Simulation Systems operation in Binghamton, New York. He has over 17 years of experience in television systems and visual simulation technology, leading the development of visual products that included one of the first commercial low-light-level surveillance TV cameras, a high-resolution camera-model visual system for simulation, and the Laser Image Generator. Mr. Tong holds a BSEE degree from the City College of New York and an MBA degree from the State University of New York.

Figure 10 AH-1S LIG DISPLAY SCENE OF A WEAPONS DELIVERY AREA

Figure 11 TYPICAL AH-1S LIG DISPLAY SCENE

Table 1 LIG TECHNICAL PERFORMANCE SUMMARY

PARAMETER	PERFORMANCE
System Resolution	Better Than 6 Arc Min/OLP
S/N Ratio	Greater than 40 dB @ 50% Rated Laser Power
Contrast Ratio	Greater than 15:1
Gray Scale	10 Shades
System Geometry	Within 2.5% Over Entire FOV
Minimum Simulated Eye Height	6.5 Ft
Display FOV	48°H x 36°V (Per Channel)
Display Brightness	7 Ft-L
Display Color Convergence	Within 0.1% for Central Circle of Picture Height, Within 0.2% Elsewhere.

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FIBER OPTIC HELMET MOUNTED DISPLAY: A COST EFFECTIVE APPROACH TO FULL VISUAL FLIGHT SIMULATION

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ABSTRACT

Wide field of view, high resolution, detailed visual displays are crucial for the effective simulation of complex air-to-air and air-to-ground combat environments. Current dome and dodecahedron systems are far too costly and lack the combination of required capabilities. The Air Force Human Resources Laboratory (AFHRL) is currently developing a fiber optic helmet mounted display (FOHMD) system which has the potential for filling these demanding requirements. The breadboard FOHMD, built through a Canadian cost-sharing contract with CAE Electronics, displays a head-slaved high resolution area of interest surrounded by a low resolution background in color. The instantaneous field of view is comparable to the view available to a pilot when wearing an Air Force helmet. Four image generation channels and projectors are used to generate individual displays for each eye. The imagery is piped to the helmet via coherent fiber optic bundles. This system is a valuable research tool for studying many of the issues associated with helmet mounted displays such as image stability, resolution/brightness/field of view trade-offs, and visual perception/fatigue. A follow-on phase will refine the basic breadboard design by reducing the number and size of fiber optic bundles, developing improved helmet tracking and refined optics, and researching a multi-mission instructor/operator station. The fiber optic helmet mounted display shows outstanding potential and may ultimately be the key to high fidelity combat simulation training at the squadron level.

INTRODUCTION

Aircraft simulators have become an integral part of both military and civilian flight training. Initially simulation training was limited to instrument or emergency procedures training because of the difficulty in simulating out-the-window scenes. Technical developments in computer image generation (CIG) displays have provided a means to achieve visual simulation. CIG is now widely used in flight simulation to train takeoffs and landings in fixed wing aircraft. A few military research simulators have successfully demonstrated that, in wide field of view (FOV) flight simulators, significant improvements can also be observed in offensive and defensive combat skills practiced in simulated threat environments.

A recent research study on the transfer of training from the Advanced Simulator for Pilot Training (ASPT) A-10 cockpit to actual flight performance in Red Flag exercises provided "empirical evidence that training under high density ground threat conditions in a flight simulator can improve the survivability of aircrews in a combat-like environment".(1) Historical experience from major conflicts has shown that the first few missions a pilot flies are the most critical for his survival. After those first few missions, a pilot's survivability significantly increases.(2) The demonstrated transfer of training coupled with historical combat data are a strong argument that combat simulation training can become a force multiplier by providing pilots with up to the fourth or fifth mission level of experience before going into battle. The strong potential impact combat simulation can have on survivability mandates the development of full visual flight simulation.

Although wide field of view simulators have been produced for research purposes, they remain prohibitively expensive for widespread distribution and lack the combination of critical capabilities needed for full combat simulation. Demonstrated approaches to wide field of view simulation use either dome projection systems or dodecahedron mosaic cathode ray tube (CRT) displays to surround the pilot with imagery. These types of systems lack the required combination of field of view, resolution, brightness, and short throughput delay needed to simulate air-to-ground, air-to-air, multi-participant scenarios. In light of this fact, both the Air Force and the Navy are pursuing alternate technology development programs to overcome these obstacles. Research efforts are beginning to take advantage of the increases in performance which can be achieved through the use of area of interest (AOI) displays which are head, eye, and/or target slaved. AOI displays need only project the "instantaneous" image currently within the pilot's FOV. This significantly reduces the area of imagery which must be generated at any one instant. AOI displays can inherently attain higher resolution, higher brightness, and more scene detail than conventional systems because of the narrower FOV which is required.

The Air Force Human Resources Laboratory (AFHRL) has had many years of experience with AOI displays. This experience includes: 1) the Simulator for Air-to-Air Combat which uses a target-slaved high resolution raster inset, 2) the High Resolution Area (HRA) Dual Projector Display system which has demonstrated a target-slaved high resolution inset using light valve projectors, 3) head-slaved AOI research studies in the ASPT(3), and 4) a head-slaved dual CRT helmet mounted display system. AFHRL research has supported the view that AOI displays are applicable to tactical simulation and has continued development in this area with a new visual display system, the Fiber Optic Helmet Mounted Display (FOHMD). This system is currently being developed by CAE Electronics Ltd. through a joint US-Canada cost sharing program. The breadboard FOHMD has been delivered to AFHRL and has already been demonstrated in limited form. The performance of this breadboard system indicates outstanding potential for providing high fidelity combat simulation at an affordable cost.

FOHMD SYSTEM DESCRIPTION

The FOHMD (Figure 1 and Figure 2) presents the pilot with a head-slaved instantaneous field of view comparable to that of a standard USAF helmet. In the center of this field of view is a fixed high resolution inset. Only four channels of color computer generated imagery are needed to produce this instantaneous field of view which is slewable over the entire 360 degrees. Light valve projectors project the display through coherent fiber optic bundles to the helmet. System goals (Table 1) include high resolution and high brightness while maintaining wide field of view and reduced CIG channel requirements.

TABLE 1

FOHMD SYSTEM PERFORMANCE GOALS

Parameter	Goal
Total Field of View	Limited Only by Cockpit Structure
Resolution	2-3 Arc Minute/Pixel
Displayed Instantaneous FOV	135° x 60°
Displayed High Resolution FOV	25° or 40°
Inset Resolution	1.5 Arc Minute/Pixel
Background Resolution	5.0 Arc Minute/Pixel
Apparent Luminance	80 Foot-Lamberts
Color	Full

FIGURE 1. BREADBOARD FIBER OPTIC HELMET MOUNTED DISPLAY

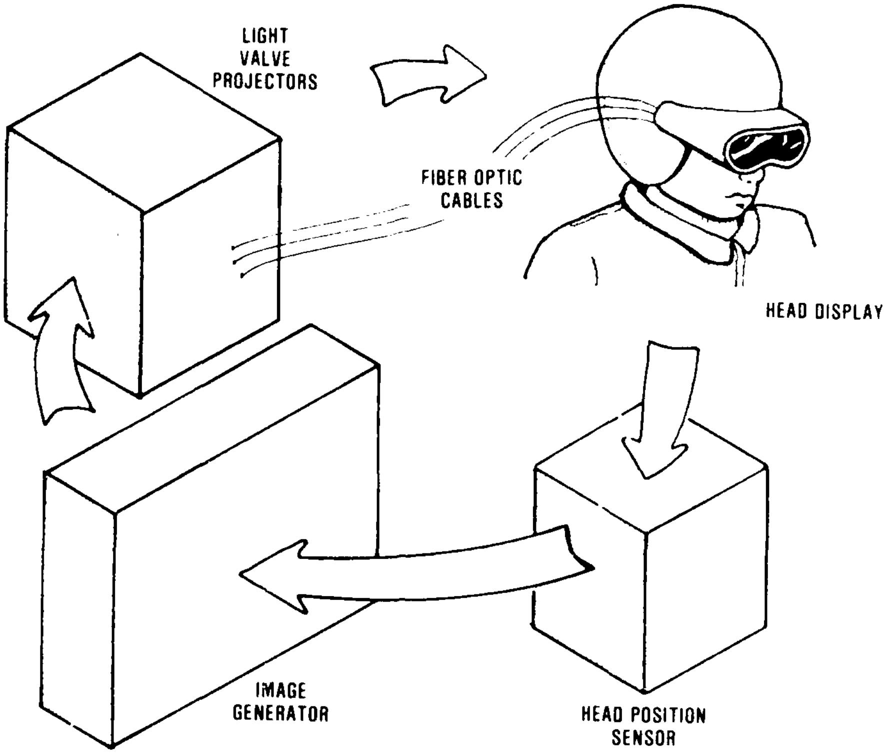

FIGURE 2. FOHMD SYSTEM DISPLAY

The complex combat tasks of low altitude flight, target acquisition, weapon delivery, threat avoidance and confined area maneuvering require a high resolution visual display. At 2-3 miles, even an artificially enlarged target disappears between the raster lines of a six arc-minute 1024 line display such as ASPT's. To achieve realistic combat conditions, a visual scene must be comparable to the resolution of the human eye: 1-2 arc-minutes. Dr A. M. Spooner has noted(4) that conventional wide field of view CRT displays would require 24 channels of CIG and displays to cover a hemisphere with two arc-minutes of resolution. Alternatively, the FOHMD design capitalizes on the characteristic rapid fall-off of visual acuity outside of the foveal region (Figure 3) by providing high resolution only in the central FOV surrounded by a lower resolution background area. This transition from high resolution to low resolution roughly approximates the acuity of the eye. The high resolution area is optically blended into the background to produce a "soft" edge between the two regions. The breadboard FOHMD has a variable 25 or 40 degree high resolution area for research purposes. The background area for each eye is 80 degrees wide, providing a total instantaneous FOV of 135 degrees horizontal by 60 degrees vertical, with 25° of overlap (Figure 4). As depicted in Figure 5, the instantaneous FOV of the FOHMD approximates the view normally available to a pilot when wearing a standard USAF helmet.

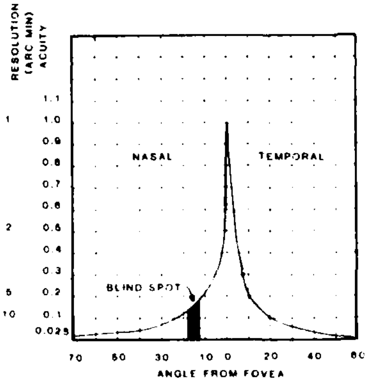

FIGURE 3. DISTRIBUTION OF VISUAL ACUITY ACROSS THE RETINA EXPRESSED IN DEGREES FROM THE FOVEA

One channel of high resolution and one channel of low resolution imagery are computed for each eye, resulting in a total of four channels of imagery. The offset between the two eyes results in a slightly different picture being seen by each eye. Since the appropriate views for each eye are computed, stereoscopic depth cues are available with the FOHMD (they are not available with most collimated image displays). In the 25 degree mode, the entire high resolution area for each eye is completely overlapped with the imagery for the other eye. Since normal binocular

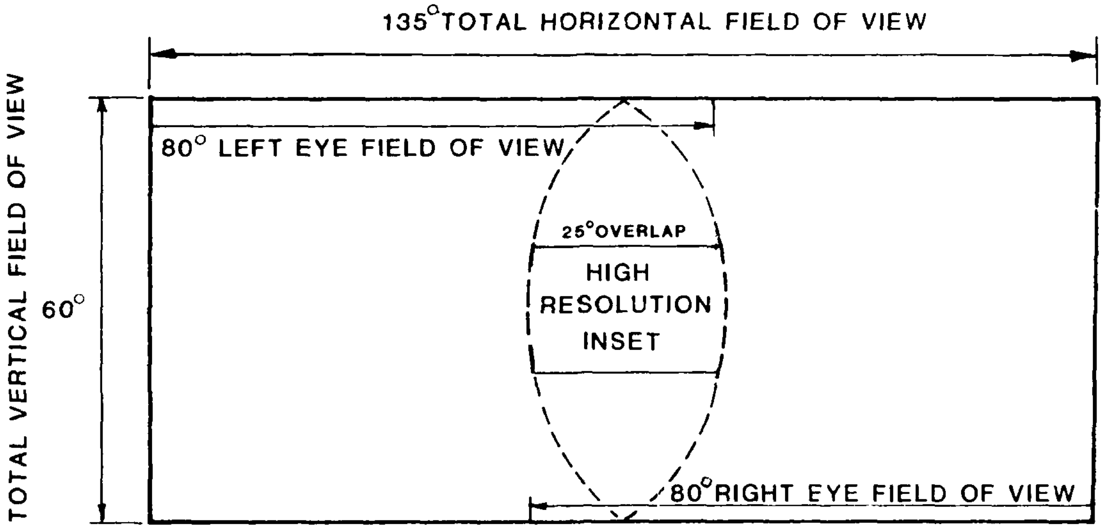

FIGURE 4. FOHMD FIELD OF VIEW

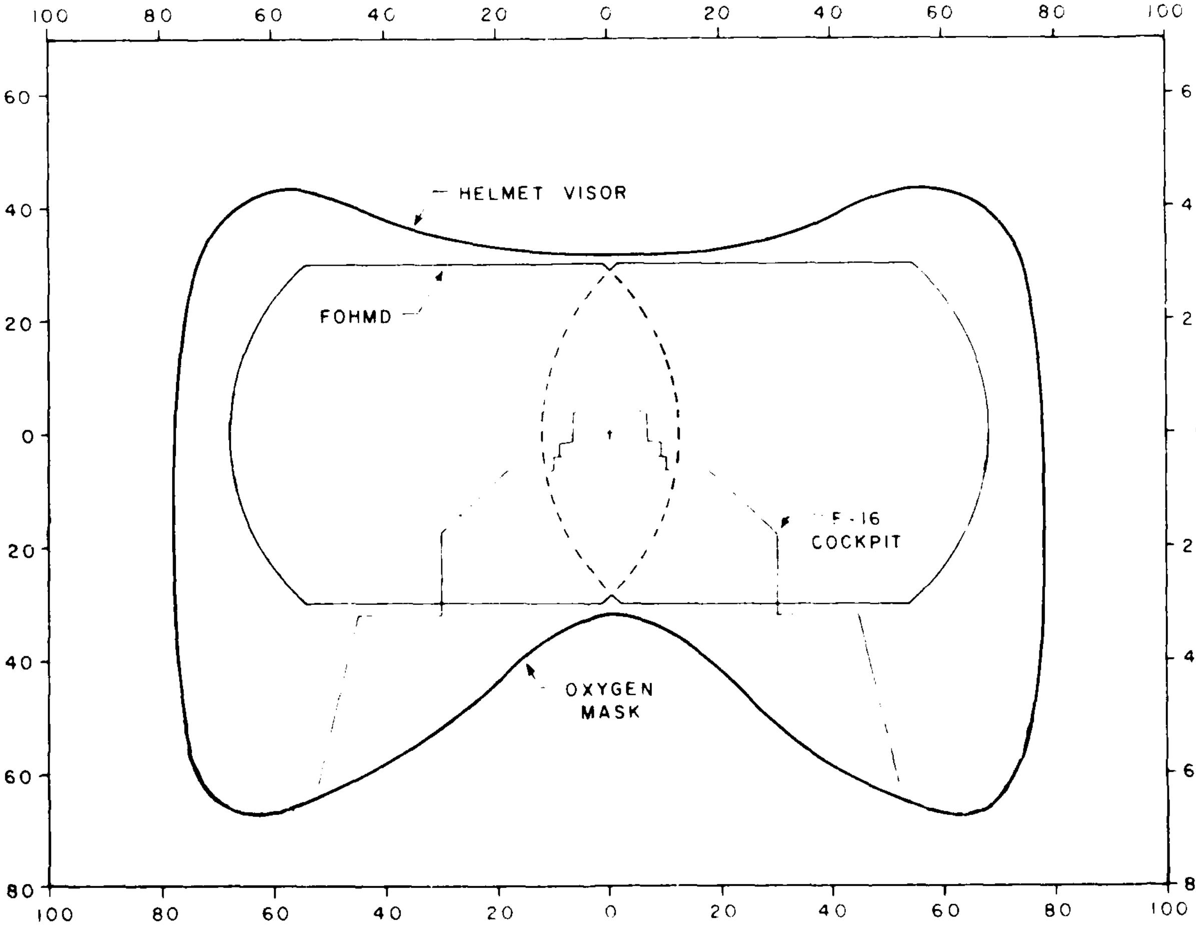

FIGURE 5. FIELD OF VIEW (DEGREES)

overlap is about 70 degrees(5), one of the research issues to be addressed with this system is the effect on visual performance of restricted binocular imagery. A closely related research issue concerns the minimum acceptable size of the overlap area.

The breadboard FOHMD uses four coherent fiber optic cables made by A. O. Reichert Scientific Instruments to transmit imagery to the helmet. Each six-foot long cable has an 8x10 millimeter cross section and is covered with a highly flexible metal hose. Individual fibers are 10 microns in diameter and are formed in 5x5 multifiber arrays. A chromatic multiplexing image enhancement technique has been implemented to lessen the visual effects of broken fibers and of the fiber structure itself.(6) This technique employs one prism to spread the image chromatically on the input end of the bundle and another prism to recreate the original image on the output end. Improvements in the fiber optic bundles and in the image enhancement have been demonstrated and will be included in the follow-on phase of this program.

Farrand Optical Company Inc. developed the FOHMD optical design. A beamsplitter and miniature Farrand pancake window™ are used on each eyepiece to provide wide angle infinity optics. Although there is the usual 99% light loss through the pancake windows™, the FOHMD system still provides an image luminance of 80 foot lamberts. This is due to the fact that the image viewed by the pancake window™ is concentrated in an area of less than one square inch. All of the helmet optics in the breadboard system are currently made of glass resulting in a total helmet/optics weight of approximately nine pounds. Although at first this may seem objectionable, the weight in the breadboard system has been successfully counterbalanced and is not a major problem. Future production systems will employ lighter weight optics and construction techniques to minimize the weight and inertia of the system. The FOHMD system has a large fifteen millimeter exit pupil and provides sufficient eye relief to permit wearing glasses.

The imagery for the breadboard FOHMD is computed by two Singer-Link F-111 Digital Image Generators (DIG I). Although each DIG I is a three channel system, the FOHMD requires only a total of four channels of imagery. Each DIG channel generates 875 lines by 1024 pixels of color imagery and drives a General Electric light valve projector having a standard 3 x 4 aspect ratio. There are 8000 edges, 64 colors, and 64 intensities available for detailed imagery. Weather effects and moving models are also available. The FOHMD is not restricted to any particular image generator and could be used in conjunction with almost any image generation source. The DIGs are currently being used to demonstrate the compatibility of the FOHMD with a commercially available color image generator.

A study of currently available helmet position sensing devices was included as part of the design effort for the FOHMD. Results showed that commercial helmet sensor systems were inadequate to meet the demanding specifications of the FOHMD program, which included a requirement for current position data at a minimum rate of 120 Hertz in all six degrees of freedom. To permit evaluation of the breadboard FOHMD, a highly effective mechanical helmet position sensing system was fabricated which consists of a two bar, three joint linkage and measures both translational and rotational movement (Figure 6). A more advanced infrared optical sensing system is being developed for the follow-on prototype FOHMD. The optical sensor will use two Hamamatsu C1454 Position Sensor Heads each of which is capable of detecting the position of an infrared light emitting diode (LED) in two dimensions. Two sensors will view a pattern of six LEDs to uniquely determine helmet position. The Hamamatsu device appears superior to other conventional noncontact position detectors because of its accuracy and speed. This optical position sensing system will be able to run at iteration rates of 120 hertz and still maintain its accuracy.

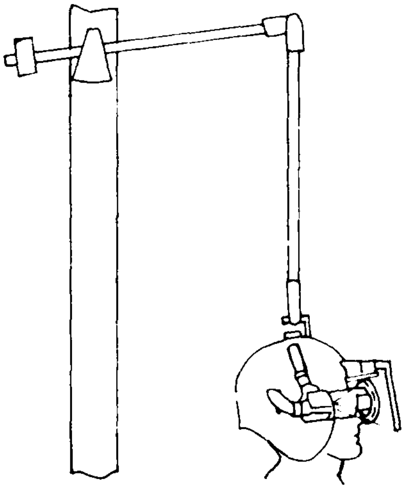

FIGURE 6. MECHANICAL HELMET POSITION SENSOR

Although the FOHMD seems to provide the solution to the brightness, resolution, and FOV problems inherent in conventional flight simulators, there are special factors which must be considered when using a head-coupled visual simulator. For instance visual scene lag becomes a critical problem. Conventional simulators must currently only generate imagery fast enough to keep up with aircraft movement. The most rapid movement of a modern fighter aircraft is a roll with typical accelerations of approximately 600 degrees/sec^2 and maximum values up to 1200 degrees/sec^2. In contrast, maximum head acceleration can be 6,000 degrees/sec^2.(7) Therefore, head-coupled visual simulators must be much more responsive. The fastest commercially available image generators can generate and display a visual scene in three fields (one field equals 16 2/3 msec). If throughput for the position sensor is added to that of the CIG, then the total lag time approaches four to five fields. This effect will create pronounced errors in the displayed imagery. Movement of 300 degrees/second (typical of intense visual search patterns) and a four field lag will produce a twenty degree error in the visual imagery. To counter this lag problem, AFHRL investigated various prediction schemes and determined that a nonlinear prediction algorithm using acceleration values can accurately predict future head position. Accelerometers have been added to the FOHMD which have effectively minimized perceptible visual lags caused by system throughput delay.

The FOHMD system also employs an optical steering technique to compensate for head motion. During head movement, a mechanical steering device using linear motors physically moves the fiber optic bundles in relation to the light valve projectors. This device can correct for pitch and yaw movements of plus or minus four degrees. Nonlinear prediction and optical steering appear to be promising techniques to compensate for the image lags which occur in a head slaved, instantaneous field of view system.

The advantages of higher resolution, higher brightness, and lower CIG channel requirements which are available with head-coupled displays can be even further exploited through the use of eye-slaved displays. A head/eye slaved system would permit use of a smaller AOI, thereby increasing resolution. Eye-slaving would also permit adoption of a variable acuity approach to more closely approximate the acuity distribution across the human retina. However, additional eye movement data must be obtained before an effective eye-slaved AOI display system can be developed.(8) Part of the FOHMD program provides for a parallel research effort to investigate issues pertinent to eye-slaved systems.(9) An off-line eye-slaved projection system has been fabricated to evaluate an eye-slaved AOI of varying sizes, within a lower resolution background. Minimally tolerable transport delays for an eye-slaved approach will also be investigated. The FOHMD has been designed to permit incorporation of an eye-slaved approach, if and when the results of this parallel research effort indicate it is possible to do so.

Additional human factors research with the FOHMD system will investigate broad issues applicable to head-coupled systems in general. For instance, calibration-oriented research will be conducted to determine to what extent perceptual anomalies such as brightness/color differences, binocular rivalry, and image misalignment are detectable and/or objectionable. Other areas to be investigated include image stability, binocular overlap, border transition, visual fatigue and the tradeoffs between FOV and resolution.

FOLLOW-ON PHASE

The recently delivered breadboard FOHMD is intended to serve as a concept demonstration to show that the system is a viable approach for achieving high fidelity flight simulation. In the follow-on phase the system will be expanded and refined to produce a prototype FOHMD. The optical tracker will be incorporated to improve overall position sensing performance as well as improve the appearance of the entire system. Already demonstrated improvements in fiber optic bundle production will be coupled with additional research to produce smaller, higher resolution bundles. A total of only two fiber optic bundles will be used on the prototype FOHMD system. This will eliminate weight and inertia on the helmet and also improve outward appearance. It is hoped that the chromatic multiplexing image enhancement technique used in the breadboard phase can be replaced by a more effective dynamic multiplexing technique to completely eliminate the visible fiber structure. In addition to the display itself, part of the follow-on effort will investigate the special requirements which a head coupled display designed for both air-to-air and air-to-ground simulation may impose on instructor/operator consoles.

Throughout the follow-on phase critical technologies pertinent to the FOHMD will be constantly monitored.(10)(11) CRT, projector, and computer image generation development could significantly affect the FOHMD design. One technology which may be applicable is that of variable resolution. A variable resolution lens, demonstrated by McDonnell Aircraft Company(12) can selectively distort the pixel spacing of an image to create a higher density of pixels in the center of the field. If a small size variable resolution lens corresponding to the acuity of the eye and adaptable to the off axis requirements of the FOHMD (higher resolution at the inner edge as opposed to the center) could be produced, the required number of image generation channels would be reduced to two, and one arc-minute resolution could be obtained. Use of a variable acuity lens would require some modifications to the image generation source due to the lack of appropriate mapping functions available on current CIG systems.

THE FUTURE?

Technical advances to date have made visual flight simulators an integral part of most flight training programs. The extension of visual flight simulation into the combat arena requires further advances, but promises higher rewards. The demanding tasks of combat engagements place correspondingly demanding requirements on the systems that simulate them. Area of interest simulation systems are being seriously pursued by both the military and industry. Successful demonstrations of systems such as the FOHMD show that AOI displays have the potential to provide that elusively affordable combination of field of view, resolution, brightness, and detail required for the performance of complex tasks. For the future, it may not be within the realm of fantasy for combat aircrews to train and rehearse their battles using full field-of-view helmet mounted displays.

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DIGITAL CONTROL LOADING -- A MICROPROCESSOR-BASED APPROACH

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ABSTRACT

This paper reports on a multi-year development effort to provide exact simulation of aircraft primary control systems under all conditions of aircraft control and operation for all regimes of flight and environment conditions. The development demonstrated the ability to develop realistic models and provide for their exact solution via digital computation while integrated with a highly responsive control force simulation system. Digital quantization effects are eliminated by very high rates of computation achieved by using dedicated microprocessors within the control loop, resulting in no degradation of control "feel," smoothness, or response. Further improvements in long-term stability, calibration, and measurement are also achieved. The paper discloses the results of various comparative analyses between digital and analog, for various force and position servo loops, leading to the development of a microprocessor-based digital control loading system. Trace comparisons are made between the final breadboarded system versus actual aircraft control measurements for force/displacement and dynamic stick response tests to demonstrate the fidelity achieved by the system.

INTRODUCTION

The control loading system of a flight simulator provides one of the prime feedback elements to the trainee. The fidelity of forces at the controls is very important in the training role, and while quantitative data is available and used for design of such systems, it is an area where subjective "feel" also provides important criteria. Today's advanced level of simulation reached in flight simulators in areas such as flight dynamics, visual display systems, and general system simulation requires that the control loading system be designed to the same level of fidelity. The unique problems of this system present a challenge to the design engineer who has usually had to make substantial compromises to achieve an acceptable solution.

The "feel" of the controls experienced by the pilot results from a number of different forces. These are characterized as spring, breakout, damping, Coulomb friction, etc., some of which are a function of velocity. The complex nonlinear functions of the above, together with usual design parameters of low cost, low maintenance, and high reliability, form the basis of the problem. The principal components of a control loading system are shown in Figure 1.

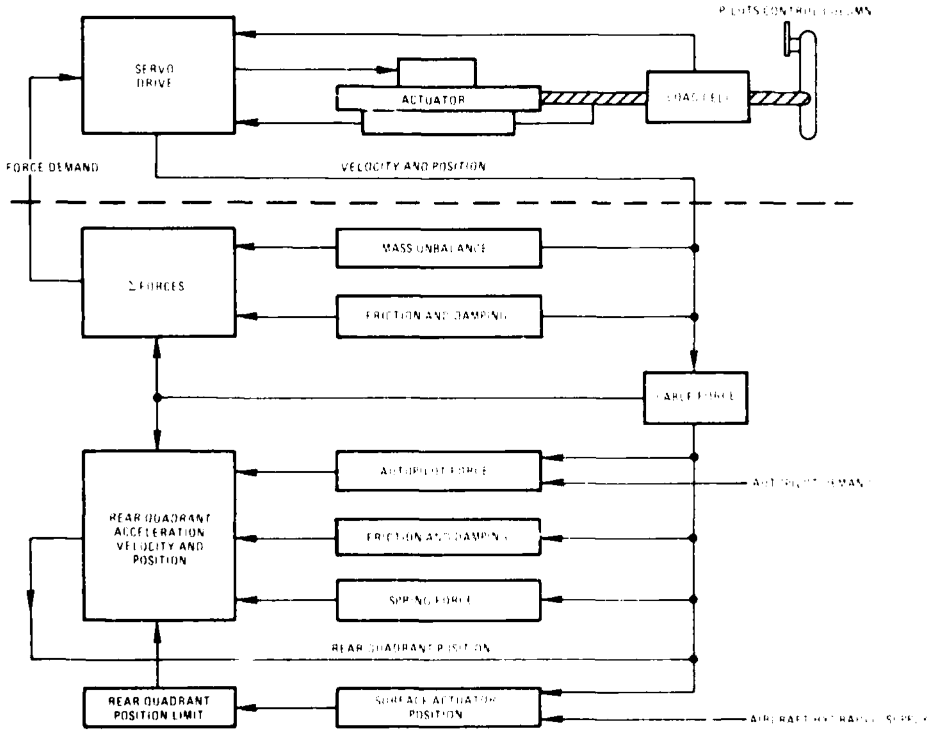

Figure 1 PRINCIPAL COMPONENTS OF CONTROL LOADING MODEL

The traditional solution is to employ a special-purpose analogue computer to solve these complex functions and second-order differential equations with sufficient frequency response to achieve the necessary smooth response. This type of system provides adequate performance but has inherent limitations. First, there is the long-term drift associated with any analogue computation which, if not corrected, affects the calibration of the system. The inability to provide adequate self-check or performance monitoring increases the problem associated with lack of general stability. The calibration of non-linear functions against associated aircraft data is also a time-consuming task with little possibility of applying automatic techniques and other aids within an analogue design.

Also, the system design for each type of aircraft is unique and consequently leads to a schedule problem and high recurring design costs. Each circuit card contains a part of the analogue computation and, while the basic design is common for most aircraft types, the non-linear functions, time constants, and other parameters associated with aircraft performance have to be designed into the resulting unique circuit card. The use of variable potentiometers offsets some of these problems, but this in turn leads to complicated calibration methods. The impact of this problem is exaggerated further if data associated with the aircraft being simulated is not available until late into the contract.

The recent revisions to the U.S. Federal Aviation Administration regulations for the evaluation and approval of flight simulators have also complicated the design task. Under the new rules it is no longer sufficient to compare the simulator characteristics with the aircraft manufacturer's engineering data for the control system. The simulator now has to be compared directly with measurements made on one of the customer's aircraft. As the differences between individual aircraft of a particular type, together with the tolerances on the measurement procedure, can easily exceed the tolerances allowed on the simulator, this can result in the necessity to modify the mathematical model for each application. In addition to this, the aircraft measurements are not always available before the simulator design is due to be completed. These two factors now make it essential that the mathematical model be easily modifiable up to the time of simulator acceptance.

The performance of minicomputers generally used for flight simulators is obviously powerful enough to achieve the required iteration rates, but they are too expensive to be dedicated to the control loading system. It is the advent of powerful microprocessors which can offer the price/performance to apply to such systems. Therefore, it was decided from the outset that microprocessors would be used in the final design.

OBJECTIVES

The objective of this development program was to produce a microprocessor-based digital control loading system which would interface with existing simulator configurations. The final design, however, also had to be compatible with possible future simulator configurations which may not be dependent on a central computing complex.

The hardware had to be configured in such a way that it would be cost-effective when applied to a large range of simulator types. The anticipated applications range from helicopters to wide-bodied commercial aircraft. The use of powered actuators to simulate aircraft control systems is not limited to the primary flying controls (elevator, aileron, and rudder). This technique is also useful in the simulation of some secondary flight controls such as speed-brake handles and toe brake pedals. In these cases, the servo actuator may well be a simple positional device with a much lower output than is required for a primary control system. It was therefore a requirement that the computing elements should be capable of controlling a number of different servomechanisms.

In order to accommodate the large range of simulators, it was also a requirement that the number of computing channels could be expanded in a modular fashion from a minimum of two up to a maximum of fourteen.

DESIGN CONCEPTS

The simulation of the correct feel of a control system can be conveniently broken down into two parts. First, there is the inner loop which comprises the actuator mechanically connected to the pilot's control, together with the servo system necessary to drive it. The outer loop contains the computing elements necessary to make the actuator reproduce the particular feel characteristics of the aircraft system.

In the case of a primary flight control system the inner loop will contain a hydraulic actuator and a force loop servo system, but in other applications it could well be a hydraulic position servo or even an electric torque motor. Whatever inner loop is chosen, the outer loop can use the same microprocessor board and digital-to-analogue conversion equipment. The use of an independent microprocessor in each channel allows the computer cycling time to be adjusted to suit each application.

It is also important that the interface between the microprocessors and the Host computer be handled in a flexible manner so that it can easily be adapted for use with any simulator computing system.

HARDWARE

Inner Loop

The most critical control loading applications on a flight simulator are the three primary flight controls plus the nosewheel steering system. For these systems the inner loop will normally consist of a hydrostatic hydraulic actuator coupled to the pilot's control through a force sensing load cell. The position of the actuator is measured with a linear position transducer (LVDT) and an analogue, force-feedback servo system provides the control signal to the servo valve. This arrangement has been used on control-loading systems for some years and has been shown to produce a sensitive, high-bandwidth, but stable system.

In addition to controlling the hydraulic actuator, the inner loop circuit must also fail safe to prevent any malfunction in the components causing damage to the simulator or harm to pilot. This is achieved by monitoring power supplies, actuator force, actuator velocity, etc., and deactivating a fast-operating hydraulic safety valve when any of the parameters exceed predefined limits.

Outer Loop

The digital outer loop for each channel one CPU card, and one I/O card as shown in Figure 2.

The CPU card employs the Intel 8 MHz 8086 processor with 4 K bytes of RAM and 32 K bytes of EPROM. Two DCL channels may be closely coupled and run in synchronism through the card's FIFO interface, giving communication between the two at 512 Hz. This facility would be used in a simulator for an aircraft which has dual control runs from sticks to control surfaces. Normally, the two controls would be used to move as one, but, in the event of a jam, the controls may be split and would then have to operate independently of each other.

The CPU has its real-world interface on the associated I/O card. This comprises a 16-channel multiplexed analogue-to-digital converter plus four channels of digital-to-analogue conversion. Although the A-to-D has 16 input channels, only eight are for conversions from the outside world. The remainder are used for wrap-around tests of the analogue outputs and power supply level checks.

For each simulator's control loading subsystem, an interface is required between the 20 Hz or 30 Hz Host tasks and DCL's specialized 512 Hz routines. For a typical SEL 32/77 Host Computer the High Speed Data (HSD) and compatible interface card is used. This contains a 1 K-word buffer RAM which interfaces to the final card in the system, the crosstalk CPU (CPUX).

The main function of CPUX, on interrupt from the Host, is to transfer data between the buffer RAM on the HSD interface card and the double-buffered RAM's on each channel's I/O card. On completion of this task, CPUX flags the double buffered RAM's which, then, in synchronism with each channel's real-time clock, swap the RAM areas over. Other functions of the card include the updating of a data entry panel and control of a multi-channel RS232 link which may be reallocated to any of the CPU's in the system entirely under software control. When a VDU is not available, the data entry panel provides a single location look-and-enter facility to any of the channels. The card again uses the 8086 with 4 K RAM and 16 K EPROM plus standard LSI to interface with the data entry panel components.

The iteration rate of 512 Hz was chosen to produce the smooth response required. It can easily be shown that such computational rates are required to achieve bandwidths of around 100 Hz. This was supported by qualitative assessments; iterations of 256 Hz produced a detectable noise level, while performance at 1,024 Hz,

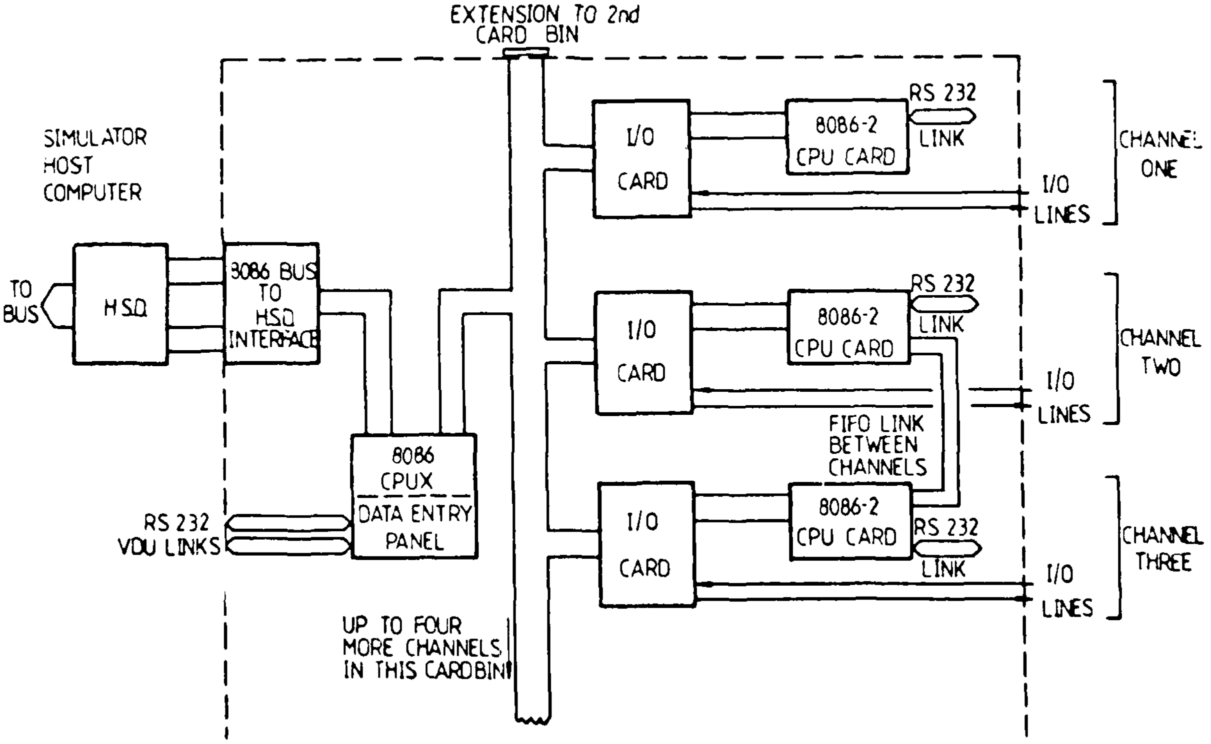

Figure 2 MULTI-CHANNEL DIGITAL CONTROL LOADING HARDWARE - BLOCK SCHEMATIC

made possible by coding certain routines in assembler rather than PLM, did not give an improvement over 512 Hz. All these tests used a complete math model for a primary 747 control channel. Each channel can be assigned an unique iteration rate, and the real-time executive and debug in each CPU and I/O can support multiple programs, say for small secondary control functions.

SOFTWARE

One of the advantages of the digital approach is that it provides a cost-effective method of implementing a detailed mathematical model of the aircraft system. A typical aircraft primary flight control system contains a number of distinct elements. On the flight deck there is the pilot's control column, torque tube, and drive mechanism to the forward cable drum. These components contribute mass, out-of-balance forces, and friction to the overall feel of the system. The next item is the cable run connecting the forward cable drum to the components in the rear of the aircraft. The primary contribution of this is a spring effect plus friction and viscous damping. Situated at the rear of the aircraft is the artificial feel system which usually comprises one or more springs, possibly with a means of adjusting the mechanical advantage so that the spring rate, as seen by the pilot, can be varied with the aircraft speed. These items largely determine the static force/displacement characteristics experienced by the pilot but they also contribute to the mass, friction, and viscous damping in the system. The aircraft-powered surface actuators are situated in this area and these also contribute to the feel of the system as they generally impose a velocity limit on components at the rear of the aircraft as a function of the flow available from the aircraft hydraulic supplies. The final component which needs to be considered is the autopilot actuator, as this usually has the ability to apply forces to the aircraft actuator input mechanism.

In addition to simulating the components of the aircraft system, the mathematical model programmed into the microprocessor must also take account of any non-linearities which exist in the simulator installation. These non-linearities, which usually occur as a result of using aircraft parts in the flight deck area, affect the relationship between pilot force and the force measured at the load cell and the control position and the position measured by the LVDT.

Once the mathematical model for a particular system has been developed, it is programmed in a high-level language. During development, the software is downloaded from a Microprocessor Development System to RAM within the DCL system and then programmed in EPROM when verified. The design of the software, due to individual processors for each channel, helps in the task and also decreases the life cycle cost of the total software.

The simulation module is run effectively as an interrupt task every 1.95 ms. Depending on the complexity of the task, this generally takes about 1 to 1.3 ms and, on completion, the CPU returns to its background program. This background routine consists, firstly, of updating information on the debug page, and secondly, of running diagnostic tests and reporting back the status of the channel to the Host in real time. In addition to these tests, the channel CPU's, at power up, pass through "Morning Readiness" checks which exercise the I/O components, perform RAM and EPROM tests and ensure that the system is in a fit state to operate control loading.

Any fault condition flags are passed back to CPUX and thence to the Host. Thus faults can easily be traced from system level to channel level to board level and, within certain constraints, to component level from the simulator's main computer.

Channels passing Morning Readiness checks automatically proceed with their simulation tasks, requiring only the manual 'hydraulics on' switch to be pressed before full simulation commences.

BENEFITS OF DIGITAL CONTROL LOADING

The digital approach to control loading systems has eliminated the need for unique analogue circuit cards in the simulator system. This, coupled with the inherent long-term stability of a digital system, should yield a significant reduction in the simulator maintenance effort. The absence of unique hardware is also important to the simulator manufacturer, as it means that the various mathematical models required can be verified and evaluated on a standard test rig before the simulator construction is complete.

With the digital approach, the mathematical model is much more easily modified to account for aircraft characteristics which were not identified during the initial analysis. This is important as sometimes these characteristics only become apparent when a pilot who is experienced on the particular aircraft type has the opportunity to assess the simulator. This added flexibility results in improvements in the standard of simulation. This has been demonstrated by programming our test facility to represent the elevator channel of a Boeing 747 aircraft. The degree of agreement achieved between this facility and a set of measurements made on a particular aircraft was excellent, with typical results shown in Figure 3. The adjustments normally required to tune a control system performance to match a set of measurements made on a specific aircraft are provided from the main simulator computer. It is anticipated that some 30 parameters per channel will be defined within the main computer data base. These parameters will allow the rapid and accurate adjustment of terms like friction levels, rate dampings, breakout forces, etc.

Digital control provides a very powerful means of implementing self-test and diagnostic features. In our standard simulator package, we include a Test Guide Driver facility to set up the initial conditions and automatically run the required force/displacement and dynamic response tests. The results of these tests may be recorded directly by connecting the output of

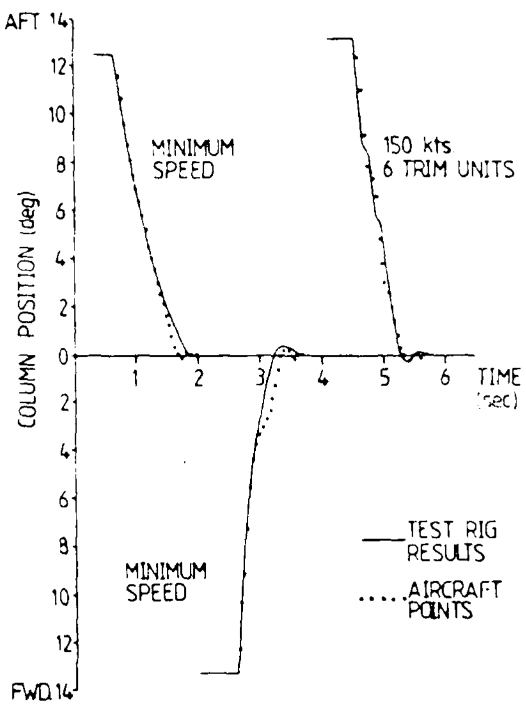

Figure 3 DYNAMIC RESPONSE CHECK - B-747 ELEVATOR

the control loading unit force and position transducers to a suitable chart recorder. Alternatively, the same results may be displayed as a graphical plot on the instructor's station visual display unit, from which a permanent copy can be made by means of a line printer.

The same instructor's VDU can be used to display warning messages should a malfunction be detected in any of the following areas:

1) The hydraulic fluid supply

2) Operation of any of the channel [illegible]

3) Operation of the data link between the control loading microprocessors and the main simulator computer.

In the event of the safety circuit for a particular control loading channel tripping, then information on the status of that channel will be recorded at the instant of the failure and will be available for subsequent display. The recorded information will include power supply voltages, analogue-to-digital and digital-to-analogue converter status, control loading actuator force, velocity, velocity error, and position error.

ABOUT THE AUTHOR

Mr. David Parkinson is a Technical Development Manager with Singer UK Link-Miles and is responsible for all Research and Development Programs undertaken at Link-Miles. He holds an honours degree in Electronic Engineering and is a Member of the Institute of Electrical Engineers.

His early experience, having joined Link-Miles in 1971 as an Electronic Development Engineer, was mainly in circuit design using a variety of analogue and digital techniques. After being responsible for a number of new designs associated with simulators, he became a Group Leader in 1977 supervising the staff of the Development Department. During the last few years he has been involved in the introduction of advanced technology and associated development. Major programs which have recently been undertaken include an Electronic Warfare Simulation System, a Computer Generated Visual System, a Distributed Microprocessor Computing System for a Flight Simulator and a Digital Control Loading System.

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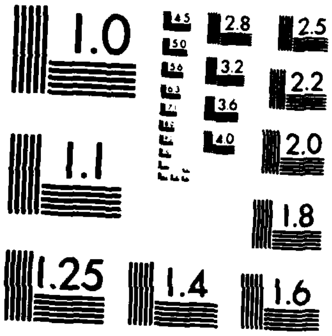

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

VHSIC FOR TRAINING SYSTEMS

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ABSTRACT

Very High Speed Integrated Circuits (VHSIC) is a new technology which promises to have a major impact on the training and training device community. As DoD and industry, in a joint effort, began to pursue this technology in 1980, it quickly became obvious that VHSIC, if successful, would result in more than just an evolutionary change in microelectronics -- it had the potential to revolutionize the way in which we design, build, and use electronic devices. At this point in 1983 the performance predictions for the VHSIC technology are very close to being achieved. Not only will we have available to us significant increases in processing throughput, but the VHSIC chips will be smaller, lighter, require less power, and be more reliable than their predecessors. Cost savings are also predicted. As these advantages came close to reality in 1982, the Naval Training Equipment Center recognized a tremendous potential in the new chips to improve the future training devices and solve some problems being presented by the limitations of current technology. Therefore, a study contract was let to Honeywell (one of the six DoD VHSIC contractors) to investigate the impact of VHSIC on training and training devices. This paper will discuss the results of that study and indicate the future direction in which the VHSIC technology will drive the training community.

INTRODUCTION

The DoD VHSIC program was established to provide focus and resources to overcome the limitations of silicon IC technology, and has far reaching implications relative to the security of this nation. Not only is VHSIC the next logical step to maintain technological leadership in microelectronics, but its application to military hardware will provide a distinct advantage in fielding more sophisticated military systems. However, as one begins to understand the tremendous improvements allowed by the VHSIC, it becomes obvious that our new weapons systems are not the only potential benefactors of the new technology. Indeed, the VHSIC advantages can be applied to almost any electronic device and have the potential to make significant impacts throughout both military and civilian arenas. Its not just a matter of accomplishing the same electronic function in a more efficient manner. The VHSIC will allow us to push back the existing electronic design boundaries and accomplish new roles which were heretofore beyond the limits of our technology. We can, therefore, expect to see impacts on how we operate, maintain, and use the new electronic devices made possible by the VHSIC development.

Since the Naval Training Equipment Center is charged with responsibility to develop, procure, and support Navy training systems, the DoD plan to push the VHSIC technology is viewed with both excitement and apprehension. After all, it is easy to envision the VHSIC as not only a better way of building the traditional training device, but also a technology that will facilitate and even demand new approaches to training. With these thoughts in mind, it became necessary to do some research and analysis into the VHSIC impact on training in order that a future course of action may be charted to allow preparation for a full exploitation of the new VHSIC technology. That was the purpose of the Honeywell study, the results of which are reported herein.

In order to make this paper understandable to those who may not have carefully followed the VHSIC development, we have included a synopsis of the DoD VHSIC program. The goals and approach of the study will then be described, followed by the results. There has been an attempt to chart a direction for VHSIC insertion into training devices which involves the development of a Training Chip Set (TCS). Plans for the TCS include the objective to make the chips available to all training systems designers without providing any competitor a major advantage in the marketplace.

VHSIC - WHAT IS IT?

Overview of VHSIC Program

The DoD`s VHSIC program was divided into several phases over a six-year period, beginning in March 1980.

During Phase 0 of the program, March to November 1980, nine contractors were selected to develop concepts and brassboard chip projects that would best meet the long-term objectives of developing new microelectronic technology and devices that are geared to the specific constraints of defense systems. As a result of the Phase 0 study, six contractors have been awarded Phase 1 contracts to take their concepts to reality by mid-1984. A Phase 2 program was awarded in August 1981 with the objectives of (1) yield enhancement, (2) technology insertion, (3) sub-micron technology development, and (4) developing integrated design automation systems. In concert with the Phase 1 and Phase 2 efforts, Phase 3 of the program (1980-1986) provides the supporting research effort in the form of a large number of small contracts (60 contractors) to enlist the innovative research and development efforts of the much broader community of researchers in industry, universities and research institutions. A summary of the VHSIC program schedule is shown in Figure 1.

The objective of the VHSIC Phase 1 program is three-fold. The first is to design, fabricate, and test 1.25 micron geometry integrated circuits (IC`s), with a minimum functional throughput rate (FTR) of 5×10^{11} gate - Hertz per square centimeter. The FTR is a product of gate density and speed. The second objective is to demonstrate a pilot line capability to produce VHSIC chips. The third objective is to deliver brassboard chips to demonstrate VHSIC performance. insert VHSIC into other military applications.

The VHSIC Phase 2 program procurement is currently underway. The original plan was to extend the limits of the 1.25 micron technology to sub-micron feature sizes. However, the experience gained from the VHSIC Phase 1 program thus far has shown that the 1.25 micron technology will yield sufficient benefits to numerous military system applications to support continued development.

The current emphasis for Phase 2 seems to have three major objectives. The first one is to facilitate VHSIC technology transfer. This involves efforts to encourage VHSIC Insertion into various weapon systems. Second, achieve IC pilot line certification and to reduce chip costs. The third objective is to develop the sub-micron process technology.

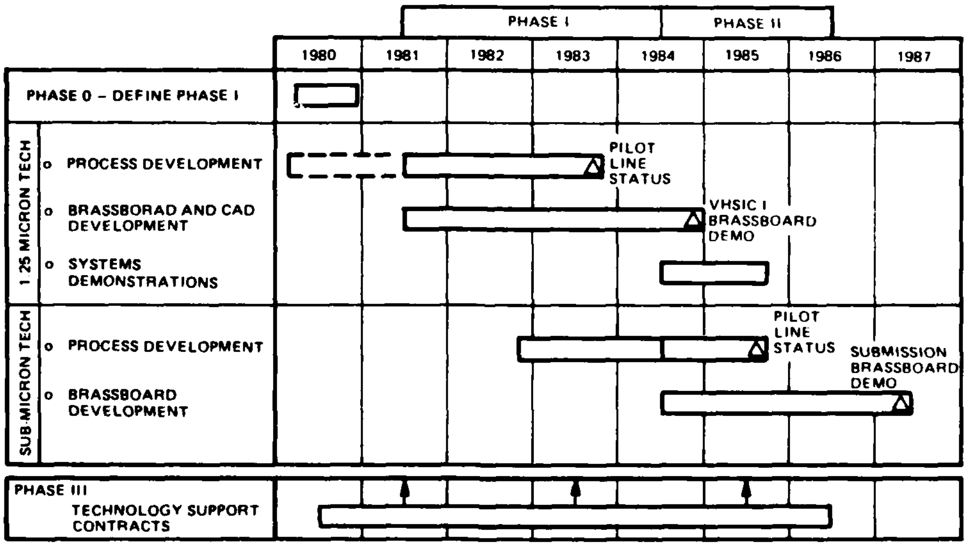

Figure 1. VHSIC Program Schedule

Currently, the overall status of the VHSIC Phase 1 program can be summarized as follows:

- o Design verification is in progress
- o Chip design is in final revision
- o Device and process characterization is in progress
- o Brassboard design is underway

A summary of the characteristics of the chip sets and brassboards that are currently being developed for VHSIC Phase 1 is shown in Table 1.

VHSIC Technology Issues

As the VHSIC Phase 1 program proceeds along with the chip development efforts, both the VHSIC contractors as well as the potential users are beginning to investigate and address the various issues that must be resolved to make VHSIC technology widely applicable to the DoD community. These issues can be grouped into three main areas:

- o Interoperability
- o Support Environments
- o Procurement Options

Each of these issues has a significant impact on the user of VHSIC technology. Without chip interoperability among the six contractors, the design of any system may be constrained to the use of chips from one manufacturer. In addition, VHSIC chips will be more easily accepted if a user-friendly software support environment is available. Finally, unless the technology can be made readily available in a variety of manners (i.e., transferable), potential users, other than the original may be faced with problems that could make the use of VHSIC unattractive.

Table 1. Summary of VHSIC Phase 1 Contractor Approaches (Excerpt from IEEE Spectrum, December 1982)

Contractor (Service)	Technology	Brassboard	Design Approach	Chip Set	Special Features
Honeywell (Air Force)	Bipolar ILS*, CML#	Electro-optical signal processor	Custom chip based macrocell library	Parallel programmable pipeline Controller	Radiation hardness Responsive generic architecture
Hughes (Army)	CMOS on SOS	Anti jam communications	Standard and custom reconfigurable chips	Digital correlator Algebraic encoder/decoder Spread-spectrum subsystem	Radiation hardness Electron beam direct-write lithography Highly specalized chips
IBM (Navy)	NMOS	Acoustic signal processor	Master image with macrocell library	Complex multiplier/accumulator	Software strength Design approach
Texas Instruments	Bipolar STL## NMOS	Multi-mode fire-and-forget missile	Programmble chip set	Data processor Array controller and sequencer Vector address generator Static RAM Multi-path switch Device interface unit General buffer unit	Operational fabrication facility Design utility system
TRW (Navy)	Bipolar-3D** TTL, CMOS	Electronic-warfare signal processor	Standard chip set	Content addressable memory Window addressable memory Registered arithmetic logic unit Address generator Matrix switch 15-bit muliplier/accumulator Micro-controller Four-port memory	Innovative memory chips Versatile chip set
Westinghouse (Air Force)	Bulk CMOS	Advanced tactical radar processor	Standard chip set unit	Pipeline arithmetic unit Extended arithmetic unit Controller Gate array Static RAM Mutiplier	Highest speeds

* Integrated Schottky logic, #Current mode logic, ##Schottky transistor logic, **Triple Diffusion

VHSIC Interoperability Issues. The six VHSIC Phase 1 contractors are all working very hard to develop and fabricate their respective chip sets and brassboards. Each is developing one of the competitive IC technologies -- NMOS, bulk CMOS, CMOS on SOS, and bipolar -- to the design and fabrication of chips. Due to the nature of the VHSIC program, each contractor is working independently. Outside of initial program objectives, little consideration has been given to the issue of interoperability; i.e., how VHSIC chips of different manufactures can be used in the same system. The need for some form of standardization among the VHSIC chips is beginning to be recognized and different committees and action groups have been set up to look into these issues and to recommend possible solutions. In particular, three topics are currently being pursued: bussing, power supply voltages, and packaging. Committees have been set up to provide guidance and standardization to the individual developers.

To resolve these questions, a VHSIC interconnect standards committee (V-BUS) has been formed, with participants from all six VHSIC contractors and the user community.

VHSIC Support Equipment. The VHSIC Support Environment needs can be divided into two major areas: support of software tools and support of Computer Aided Design tools.

Software Support. The software support tools development effort is directed at two levels:

- o High Level - Ada programming support
- o Low Level - Microcode compiler

DoD has identified Ada as the standard high order language for use in the future. All the VHSIC chips have been designed to be compatible with this requirement. Two programs are currently in progress to define and develop the Minimal Ada Programming Support Environment (MAPSE). The first one, called Ada Language System (ALS), is let out of the Army (CECOM) to Softech. The effort is hosted on a VAX-700/VMS and is scheduled to be completed by January 1984. The second effort, called Ada Integrated Environment (AIE), is let out of Air Force (RADC) to Intermetric. The system is hosted on IBM 370/VM and is due at the end of 1984.

Table 2 shows the tools for use in Ada Programming as a result of the two programs.

While these two efforts are going on, there are already available in the commercial market less sophisticated compilers for subsets of Ada. These tools can be very useful for learning Ada and for training Ada programmers.

Table 2. Ada Support Tools

KAPSE	(Kernel Ada Programming Support Environment)
	Virtual Support Environment
	I/O Support
	Data Base Support
	Operating System Support
MAPSE	(Minimal Ada Programming Support Environment)
	Text Editor
	Prettyprinter
	Translator
	Linkers
	Loaders
	Analysis Tool
	Terminal Interface
	File Administrator
	Command Interpreter
	Configuration Manager

For VHSIC chips to be microprogrammable, microcodes have to be prepared. In order to generate microcodes efficiently, a microcode compiler is needed. Currently each VHSIC contractor has his own approach to preparing the microcodes for his particular VHSIC chip architecture design.

At Honeywell, a microcode compiler for the EOSP chip set has been completed. It uses a high level Ada-like language called HML. The compiler is hosted on a VAX/780. In the near future, there are plans to extend the capability of the microcode compiler to enable it to be retargetable to other architectures more conveniently, to extend the versatility of the language (HML) and to generate more optional code.

A versatile and efficient microcode compiler is essential as VHSIC chips find wider applications.

Computer Aided Design Support Tools. One of the side benefits of DoD's VHSIC programs is the development of various CAD support tools. In order to successfully fabricate VHSIC chips, the VHSIC contractors had to upgrade their CAD systems to meet VHSIC Phase 1 goals. These CAD tools will then be delivered to DoD to support the future development of ICA's.

At Honeywell, the CAD system utilities for VHSIC is called the Advanced Integrated Design Automation (AIDA) system. The development of the AIDA system can be divided into two stages. The first stage (AIDA I) has been completed and is being used for the VHSIC Phase 1 design. In the AIDA I system, the data base is in the form of a collection of files. The second stage (AIDA II) is expected to be completed by the end of VHSIC Phase 1 and is to be a VHSIC Phase 1 deliverable to the Government. For AIDA

II, there will be an integrated data base which will facilitate the design process via remote design centers.

The Honeywell AIDA system is based on a hierarchical approach with the design process dividing into various levels, namely; gate, macrocell, functional blocks, chip and system levels. With the incorporation of an integrated data base system and one single hardware description language (HDL), the AIDA system will be a very powerful and versatile CAD support tool system for VHSIC.

Procurement Options. One of the questions that is frequently brought up is that of procurement options; that is, how is the VHSIC technology to be made available to the various users? To answer this question, each VHSIC contractor has to formulate an approach to answer this question.

A typical approach to accomplish this objective is to provide a full range of services ranging from sale of chips to various design and processing options. This may be further facilitated by some developers design approach which includes the use of a macrocell type design methodology, a complete CAD system, and distributed design centers.

The VHSIC design and processing functions can be illustrated by the flow diagram shown in Figure 2. The VHSIC chip development process can be divided into five stages: conceptual design, system design, chip design, processing, and finally packaging/testing.

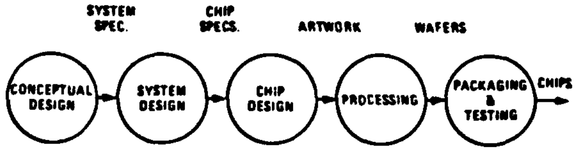

Figure 2. VHSIC Design and Processing Functions

It is conceivable that with this approach the developers could provide four different service options to the VHSIC users. They are described as follows:

Option 1. The conceptual design could be performed by the customer. The VHSIC supplier will provide the customer with the necessary VHSIC technology: performance descriptions, power requirements, and VHSIC library listings. The customer will then generate the appropriate systems specifications and the VHSIC supplier will perform the rest of the design and processing functions.

Option 2. The customer will perform both the conceptual design and the system design. In addition to the VHSIC technology description, the VHSIC supplier may also provide the customer with access to their VHSIC chip library, the macrocell library if available, and the necessary CAD tools for system design. The customer will then generate and provide to the supplier the chip specification for chip design, layout mask fabrication, processing, packaging, and testing.

Option 3. For this option, all the design work could be performed by the customer, with the VHSIC supplier providing the necessary design rules, access to the macrocell library, and CAD tools for chip design. The customer will then generate and present the supplier with the appropriate digitized layout tape and test and design check tools. The supplier will do the IC processing, packaging, and testing.

Option 4. For this option, the VHSIC supplier would provide a silicon foundry service whereby they will receive from the customer the necessary artwork tape to fabricate and process the VHSIC IC's. The customer will perform all the design work, and will get back from the supplier the processed wafers. The customer will provide for their own packaging and testing functions.

VHSIC Status Summary

Those elements of the status above which are relevant to the insertion of VHSIC technology into operational equipment and training devices are:

- The Phase 1 developed 1.25 micron geometry IC's are directly applicable to military systems -- including training devices.
- One of the Phase 2 submicron objectives is to provide VHSIC Insertion into Weapon Systems.
- An interoperability concern exists with the IC's being developed by the six different contractors which is presently being jointly addressed by the Phase 1 contractors with the VHSIC Phase 1 office.
- Software support is also unique for each of the six contractors.
- IC's can be procured in a variety of manners -- from preparation of system design concept specifications through the ordering of 'standard' chips.

The status of the VHSIC program can be summarized as follows: VHSIC as a technology is here, the problems have been clearly defined, and solutions are being developed. VHSIC as a culture has not yet been examined by the majority of the users. The question before us is what are the impacts, and how do we respond?

The implication of VHSIC to trainers is shown in Figure 3. VHSIC as inserted into weapon systems will impact both the system capabilities and employment, thus requiring new training requirements and approaches. VHSIC as inserted into Maintenance, will allow new trainer concepts and capabilities. Both avenues of VHSIC Insertion impact will result in improved training.

THE VHSIC FOR TRAINING SYSTEMS STUDY

The objectives of the study performed by Honeywell's Training and Control Systems Operations were to identify the impact VHSIC would have on Training Systems, and to develop an approach for coping with this new technology. The impetus to the study was to answer the questions "VHSIC is here, how do we respond?" It was felt that we need to prepare for the training impact caused by VHSIC insertion into Weapon Systems, platforms, we need VHSIC to solve some persistent high priority training problems and training must take full advantage of the new technology.

Specifically, the goals of the study were:

- Identify classes of operational equipment for which VHSIC technology is considered appropriate, that is, VHSIC Insertion candidates.
- Select specific candidates to explore in general terms the impact of VHSIC Insertion on operation and maintenance.
- Evaluate the skill changes for these candidates for use in determining the impact.
- Identify the changes in training requirements which will be necessitated by VHSIC insertion into operational equipment.
- Identify those training requirements which result from persistent training needs.
- Identify the training device requirements which will be needed to support the evolving training requirements.

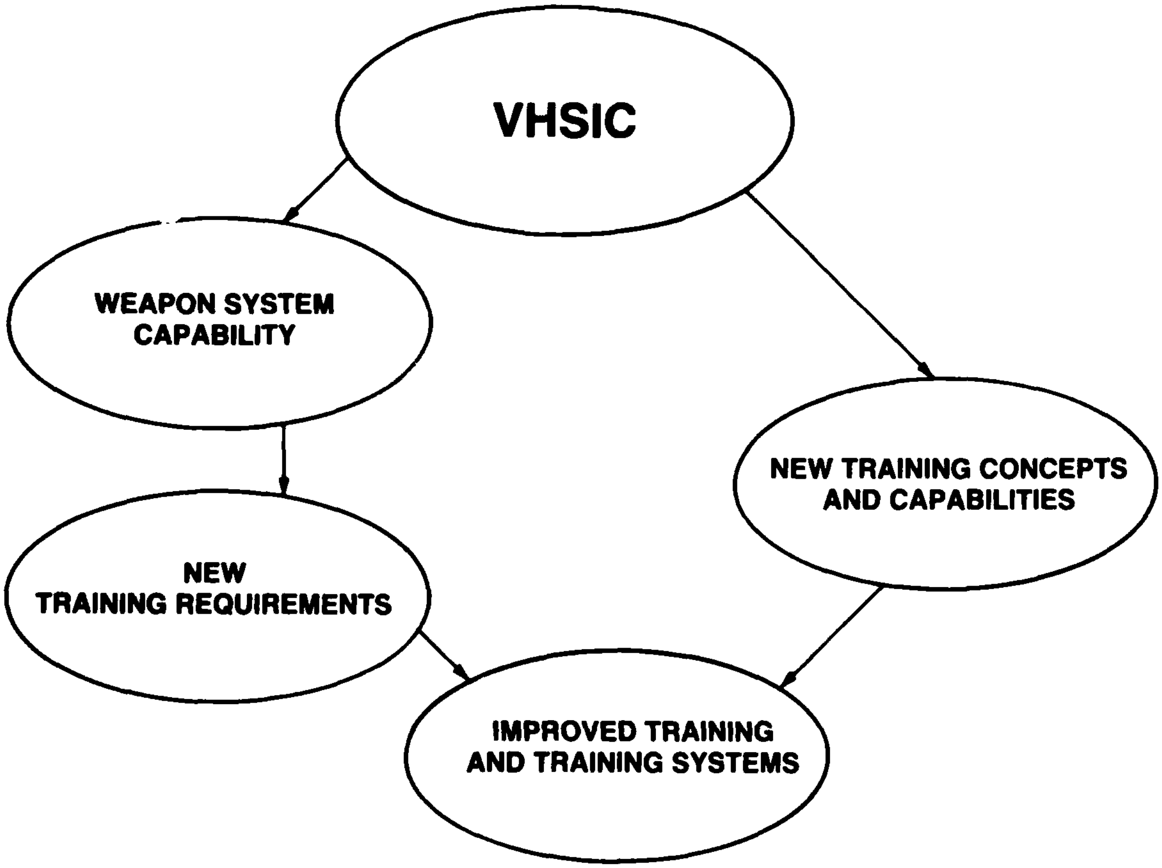

Figure 3. VHSIC Relationship to Training

- Develop an application approach to meeting the new training needs.

- Characterize a concept which results from the approach.

- Identify recommendations related to further development of the concept.

VHSIC Technology Impact on Operational Equipment

The determination of the impact of VHSIC technology insertion into operational equipment was made to identify the skills necessary to operate and maintain VHSIC based equipment. Figure 4 illustrates the major milestones in the VHSIC program. The approach to skill identification was conducted in two phases.

The first phase identified the classes of operational equipment for which VHSIC technology is considered appropriate, that is, VHSIC Insertion candidates. The second phase identified the types of skills or changes in skills necessary to operate and maintain the insertion candidates.

The results of the second phase indicated that skill changes will occur for three types of personnel: equipment operators, maintenance technicians, and operator teams.

Equipment Operator Skills:

- Proficiency on several pieces of equipment

- Increased tactical decision capability

- Decreased equipment manual operation

- Addition of simple maintenance skills

Maintenance Technician Skills:

- Two skill levels will be required:

  - Operator/Maintainer to interpret BIT displays and perform remove and replace tasks

  - Expert technician to perform tasks beyond the level of BIT repairs

Operator Team Skills:

- Increase in shared tactical responsibilities

- Increased emphasis on communication and coordination

- Emphasis on skill retention

VHSIC Technology Impact on Training

The development of VHSIC technology has prompted the Naval Training Equipment Center to identify two important issues driving changes in training requirements:

1. The need to prepare for the training impact caused by the use of VHSIC technology in weapon systems platforms, and
2. The solution of some of the persistent problems which have inhibited effective training.

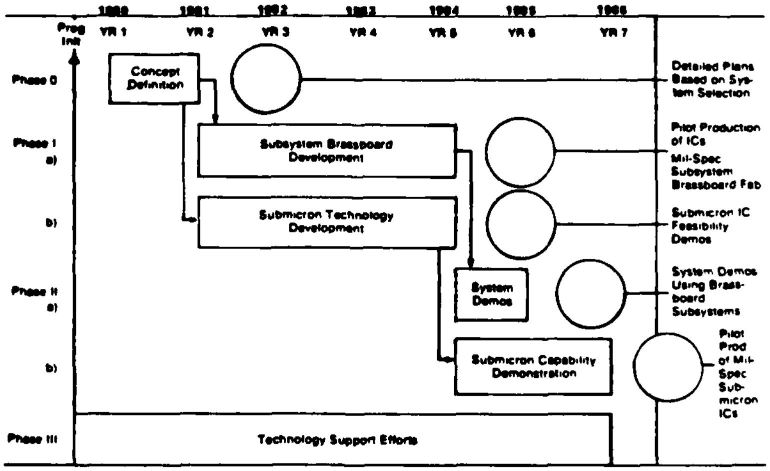

Figure 4. Milestones for DoD VHSIC Program (Take from Military Electronics/Countermeasures, December 1981)

The approach to identifying changes in training requirements was as follows:

- o Identify the changes in training requirements necessitated by VHSIC insertion into operational equipment.
- o Identify training requirements resulting from persistent training problems.
- o Specify the training device requirements needed to support evolving training requirements.

The training changes identified (Figure 5) to accommodate skill changes for equipment operators, maintenance technicians, and operator teams were as follows:

Equipment Operator Training:

- o From less emphasis on routine tasks to more emphasis on quick decision making.
- o More emphasis on cross-training to acquire multiple equipment skills.

Maintenance Technician Training:

- o More emphasis on simple mechanical skills to support equipment maintenance at a BIT interpretation and remove-and-replace repair level.
- o Basic technician will be replaced by an Operator/Maintainer.
- o The expert technician will receive more emphasis on complex trouble-shooting, detailed fault isolation, and in-depth system understanding and theory of operation.

Operator Team Training:

- o More emphasis on communication and coordination skills to support team training.
- o More wargaming exercises.

VHSIC will, therefore, significantly change the roles of equipment operators and maintainers. With the significant increases in weapon system computing power and speed, coupled with the significant reductions in electronic assembly size, operators will now become more tactical decision makers, and maintainers will follow more structured and automated checkout procedures. The following is a summary of such predicted changes.

Offensive Weapon System Role Changes. As a result, future offensive weapons will be autonomous after launch (i.e., fire and target), and, in the distant future, even before launch. Weapon autonomy will improve the survivability of the launching platform due to the shortened exposure time.

In addition, VHSIC based weapon systems will be more reliable, easier to maintain, and have a higher inherent availability (Ai). These improvements will be due to the high reliability of VHSIC chips, the decreased size and number of components which result from VHSIC insertion, and a more extensive use of Built-In-Test Equipment (BITE).

The use of more BITE will improve the maintainer's ability to isolate and replace faulty components or units. Size and quantity reductions will reduce the

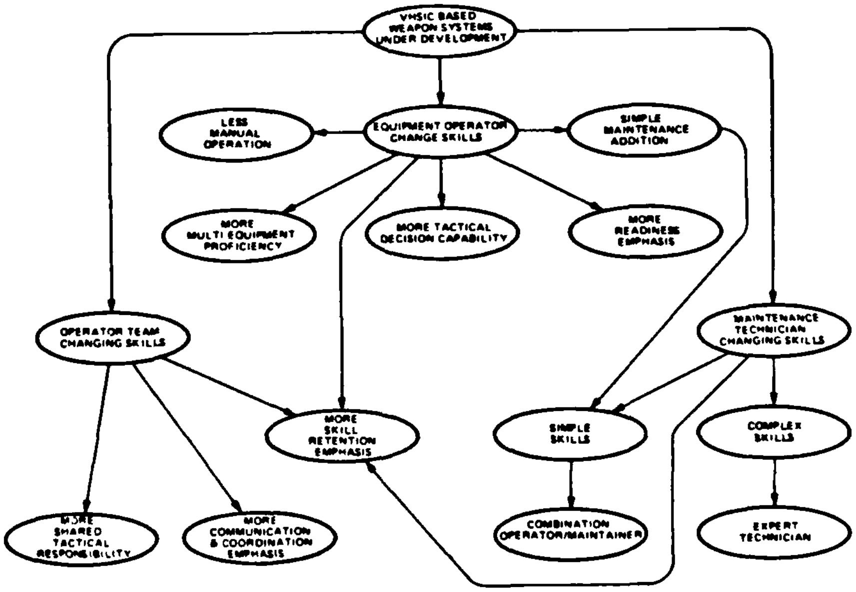

Figure 5. Roadmap for Skill Changes

time to repair, higher reliability will decrease the failure rate, and thus Ai will increase.

Role Change for the Offensive Weapon Operator. The change foreseen in the offensive weapon operator role will be from that associated with weapon control to that associated with a tactical decision capability. The time gained through the use of a fire-and-forget type munition will be used for combat scenario assessment, multiple target selection, survivability tactics, etc.

Role Change for the Offensive Weapon Maintainer. The change foreseen in the role of the offensive weapon maintainer will be from that associated with troubleshooting and repair to that associated with interpreting BIT indications and performing routine remove and replace actions. Cases beyond BIT fault isolation, although relatively fewer in incidence, will require more knowledge and skill on the part of the maintainers.

Role Change for the Offensive Weapon Team. This change will require a higher degree of shared tactical responsibility -- a trend now evident in modern weapon systems.

Defensive Weapon System Role Change. Major conflicts in the future will be manifested by multiple threats from different enemy platforms. The positive, early detection of such a scenario can be enhanced through the use of defensive systems which are capable of detecting, acquiring, classifying and tracking a large number of threats. The use of VHSIC technology can provide the data processing power necessary to automate all of these functions.

Role Change for the Defensive System Operator. The role change foreseen for the operator of a defensive system, such as a search and surveillance radar, will be from a control manipulator to a tactics decision maker.

In addition, it should be possible for one operator to oversee several pieces of automated equipment. This capability will reduce manning requirements and/or serve as a casualty response during battle.

Role Change for the Defensive Weapon Team. The defensive weapon team role will change from a detection/reaction role to a more effective reaction role which is responsive to multiple threat scenarios. This change will require better communication and coordination between members of a weapon system and between teams aboard a multi-weapon system platform.

Impact on Training and Training Devices

As VHSIC is introduced into the weapon system design, the above changes in roles are forecast to result. These will, in turn, necessitate changes in the training techniques and devices used to support the weapon systems. It is not a direct conclusion that training and training devices will become more complex. Rather, they will employ different features and functions which are not necessarily more difficult to simulate. Since simulators generally simulate only what is seen by the operator, not how the equipment functions, training devices may, in fact, become simpler. Because the weapon system will process many more sensor inputs, reduce the data to a summay form and require decision making on the part of the operator, the simulated information presented to the trainee may be less complex than today's training devices.

In the case of stimulated training devices such as sonar systems having synthetically generated signal sources driving an operational equipment mockup, the training device design may also be simpler. Through the use of VHSIC components in the design of the training device, ocean and target modeling may, in fact, be simpler than today. Computational bounds on speed and size may be resolved through the use of VHSIC components in new distributed architectures.

It is, therefore, anticipated that the introduction of VHSIC into weapon systems will not make the training system design more difficult. It will, however, be different and we must anticipate these impacts in our training system requirements and designs. We must stay abreast of the technology advances to ensure that training systems ensure student and weapon system readiness.

The concluding part of the study was conducted to identify how VHSIC technology can be applied to the design of training devices. The approach to application was:

- o Identification of appropriate VHSIC attributes.
- o Selection of VHSIC Insertion training device candidates from the identified training device needs.
- o Development of an application approach.
- o Characterization of a concept which resulted from the approach.
- o Identification of recommendations related to further development of the concept.

This approach led to specific VHSIC application areas, to a generic method of providing VHSIC Insertion cost effectiveness to the selection of a prime candidate training system, and to a set of recommendations for the pursuit of achieving VHSIC insertion into training devices.

The conclusions of the study identified specific areas where VHSIC could benefit the design and performance of training devices. These benefits were primarily in the areas of size, speed, cost, and reliability.

The reduced size of VHSIC IC's currently in development (1.25 micron feature size) permits a veriety of new applications and capabilities. Today's complex system trainers such as flight simulators, tactics trainers, and ASW trainers involve many racks of electronic equipment. This large hardware complement requires significant dedicated facilities, cooling, and power. Through the introduction of VHSIC components into the system design, significant reductions in equipment size, even approaching or exceeding fifty percent, are possible by the late 1980's. These hardware reductions will also impact system and facility support costs through reduced maintenance, cooling, and power requirements.

The use of VHSIC components will impact system cost by combining many different circuit functions on a single chip. This, in turn, will reduce the number of circuit boards, card frames, and equipment racks. Distributed processing designs will be both practical and cost effective. However, it remains questionable whether true system cost savings will be achieved due to the increased functionality possible. It is likely that the added computing capability possible with VHSIC will be used to enhance the training device effectiveness, thus making up for the inherent cost reduction through more compact, efficient system design.

There exists today a variety of persistent high priority training problems which cannot be solved with today's VLSI technology. The sheer amount of computations for many of today's training devices limit their ability to realistically perform in real time. NTEC has identified eight training device areas which are presently capacity or speed limited by current technology:

1. Dynamic Target Modeling
2. Real Time Scenario Event Control
3. Intelligent Adversary Modeling (Responsive Targets)
4. Computer Aided Instruction (CAI) and Computer Managed Instruction (CMI) Modeling
5. Environmental Modeling
6. Acoustic Modeling
7. Image Scene Generators
8. Organic (Built-in) Training Capabilities in Tactical Equipment

Through VHSIC, it will be possible to significantly increase the realism of weapon system trainers through more detailed real time computation and simulation of the operational environment. The limitations of size and speed have precluded effective organic training. These same problems have limited the development of highly effective, field-portable training devices. Tactical environments and power constraints have limited the use of large portable vans in the field. Through VHSIC, small hand-held portable devices can be displayed which will provide highly effective training. Both organic and strap-on training approaches will become a practical reality. As the use of Artificial Intelligence (AI) technology emerges into an application phase, VHSIC technology will become an integral part of the AI application into training devices. VHSIC will significantly aid the training system designer in meeting the evolving needs of future weapon systems.

Through the study, it emerged that a high payoff area for the introduction of VHSIC into training systems was in the area of visual simulation systems. In computer image generation (CIG), a present limiting factor to the number of polygons (image detail) generated is the ability to process in real time the various algorithms making up the simulated image. Through the use of VHSIC hardware and architectures, it will be possible to significantly improve image resolution and quality. It was recommended that this area be explored further as the first candidate application of VHSIC.

It was determined in this study that a generic core set of VHSIC chips could meet the requirements of a large majority of training devices. Through an examination of common computation/processing requirements found in a variety of different training device applications, a common core of VHSIC chip requirements was identified. This common core, called the Training Chip Set or TCS, was further defined to determine its optimal configuration to meet this diverse range of training device applications. A key conclusion of the study was, therefore, the need for the development and application of this generic chip set to training devices.

THE TCS - WHAT IS IT?

The approach to the TCS concept was based upon measurable design and development goals.

Design Goals

Three design goals were established.

Performance. The measure of performance was taken as data throughput expressed as Millions of computer Instructions Per Second (MIPS). The goal was to achieve an order of magnitude greater than that for devices using conventional technology, with an absolute goal of not less than 10 MIPS.

Size. The goal was to reduce by an order of magnitude the volumes of conventional devices. This change in size would permit desk-top simulators which now occupy cabinets, or from a desk-top size to a hand-held device.

Cost. The goal was to achieve a 50 percent reduction in the Life Cycle Cost (LCC) of conventional technology based devices.

Development Goals

The following four development goals were considered.

1. A single development effort should be pursued to achieve a universal set of VHSIC chips applicable to training devices. The benefits are obvious: lower cost and higher priority position in a critical technology.

2. The chip design should have the capability to provide functionality for all foreseen applications. In addition to meeting the needs of the entire instructional environment, the designs should not be platform unique (i.e., only classroom trainers).

3. The chips and the design process should be available to the entire training community. This includes Joint Service access and use by all device designers.

4. The design of the chips should fully incorporate existing VHSIC technology. This includes not only specific chip designs, but also design techniques and tools, fabrication techniques, and testing techniques.

The identification of this set of goals set the stage for the major effort of the study -- the VHSIC implementation technique.

VHSIC Implementation

The benefits of VHSIC technology to training devices are profound and numerous. However, successful insertion of VHSIC technology into training systems will have to be made in a timely and cost effective manner. The Training Chip Set (TCS) concept developed under this study allows the insertion of VHSIC technology into a variety of Training Systems at a reasonable initial cost and minimal marginal cost.

The goals of developing a TCS were:

1. Modularity to allow application to various current systems and to allow expansion to future training systems.

2. Separation of functions to simultaneously allow flexibility (i.e., programmability) and high throughput.

The training chip set concept is depicted in Figure 6. For any given training system, the TCS will consist of two major portions: the core controller and the adjuncts specific to that particular training system.

The insertion of VHSIC technology into a particular training system will consist of several core controllers (each of which consists of several VHSIC chips as described later) and a much larger number of adjuncts (each one of which will be typically implemented using a single VHSIC chip). In this configuration, each core controller will control several adjunct chips. The number of adjuncts which can be controlled by a core controller depends upon data rates in a specific training system and will typically vary for different training systems.

The core controller is highly programmable and thus allows flexibility to accommodate changes and updates in the functioning of the training system. The adjunct(s) are directly in the path of the data flow and provide very high throughput operations on the data. Thus, the goal of high throughput together with programmability is achieved.

Under this study, we have evaluated the applicability of the TCS concept to two training systems. These are:

1. Computer Generated Synthesized Imagery (CGSI).

2. Anti-Submarine Warfare Trainer (ASW Trainer).

The CGSI system is being developed for more realistic visual training and the use of VHSIC technology will allow real-time operation of a complex, multi-channel CGSI system. The ASW trainer is the traditional sonar trainer and the insertion of VHSIC technology will dramatically reduce the size of sonar trainers.

Preliminary design of a one chip CGSI adjunct VHSIC chip and a one-chip ASW adjunct have been completed. Preliminary estimates show that a controller, implemented using four VHSIC chips, will be able to control up to 100 CGSI or ASW adjunct chips.

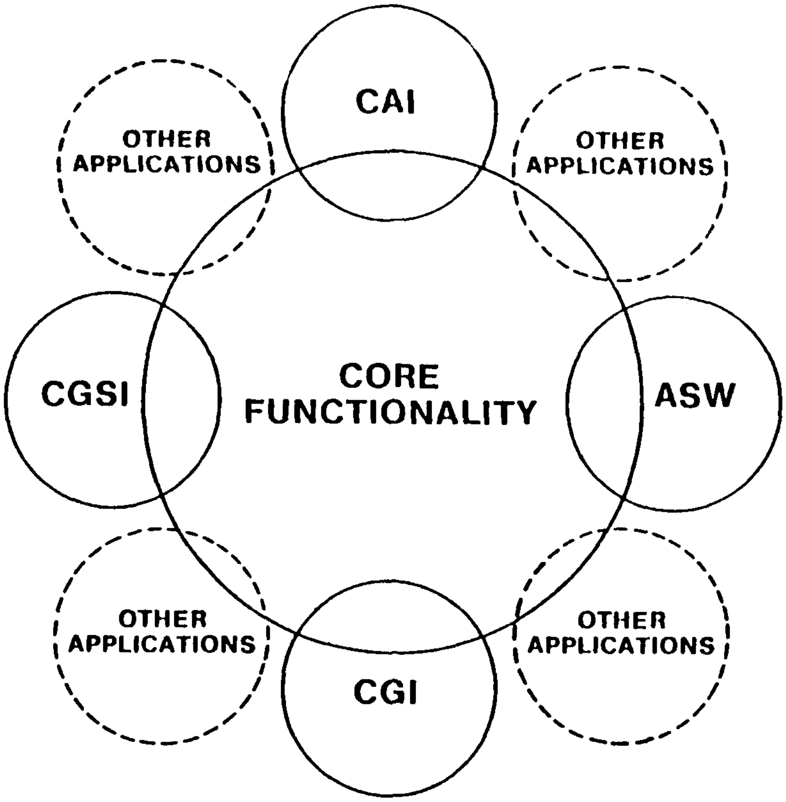

Figure 6. Training Chip Set Adjunct Concept

The modular approach to the TCS will allow the application of VHSIC technology to other training systems by using the controller and new adjunct(s) specifically designed for these training systems. Thus, the meaningful cost of inserting the VHSIC technology into future training systems will be drastically reduced.

SUMMARY

The primary goal of the NTEC VFTS study was to determine the impact of the DoD VHSIC program on weapons systems, training and training devices and to derive a comprehensive impact assessment. This goal has been achieved and, in addition, the concept of a VHSIC Training Chip Set (TCS) evolved as the study progressed.

The availability of proven VHSIC components for insertion in weapon systems can occur as early as 1986. New and different training devices and training capabilities will be required tc meet the training needs of the future; the Training Chip Set -- can meet the requirements of a large majority of these requirements.

Increased system performance of VHSIC technology provides the forecast of increased system performance and reliability in diverse application. Both training requirements and trainers will change. In particular, performance, physical characteristics and projected cost of VHSIC technology under development will significantly improve present and future training devices. This basic technology could become available as early as 1985 for the 1.25 micron feature size IC's. The increased performance of a VHSIC TCS will result in fewer unique designs in support of trainers and therefore shorter design times. VHSIC technology embededed in the design of a core generic training chip (TCS) should be capable of supporting approximately 80% of the processing computation and control requirements of any trainer.

Potential applications of the TCS encompass training requirements for all military services and should be addressed as a future joint service program for insertion. The core TCS has been conceived to support all foreseen applications since it is not platform unique, service unique or limited by performance constraints that could conceivably result in early or premature obsolenscence. The requirements of chip sets for adjunct functions (e.g., visual, ASW simulation, etc.) may be unique. However, in many applications the TCS can support the total real-time processing requirements of some trainers, and thus not require adjunct chip developments.

In summary the VHSIC technology is upon us, its impact is expected to be significant, and its benefits plentiful. VHSIC will impact skills, training concepts as well as trainer devices. It is imperative that we recognize VHSIC's potential, and begin developing plans and techniques for implementing these new concepts.

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MICROPROCESSORS IN AIRCREW TRAINING DEVICES

Richard J. Sylvester, President
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Dayton, Ohio

ABSTRACT

Microprocessors are already embedded in Aircrew Training Devices (ATDs) for display generation, input/output control, and other special purpose applications. This paper deals with the key factors relating to the use of microprocessor systems (rather than minicomputers) in performing the central computational function for ATDs. Such factors include key performance parameters to be considered when replacing a 32-bit minicomputer by a system of microprocessors; requirements for a recent Air Force ATD system; benchmarks for computational performance; and specific changes to ATD prime item development specifications.

INTRODUCTION

To limit the scope of technical activity to reasonable bounds, the C5A/C141 Aerial Refueling Part Task Trainer (ARPTT) was chosen as an example for which micros might be used. A recent draft Request for Proposal for this system was used as guidance in this study. Data from comparable systems were used to estimate the C5A/C141 ARPTT computaton requirements. A "sizing" exercise based on the B-52 ARPTT using micros to satisfy computational requirements was performed. This exercise plus considerable information from microprocessor vendors provides the bulk of the data presented here. Such technical and performance data are summarized.

KEY PERFORMANCE PARAMETERS

The key parameters for distributed microprocessor systems are similar to those for minicomputer systems. These are discussed below.

1. <u>Floating Point</u>. Real-time simulator performance requires mathematical computing in floating point to solve the large, highly accurate flight and aerodynamic equations. Because of the precision, accuracy, and numerical range of these equations, the numbers involved require 32 bits or more of representation. Thus, the arithmetic computing elements must have adequate execution times. Software floating point implementations require a fairly large number of instructions which result in long execution times. Hardware floating point implementation requires only a few instructions with the actual floating point calculation being done in hardware. The hardware performance floating point is approximately 100 times faster than a software implementation of the same functions.

2. <u>Data Bus Considerations</u>. In single bus systems all commmunication activities must use the system bus resource. As the microprocessor system size and performance levels increase (i.e. as more microcomputers are added to the bus) to meet larger application requirements, the reserve bus bandwidth becomes depleted. Eventually, as the system computational capabilities and resources are increased, the total system performance will decrease due to inadequate bus capacity.

In systems where bus control exchanges are synchronized to a common bus clock, no data will be lost or destroyed when system bus reserve bandwidth is exceeded. What will happen is the system functions demanding system bus resources will have to wait longer periods of time to be serviced. To alleviate this situation specially dedicated buses may be added to relieve the single bus congestion.

Memory buses independent of, but coupled to, the main system bus by dual ported memories play a large role in increasing the main system bus effective capacity. This is extremely important where single task partitioning among multiple microprocessors is required to obtain specified functional performance levels.

Multichannel, I/O buses independent of, but coupled to, CPU local buses, local memories, I/O peripherials, and the main system bus by dual ported memories and special I/O controllers are again useful in reducing the main system bus traffic.

Bus bandwidth is the computer system transfer rate capability to distribute data among various sources and destinations across the system bus or buses. It is essentially the lifeline of the computing system. When exceeded by various demands, limited bandwidth degrades the system performance. The capability to determine the reserve bus bandwidth is an essential requirement in the evaluation and design phases for specific distributed microprocessor system applications.

3. Execution Times. How useful are microprocessor execution times in evaluating total system performance? System performance estimates depend very strongly upon what tools and methods are used to measure and analyze the execution times.

One common measure of microprocessor execution performance is MIPS (Millions of Instructions Per Second). The MIPS value states only the number of instructions that can be executed in a unit time. "MIPS" ignores the type of instruction set, internal and external architectures, and the language implementation efficiencies to be employed for a specific system application. For example, a low MIPS microprocessor with a powerful instruction set and architecture may outperform a high MIPS one with many instructions and limited architecture. In this sense MIPS is not always a very precise indicator of a microprocessor's total system performance capabilities.

Benchmarks are special programs written to determine the performance of microprocessors within a given product line or between different manufacturers. Benchmarks can be a better technique than "MIPS" for evaluating microprocessor performances. The utility of a benchmark, however, depends upon the source of the benchmark and the purpose it is intended to convey. The Whetstone Benchmark was developed at the National Physical Laboratory, Teddington, England, to provide a meaningful way to evaluate scientific computational performance of machines with different architectures and language implementations. The Whetstone Benchmark has a good mix of both logical and mathematical instructions to provide an indication of different microprocessor performances in scientific applications.

Adequate benchmarks for all classes of ATDs do not presently exist due to the great design variability possible for the software for a given ATD implementation.

4. Memory Considerations. The direct memory addressing capability of a microprocessor has a considerable impact upon the total system capability and performance. The more extensive the addressing (coupled with proven virtual memory techniques and memory management functions), the more flexible and adaptable the microprocessor becomes, permitting a wider range of different types of applications. Adequate memory addressing reduces the burden on software engineers to design around memory limitations.

Memory usage can be categorized into two types (local or private and global). Local memory capabilities should be used as much as practical to enhance the performance and expansion by reducing memory dependence and traffic on the main system bus. Local memory usage generally enhances memory access time by 300 to 400% over that of global memory requiring use of the main system bus. Microprocessors are now available that have local or private memory capabilities of up to 16 megabytes. These systems are dual ported which also permits partitioning of a given memory for local and global applications.

5. Operating Systems. Microprocessor operating systems have evolved from little more than hardware monitors to the current multitasking and multiprocessing types. The latest operating systems are as sophisticated and powerful as those for some large main frames. Furthermore, microprocessor operating systems are fully configurable to meet the system and application requirements. The newer microprocessors have many of the operating system elements in hardware to improve the performance. These hardware elements include task switching, memory management, and interrupt handlers.

Operating systems for micros must be configured at a much lower level of detail than those for minis. This activity requires a more detailed knowledge of operating systems on the part of the ATD contractor.

MEETING C5A/C141 ARPTT REQUIREMENTS

The commercial microprocessor products which have the potential to satisfy the specified C5A/141 ARPTT requirements are evaluated below. The requirements which must be fulfilled include the following: (1) all system components and packages are currently available in off-the-shelf form and on a plug-together basis, (2) multitasking and multiprogramming operating systems are complete and validated, (3) the multiprocessing operating system is complete and validated, (4) FORTRAN 77 and Assembly languages are available, (5) data paths are a minimum of 16 bits, and (6) there exist system bus hardware arbitration, upward compatibility and floating point capability. (See Table 1 below).

HARDWARE BOARD LEVEL ------- VENDORS	COPROCESSOR FLOATING POINT --------- AVAILABLE	SYSTEM BUS ARBITRATION	MEETS SPECS CITED	MICRO PROCESSOR MULTI-TASKING	MULTI-PROCESSING	LANGUAGES
INTEL	8087 287 ------- NOW	YES PRIORITY MASTER/ MASTER	YES	RMX-86 RMX-88 RMX-80	MMX-800 -MMX-80 -MMX-86 -MMX-88	FORTRAN 77 COBOL PASCAL BASIC PL/M ASSEMBLY
MOTOROLA	MC68881 ------- 4Q 83	YES PRIORITY LEVEL	NO	RMS-86K	MSP/ 68000 ----- 4Q83	FORTRAN 77 COBOL ASSEMBLY
ZILOG	------ 4Q83	NO	NO	ZEUS	NONE AS OF 1 DEC 82	FORTRAN ASSEMBLY
TEXAS INSTRUMENTS	1421 FIRMWARE (BIT SLICE) ----------- NOW	NOT COMPLETE	NO	RX	NONE AS OF 1 DEC 82	FORTRAN PASCAL BASIC ASSEMBLY
DIGITAL EQUIPMENT	FPF-11 ------ NOW	YES MASTER/ SLAVE	YES	RSX-11S RSX-11M	NONE AS OF 1 DEC 83	FORTRAN ASSEMBLY BASIC COBOL

Evaluation of Vendor Capabilities
Programming Language and Operating System
Table 1-1

OPERATING SYSTEMS ----------- VENDORS	MULTI PROCESSORS (16 Bit)	LOCAL AREA NETWORK (Optional)	MEETS ALL SPECIFICATIONS CITED
INTEL	8080A (8 Bit) 8085A (8 Bit) 8088A 8086A 186 286 386 (32 Bit)	ETHERNET (10 Megabit) (100 Stations) (500 Meters)	YES
MOTOROLA	68000 Series (16/32)	NO INFO	YES
ZILOG	Z 8000 Series	Z Net	NO
TEXAS INSTRUMENTS	TMS-9900 1481 BIT SLICE SERIES	IBM SYSTEM	NO
DIGITAL EQUIPMENT	LSI-11 PDP-11 SERIES	ETHERNET DEC NET	NO

Evaluation of Vendor Capabilities
Programming Language and Operating System
Table 1-2

HARDWARE BOARD LEVEL	MASS STORAGE					
----- VENDORS	HARD DISK TO 330 M BYTES	WINCHESTER TO 84 M BYTES	MAGNETIC TAPE 9-TRACK	FLOPPY DISK SYSTEMS	MAGNETIC TAPE CARTRIDGE TO 60 M BYTES	BUBBLE MEMORY TO 512 K BYTES
INTEL	SBC-220 YES	SBC-215 YES	Independent Vendors YES	SBC-204 SBC-208 YES	SBC-217 YES	SBC-251 SBC-254-4 YES
MOTOROLA	No Info As of 1 Dec 82	No Info As of 1 Dec 82	None Indicated	YES	NO	NO
ZILOG	None Indicated	None Indicated	Independ- Vendors	YES	NO	NO
TEXAS INST.	NO	Independent Vendors	NO	YES	NO	NO
DIGITAL EQUIP.	YES	NO	RTO Series	YES	YES	YES

Evaluation of Vendors Capabilities
Hardware & Peripherals
Table 1-3

1. Evaluation of Individual Manufacturers

1.1 Texas Instruments. As of February, 1983, T.I. did not have a multiprocessor operating system nor microprocessor floating point coprocessor available. There were no immediate development plans.

1.2 Zilog. As of February, 1983, Zilog had no multiprocessing operating system nor hardware floating point processor available. There were no immediate development plans.

1.3 Digital Equipment Corporation. As of February, 1983, DEC had a variety of hardware available but did not have a multiprocessing operating system for the LSI-11.

1.4 Motorola. Motorola has in development a multiprocessing operating system and hardware mathematics coprocessor with a release date of late in 1983.

1.5 Intel Corporation. As of early 1983, Intel was the only company investigated that had everything to implement a complete distributed microprocessor system meeting the ATD requirements. Also to aid in the development of a distributed microprocessor system, Intel has a wide variety of ICE (In Circuit Emulation) systems. Intel advertises total upward compatibility. All software developed for the 8086 microprocessor is upward compatible with the 8088, 80186, 80286 and 80386.

BENCHMARKS

This section highlights key technical evaluations; namely, hardware floating point and operating systems performance benchmarks.

1. Intel Benchmark. The data supplied for this benchmark was obtained from Intel Corporation to show the Whetstone floating point performance of the 8086/8087 and 80286/80287 microprocessor systems. The following table gives this data.

MICRO	MICRO CLOCK	COPROCESSOR	COPROCESSOR CLOCK	WHETSTONE
APX-286/10	8 mhz	80287	5mhz	150 KOPS
86/30 SBC	5 mhz	8087	5mhz	100 KOPS

Table 2

The Whetstone benchmark unit (KOPS) implies thousands of floating point operations per second. The APX-286/10 and the 86/30 are single board computers that may be purchased off the shelf.

The architecture of the above microsystems is such that the 8086/80286 micros perform logic and data access functions, while the 8087/80287 perform floating point calculations. The micros and their coprocessors operate in mixed concurrent and parallel modes.

2. Author's Floating Point Software Benchmark (P.E. 8/32 Mini vs. Intel 286/287 Micro. A comparison is made between the floating point performance of a Perkin Elmer 8/32 minicomputer used in the B52 Aerial Refueling Simulator (1977 vintage minicomputer) to that of an Intel SBC 286-10 single board computer with a 287 mathematics coprocessor.

Two assembly language programs were coded implementing the same algorithm for both processors. The algorithm implemented is a randomly chosen flight equation used in the B-52 ARPTT. The form of the equation is:

$$Z = \text{MgCos Theta Cos Phi} + \text{Zs-Cos X} + \text{Xs sinX} + \text{Zt}$$

Neither of the two assembly language programs was run on its respective target machine; however, it is felt that these programs are coded sufficiently well for the purpose of calculating the required execution times.

The implementation of the equation used "table look up" techniques to assess the trigonometric functions where the address computations are not done in floating point. Consequently, the timing is represented in terms of floating point and table search as shown below.

	PE 8/32D	Intel 286/287
Floating Point	20 uSec	161 uSec
Table Search	107 uSec	311 uSec
Total Time	127 uSec	472 uSec

Table 3

The overall performance factor is 3.7 to 1 for this example. Note that the floating point time ratio is 8 to 1, while the table search is 3 to 1. For the PE 8/32D the Whetstone rating is 900 KOPS, whereas the Intel board is 150 KOPS giving a Whetstone performance ratio of 6 to 1. Consequently, the real performance ratio between the PE 8/32D used on the B-52 ARPTT and the Intel single board computer ranges between 3 to 1 and [illegible] to [illegible] depending on how much floating point computation is designed into the software. The key point here is that the details of the software design itself can influence substantially the benchmark comparisons. There is no way to accurately benchmark ATD computer performance without detailed knowledge of the software design approach.

3. RMX-86 Operating System Benchmark. This section contains a benchmark which relates the performance of a RMX-86 base operating system on two different Intel singe board computers. One implementation is using Intel's SBC-86/30 single board computer having a 8086 microprocessor. The other implementation is using an Intel SBC-286/10 board containing a 80286 microprocessor. The fundamental difference is that the 80286 microprocessor implements in hardware the following functions: memory management, task switching, and an interrupt handler. The 8086 microprocessor implements the above functions by means of RMS-86 operating system software.

The specifications for the benchmark are as follows: (1) 8086 microprocessor operating at 5 mhz, (2) program and data in local memory, and (3) software functions execution times are linear with respect to clock speed. As indicated in the performance ratio column of Table 4, it is important to implement as much as possible all operating system functions in hardware if speed is important.

OPERATING SYSTEM	FUNCTION ** IMPLEMENTATION	FUNCTION	MICRO-PROCESSING	CLOCK SPEED	EXECUTION SPEED	PERFORMANCE RATIO *
RMX-86	SOFTWARE	TASK SWITCHING	8086	5mhz	1.2mSec	1.0
RMX-86	SOFTWARE	TASK SWITCHING	8086	8mhz	750uSec	1.6
RMX-86	SOFTWARE	INTERRUPT LATENCY	8086	5mhz	240uSec	1.0
RMX-86	SOFTWARE	INTERRUPT LATENCY	8086	8mhz	150uSec	1.6
RMX-86	HARDWARE	TASK SWITCHING	80286	10mhz	17uSec	70
RMX-86	HARDWARE	INTERRUPT	80286	10 mhz	3uSec	80

* Based on 8086 Operating at 5mh Clock

x** Primary Implementation

Operating System Benchmarks

Table 4

BUS BANDWIDTH

Distributed microprocessor bus performance is a complex subject. The author presents below a concise outline of the major considerations involved in bus performance.

1. Overhead Introduced by System Functions. The multitasking and multiprocessing operating systems are the major contributors to overhead times. The multitasking operating system affects the total system overhead at task execution level; that is for task switching interrupt handling, exception handling, error detection and correction, and data validation functions. The component overhead is due to the main system bus priority and bus arbitration control hardware.

The multiprocessing operating system and its priority level and bus arbitration hardware logic affect the main system bus overhead. The effects of the hardware overhead only become a serious problem when the software and system configuration cause an excessive number of main system bus accesses. This occurs when the design forces a large number of small data transfers between many single board computers resident on the main system bus, causing the overhead factor to become critical.

The multiprocessor system overhead is caused by main system bus interprocessor message transfers and system calls. If the software and system configuration design create the requirement for a large number of these functions, then the multiprocessing operation system overhead also can become a critical factor.

2. Multibus Interprocessor Protocol (MIP). The MIP specifies the implementation, environment and form of the multiprocessor operating system software and main system bus hardware. The MIP specifications permit intertask synchronization, message, and data transfers residing on different single board computers as easily as task switching on single board microcomputers. Communication between tasks can be either tightly or loosely coupled, depending upon the application requirements.

Loosely coupled tasks require only single messages to be sent to the receiving computer. Tightly coupled tasks provide synchronization by means of handshaking.

3. Optimal Considerations for Single System Bus. The following rules are configuration guidelines to aid in determining the performance level of distributed microprocessor single bus systems.

Each SBC microcomputer operates as independently as possible with the following local resources: local data memory, local ROM memory for program storage, local I/O system, and local specialized funcions such as floating point.

Main system bus bandwidth resources should be limited when possible to interprocessor and system data transfers and message communications.

When a single task is partitioned among multiple SBC microcomputers, application system design should be directed towards total system performance causing system bus bandwidth resources minimization and microprocessor efficiency maximization.

System bus parallel priority scheme and system application design can optimize system performance.

Data transfers when possible should be medium to large blocks.

ATD COMPUTATIONAL PERFORMANCE EXAMPLE

This section of the paper uses the computational characteristics of the B52 Aerial Refueling Part Task Trainer (ARPTT) as an estimate of the C5A/C141 ARPTT computational requirements.

1. B52 ARPTT Data. The B52 ARPTT was implemented using a single Perkin-Elmer 8/32D minicomputer in each trainer. From informal data used to track the development of the project software, Table 5 was derived. This table presents an estimate of computational performance at the time of completion of system development. The table lists the real time functions implemented in the B52 ARPTT, the memory requirements for data used by each function, the memory requirements for the executable instructions (code) and the execution times on the PE 8/32D.

It is clear by examining the data that the flight/motion and the visual display functions dominate memory and timing utilization for this ATD. These functions represent over 50% of the utilization of memory and execution time.

2. Sample Micro Layout for B52 ARPTT. Table 6 shows the B52 ARPTT real time functions distributed over a total of eight single board computers (SBC) each residing on the same single main system bus. In this example, the following assumptions are made.

A. The ratio of the PE 8/32D minicomputer to the Intel 286/287 microprocessor system performance is 6 to 1 as indicated by the Whetstone performance comparison.

B. Single board computer utilization at 50% or less was a design goal based on the uncertainty in the time execution and bus loads and based on the inexpensiveness

REAL TIME FUNCTIONS	MINICOMPUTER INTERDATA 8/32D		
	DATA *	CODE *	TIME **
Supervisor	780	20	6.2
Instruction Aids	132	1,872	7.5
Host VDU.	13,760	9,960	142
Boom Control	1,408	3,656	17.6
Visual	984	4,680	80.4
Hydraulics	360	1,920	5.0
Fuel	3,320	5,380	49.3
AFCS	780	3,000	22.5
Engines	1,184	1,460	7.2
Flight/Motion	11,300	9,600	247.5
Control Loading	1,140	3,564	23.7
Sound	688	1,268	6.7
Test/Preflight	424	536	1.0
Cycle Time Check	168	478	1.6
Digital Read Out	948	4,288	5.6
Subroutine/ Libraries			
IOS/IOC	2,024	4,168	23.0
Global Data Library			
VDU Page Generator	12,960	21,136	7.7
TOTALS	52.4K	77.1K	655.0

* Bytes
** Milliseconds/Second

B-52 ARPTT
Computational Performance
Table 5

of the processor hardware.

C. The flight/motion task is partitioned equally among single board microcomputers (SBC) A, B and C, assuming no transport delays.

D. The two tasks "Host VDV" and "VDU page generation" between SBC D and E.

E. Task partitioning of the B52 ARPTT tasks is based upon execution times.

Fewer SBC could be used in the design (perhaps five) if one wished to increase the risk by decreasing the execution margin; however, unless the number of ATDs being purchased is large, the additional hardware expense is easily offset by the risk reduction in the software design.

To estimate the bus bandwidth used in this example, it is further assumed that all data for each function (shown on Table 5) is transferred in block form over the bus during each cycle of execution of that function. This provides the bus utilization for application data. In addition fifteen system calls and messages per application cycle were included to represent operating system bus overhead. This estimate is based on one call per function per cycle shown in Table 6. Under these assumptions only 40% of the single bus capacity was used.

Again, it must be emphasized that the software implementation approach affects these margins considerably.

SPECIFICATION CHANGES

The prime item development specification (PIDS) for the C5A/C141B ARRPTT was reviewed for changes based on the concepts of distributed microprocessor systems. Four categories of additions/changes are suggested. These deal with board level products, margin reassessment, operating system configuration, and the support concept; each category is discussed below.

1. Board Level Commercial Products. To avoid the contractor temptation to construct unnecessary special purpose microprocessor configurations, the distributed micro based central computational system should be constructed of commercially available (and second sourced) board level products. Where the cost is not prohibitive, as few different single board computer (SBC) types should be used (as practical), leading to much board level commonality even at the expense of some performance inefficiency. Commercially availalble and compatible system buses should also be used. This will lead to a lower parts cost and tend to curb contractor development at the piece part level.

2. Margin Reassessment. Timing, memory, and I/O margins were cited at 25% in the PLDS. As the cost of computer hardware drops, it makes sense to require additional margin (perhaps as much as 50%) to ease the development and support burden. The uniform application of margin over each SBC may no longer be reasonable since certain processors may exercise functions known not to expand while other processor functions may see all the growth. For a distributed system of this nature it may be wiser to indicate the margin in terms of functional growth if that is possible.

If, above and beyond margin, hardware add-on capability is specified, then the acceptance tests should include tests in the expanded hardware mode.

As bus layout and bandwidth are important system throughput parameters, a "bus bandwidth burner" analogous to the "time burner" is recommended for the system. This would permit the more precise estimation through measurement of the actual bandwidth margins.

3. Operating System. The selection of commercially available operating systems should be specified, but the operating system will require configuration for not only the nominal hardware topology but also for various growth

B52 ARPTT (8/32D) / SINGLE BOARD MICROCOMPUTER ASSIGNMENT

REAL TIME FUNCTIONS	EXECUTION TIMES M SEC/SEC	SBC DESTINATION ASSIGNMENT (INTEL 286-10)	REAL TIME FUNCTIONS	EXECUTION TIMES PER FUNCTION M SEC/SEC	TOTAL EXECUTION TIME M SEC/SEC
Flight/Motion	247.5	A	Flight/Motion	495.0	500.0
			RMX-86 O.S.	5.0	
		B	Flight/Motion	495.0	500.0
			RMX-86 O.S.	5.0	
		C	Flight/Motion	495.0	500.0
			RMX-86 O.S.	5.0	
Host VDU	142.0	D	Host VDU	426.0	431.0
			RMX-86 O.S.	5.0	
VDU Page Generation	7.7	E	VDU Page Generation	426.0	431.0
			RMX-86 O.S.	5.0	
Visual	80.4	F	Visual	482.0	530.6
Engines	7.2		Engines	43.2	
			RMX-86 O.S.	5.0	
Fuel	49.3	G	Fuel	295.8	536.0
AFCS	22.5		AFCS	135.0	
Boom Control	17.6		Boom Control	105.0	
			RMX-86 O.S.	5.0	
Supervisor	6.2		RMX-86 O.S.	5.0	
Instruction Aids	7.5	H	Instruction Aids	37.2	310.2
Sound	6.7		Sound	45.6	
Test Preflight	1.0		Test Preflight	40.2	
Digital Readout	5.6		Digital Readout	33.6	
IOS/IOC	2.3		IOS/IOC	138.0	
Cycle Time Check	1.6		Cycle Time Check	9.6	

Microprocessor Assignment Example
Table 6

modes. Documentation on how to reconfigure the operating system for these growth modes should be procured.

4. Support Concept. The support concept implicit in the PIDS is one of procurung the latest computer and operating system versions and continually accommodating all vendor changes. This may prove to be inappropriate for distributed micro systems. Spare parts may be delivered with the system. Freezing the hardware configuration and the operating system for a period of time (i.e. seven to ten years) followed by a complete replacement of the computational system may be more cost effective. This will require further study.

ABOUT THE AUTHOR

Richard J. Sylvester has over twenty-eight years of engineering, technical and management experience encompassing system and software requirements definition and validation, computer resource support planning, software development methodology and management, configuration control, computer program design and testing, software verification, validation and certification, software related research and development, mathematical modeling and simulation. He obtained a B. E. in civil engineering and a M.E. in structural engineering from Yale University. His Ph.D. in civil engineering and applied mathematics was earned at the University of Colorado. He has worked in various capacities for Martin-Marietta, Aerospace Corporation, General Research Corporation and the Aeronautical Systems Division, USAF, Wright-Patterson Air Force Base, Ohio, among others. He is currently president of The Systems Productivity & Management Corporation of Dayton, Ohio.

DATA BASE MANAGEMENT OF SOFTWARE DEVELOPMENT

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ABSTRACT

The incessant increase in computational power provided by microelectronics has not begun to be matched by corresponding improvements in software productivity. This now trite observation has especially pernicious implications in the Weapon/Mission simulator field, where massive developments of demanding, new, real-time software in relatively short time spans are a way of life.

This paper describes a new, comprehensive approach to satisfy this need: a software development environment which relates the total set of information relevant to the software product through data base management techniques. The main elements of the concept include:

1) Organization of the simulator (software and hardware) into a hierarchical framework, clearly separating functions so that top-down design and modularization will be substantially easier.

2) Arrangement of all types of product information -- from specifications, through requirements and designs, to code itself -- in an engineering data base patterned exactly upon the hierarchical framework in "1" above.

3) Merging of management status information and configuration control data into the same framework.

4) Provision of a coherent set of tools to "connect" all elements of the data base for development, control, and management purposes.

Progress to date has shown that explicit correlation among all elements of the data base can exist and that traceability (location and identification) of each functional entity is readily provided. Precise configuration is known at each level of development, which inherently leads to configuration management, an automatic "coldstart" capability, and correlation of changes to related information sets.

It is our conviction, based on experience, that the creation of an all-inclusive, data-based product development and management system such as the one described herein is essential to cope with the software quality and schedule needs of modern Weapon/Mission simulator development programs.

BACKGROUND

For a number of years, the frustration associated with specifying, managing, developing, testing, and maintaining complex simulators has tormented both customer and supplier. The industry has witnessed a significant growth in the development of training devices with heavy emphasis on software. Methodologies and tools have been generated in order to identify and correct problems but software induced overruns still occur while products fall short of their goals. In May 1980, Dr. Boehm presented the accompanying figure (see Figure 1) depicting the cost trends related to hardware and software.

As larger, more complex programs are undertaken, previous tools and methodologies no longer are adequate. Added to the complexity factor is the schedule factor which has remained unchanged or shortened. The sum total is software development which is burdened with problems and issues that work against a high quality end product.

In general, the errors associated with these software intensive devices can be classified into three basic areas: requirement errors, design errors, and coding errors. Figure 2, presented at the AIIE 1977 Software Conference, illustrates the dominant type of error as program size grows.

The software development problem has reached its present level of severity largely because of the use of manual, or, at best, semiautomatic means originally formulated for "average" programs. On today's medium- or large-size projects the software structure and all of the data associated with each of its modules cannot be recorded and manipulated manually with any hope of accommodating, in real time, the high level of change activity associated with the software engineering process. This paper describes an approach to creating an orderly, coherent software development environment for simulator software.

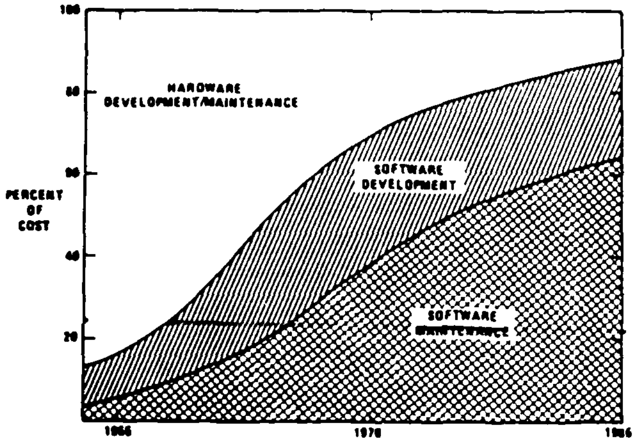


Figure 1. HARDWARE-SOFTWARE COST TRENDS

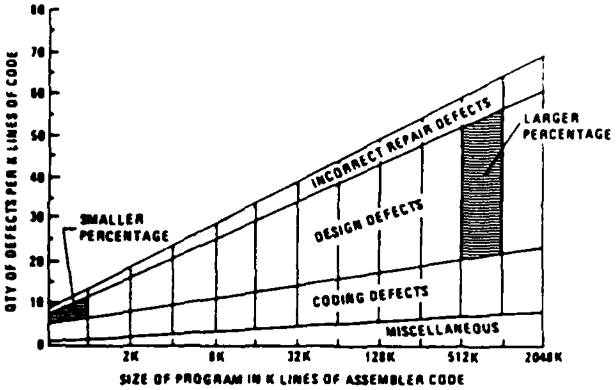


Figure 2. POTENTIAL DEFECTS IN PROGRAMMING

APPROACH

One of the most obvious conclusions that can be drawn from past programs is that there must be an effective procedure by which software development for a simulator can be broken down into segments which can be effectively managed, produced, tested, and documented. The software engineering process itself consists of many integrated, creative, and procedural tasks. Therefore, the first requirement for management of a large software enterprise is that it be broken down into units small enough to be effectively worked on individually. This can generally be done by constructing a "software family tree" which, at a minimum, assigns module designations to identified software functions that must be performed for the proper operation of a simulator system or subsystem. The software functions must be responsive to provisions of a specification, a functional description of an operational unit, or a formal statement of requirements. Ironically, these requirement-type documents themselves tend not to follow the functional breakdown of the software family tree, since they were prepared completely independently of the functional structure. Consequently, multiple cross-referencing becomes necessary if the functional software modules are to be traceable and accountable to a customer-approved or customer-furnished standard.

A hierarchical structure for partitioning a simulator into functionally meaningful elements has been developed. The elements were selected so as to maximize internal coherence and trackability while minimizing harmful interaction between various simulator parts. Each major function can be partitioned hierarchically until levels are reached where the complexity of the elements are readily manageable by an individual with a single work assignment. Partitioning rules are being developed to ensure that the following benefits are realized:

1) Well-defined interfaces will exist between elements at all levels of the hierarchical structure.

2) Progress in each element will be independent of all others as long as interfaces have been defined and are properly maintained.

3) Clearly defined element responsibility will be established within the hierarchy.

4) There will be a minimum propagation of disruption to other parts of the simulator caused by requirement changes, data corrections, limitations on availability of manpower assigned, quality of output, etc. The extent of this propagation will be evidenced by reflecting changes in the established interface conditions.

5) Documentation will have a one-to-one relationship with the structured partitions and, therefore, will receive the benefits of visibility and insensitivity to schedule disruption or change activity occurring in unrelated parts of the simulator.

Because of the complex nature of current simulators and the real-time requirement changes that go on during the life span (anywhere from 3 to 7 years) of a contract, an automated management system relating all of the data is paramount. The development of a Software Engineering Management System (SEMS), which integrates, within a single common data base, information relating to the content and progress of the elements in the hierarchy, is underway. The SEMS is the means by which complete information regarding status, content, constraints, and interfacing will be assembled and maintained within a common computer-based environment for engineering, logistics, and management purposes.

A major requirement of the data base philosophy employed in this development was that each bit of information will be contained within the data base but must only exist once within the data base. This key factor established the requirements for a distributable, relational data base. Since there are a relatively large number of Data Base Management Systems (DBMS's) available, the following major criteria were used to narrow the selection process:

- Strong support for unstructured management inquiry of the data base.
- Minimum load on the resources of the host computer.

- Avoidance of heavy commitment to a particular computer vendor's product line.

These factors lead to the conclusion that a back-end processor (data base machine) which operated within the definition of relational data bases and which could be interfaced to any of the more commonly used simulator computers (i.e., Perkin-Elmer, SEL, Harris, Digital, etc.) was essential. The proof of this hypothesis is now being developed on a Britton-Lee IDM 500.

With the proposed use of a back-end processor, it was clear that the main operating environment of the primary processor must be flexible and rich with support tools. The UNIX (licensed by Bell Laboratories) operating environment was selected for three primary reasons:

1) UNIX is currently hosted on all mini/super mini-computers presently used in flight simulators, plus several (IBM and UNIVAC) main-frame computers, as well as several microcomputers. As a result, a broad range of UNIX-based systems exist which are capable of handling a variety of efforts, from major development in-house to on-site software maintenance.

2) UNIX provides a stable work environment for engineering, logistics support, and project management, producing a development process which is done in a similar manner from project to project. This is a great advantage in that it avoids retraining costs, redevelopment of the same subsystems, schedule delays, etc., while providing independence from vendor computational systems (e.g., software development for a Vendor A based simulator could be conducted on a Vendor B computer or any desired combination).

3) UNIX use is expanding rapidly, thus allowing great access to additional software tools developed by other users which may have applicability to our own development process.

Initially, the SEMS is targeted to be able to provide the following capabilities:

1) Requirements/specification reference
2) Module interface information
3) Status information for each component of software design
4) Design code implementation
5) Software change tracking

Figure 4 presents the general software development environment which is made possible through the UNIX tools and utilities. A work center can be located at any number of sites and remain in continuous communication through the UNIX network capability. It has been proven that each of the sites can have different computer vendor equipment and still be a fully compliant network work center providing file transfers, data base transactions, and project interaction.

Figure 5 represents the distribution of functions of a typical network work center. User system connections are through a front-end teleprocessor referred to as the network interface. This interface also services all work center-to-work center communications. The rich tool set available in the UNIX environment provides a sound basis to meet the present and future needs. The data base machine, augmented by the UNIX file structure, serves as the vehicle for data base management. A project data base housed within the data base machine will contain all necessary intelligence for simulator load build and software test. These data and directives must be formulated into command/data sequences acceptable to the target environment for the particular project. The functional distribution represented by Figure 5 provides for the inevitable condition when the target or simulator computational system is of a different manufacturer than the simulator development system.

The software test capability for a simulator will be hosted on a computational system similar to the actual systems used on the particular simulator. The testing (modules, module groups) of simulator software will be performed by this system. The activities typical of the test system will be compilation, link/load, program variable location resolution, test program operation, preparation of test results and residency for test programs and data. SEMS will provide the vehicle for test processing. Test results will be received back in the SEMS environment. Transmission and receipt of the test-associated data and software will require no special handling by the development engineer. The fact that another computer is involved will be transparent to the user. Definition of the SEMS-to-simulator software test system interface will require the determination of appropriate protocol, a detailed list of the data items and commands to properly direct the operation of the software test facility computer, and a description of test results returned.

For each simulator target computational system, an interface with SEMS must be developed. All software, data, constructs, and load-building information will reside in the SEMS environment and must be manipulated uniquely for each different target to achieve the desired operational result. A key principle of software configuration management is satisfied by controlling all materials for the product in one place, namely the SEMS data base. The fact that the final product is generated from this controlled environment ensures predictable product content. The fact that no other sources of input to the final product will be tolerated guarantees product configuration integrity. The tasks necessary for implementation are to define a protocol for SEMS/target communication interface and to determine the data, software items, and directives necessary for successful load building on the simulator computer.

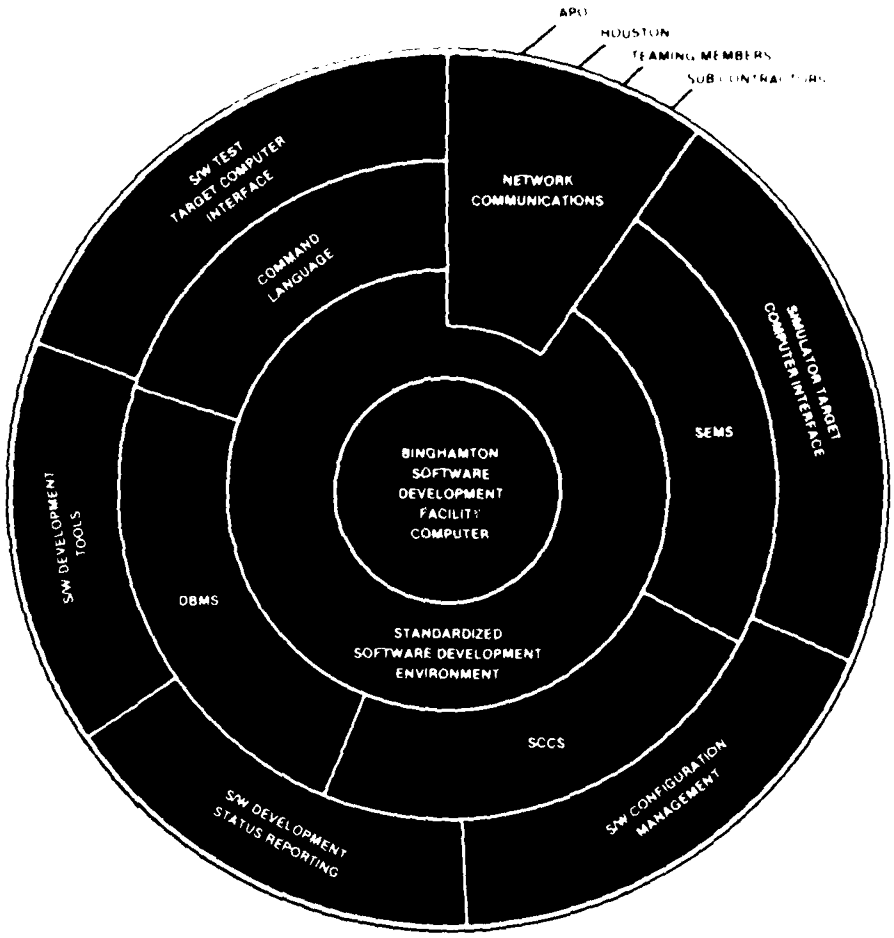
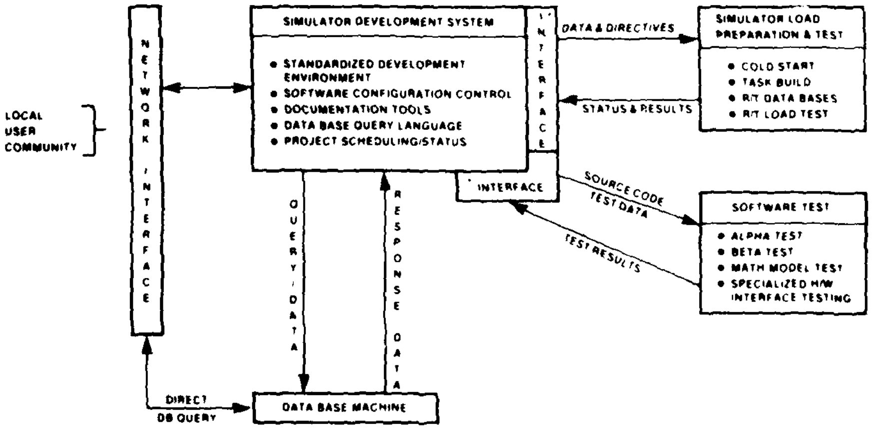


Figure 4 GENERAL SOFTWARE DEVELOPMENT ENVIRONMENT



*INTERFACES CUSTOMIZED TO CURRENT PROJECT(S) COMPUTATIONAL SYSTEM TYPE & ARCHITECTURE

Figure 5 SIMULATOR PROJECT NETWORK NODE (TYPICAL)

PRESENT STATUS

A UNIX environment, hosted on a Perkin-Elmer 3210 and interfaced with a Britton-Lee IDM 500, is installed and working. The system has an auto-dial/auto-answer modem hookup. The system has conversed with UNIX systems hosted on SEL and VAX computers. It has accomplished file transfers and file manipulations on other UNIX systems in directed, when available, and as-required modes.

The development of a relational data base, cross-referencing the software elements of a typical simulator, has been accomplished. Additionally, documents (not code) related to the software elements have been entered into the data storage of the UNIX environment. This data has then been manipulated, both intentionally and unintentionally, and successfully controlled within the UNIX environment. (In fact, the schedule and on-going progress of this development program is contained in the "experimental" environment.)

The policies and procedures for system implementation are now being refined. The B-52 WST is being used as a model since it represents one of the most advanced, complex simulators built to date. In conjunction with the procedures being developed, key individuals from the engineering, logistics, and program management areas are providing real-time feedback regarding present experiences, both good and bad. In this manner, the development project is exploiting both earlier and current experience. It is expected that this project will be an evolutionary system with refinements far into the future.

FUTURE GOALS

The proof of this software development environment will be in its universal application to new simulator programs. Since all new programs tend to have their unique requirements and development patterns, the true worth of the system will be in its flexibility for growth. The present system has concentrated on the "Product Baseline"; i.e., the set of technical documents and software that defines the trainer software at the end of the product phase of the software development. Expansion into the following areas is occurring:

- Software Functional Baseline -- i.e., the set of technical documentation that defines trainer software at the end of the software planning phase.

- Software Allocated Baseline -- i.e., the set of technical documentation that defines trainer software at the end of the analysis phase of the software development.

- Software Design Baseline -- i.e., the set of technical documentation and software that defines the trainer software at the end of the design phase of software development.

- Software Operational Baseline -- i.e., the set of all technical documentation and software that define the trainer software at the point of release to the Customer Configuration Management System.

And if the software development process can be captured in an automated, data base system with the visibility and control which is the objective here, why not capture the entire simulator project on such a system? Many activities now under way are proving that this concept is viable and desirable.

CONCLUSION

The system described in this paper is presently under development. It appears to have great potential and even greater flexibility. As was noted, the policies and procedures for implementation will have a profound effect on the successful implementation of the system. In the end, this development system may represent *the* technical feature which most affects simulator programs in a positive manner in the years to come. It will be the tool used by both technical and management personnel.

ABOUT THE AUTHOR

Robert L. Schwing is the Director for Research and Development, Link Flight Simulation Division, The Singer Company. He came to Link in 1982 after more than 15 years of civil service with the U.S. Air Force at Wright-Patterson AFB. He was the Assistant for Software to the Deputy for Simulators and, prior to that, the Program Manager for the B-52/KC-135 Weapon System Trainer program while at the Simulator SPO. He was a key participant in the design and construction of the Flight Control Development Laboratory facilities, including the unique engineering flight simulation equipment contained in the USAF Flight Dynamics Laboratory. Mr. Schwing is a registered Professional Engineer and is a member of Tau Beta Pi, Pi Tau Sigma, ASME and AIAA.

SOFTWARE DOCUMENTATION SUPPORT

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ABSTRACT

Generation and support of documentation accompanying software development is historically a low-efficiency, high-cost undertaking. Frequently the situation arises where a choice must be made to fulfill documentation requirements and incur cost and schedule overruns, or to complete the software product in a reasonable time and deliver less than adequate documentation. The primary difficulties are efficient generation, quick and thorough update, and document correlation on large projects. Automated methods can alleviate these problems by (1) application of word processing systems to the generation and editing of descriptive text, (2) use of a data base manager-type control of system interface definition and document correlation, (3) use of pseudo-code for first-time design and flowchart generation, and (4) the use of special purpose software tools to perform analysis of code for flowchart and module interface updating.

Documentation of software can be performed on several levels of complexity. The lowest level is perhaps the basic user's guide that accompanies small software items or those packages where a detailed knowledge of the software internals is unneeded or undesirable. This guide is usually textual, giving only installation and usage instructions. A higher level of complexity is encountered when system descriptions are included, as may be the case with a vendor's operating system. The user in these cases is given needed information on the interplay of the system's elements and possibly a fair amount of detail on the internal workings of the system in addition to the installation and usage information. Still omitted are the detailed design information, engineering trade-offs, and associated background information on philosophy, methodology, etc., that must accompany the most complex level of documentation – that given to the military or the government in general. Examples are compliance with the "Part II Specification" called out by USAF Data Item Descriptions DI-E-3120B/M1 Computer Program Product Specifications, and the DI-H-3277/M7 Training Equipment Computer Program Documentation.

The Part II Specification includes computer program descriptions, table and data base descriptions, a real-time cross reference, programmer's notebooks, time and memory allocation tracking data, a Computer Program System (CPS) guide, and of course, any associated vendor manuals. The general contents of the Part II Specification are depicted in Figure 1. Of the documentation items listed, only two items are easily supplied: the listings and vendor manuals.

```
                PART II SPEC
                      !
                      !
  +-------------------+
  !
  !--COMPUTER PROGRAM DESCRIPTIONS
  !         !    MODELING
  !         !    NARRATIVE
  !         !    CHARTS
  !         !    LISTINGS
  !         !    AS-BUILT TIME AND SIZE
  !
  !--TABLES AND DATA BASES
  !         !    GENERATION
  !         !    STRUCTURE
  !         !    USAGE
  !         !    TIME AND MEMORY CONSTRAINTS
  !
  !--REAL TIME CROSS REFERENCE
  !
  !--PROGRAMMER'S NOTEBOOK
  !         !    PECULIAR NOTATIONS
  !         !    INDIRECT TECHNIQUES
  !         !    CODING SIMPLIFICATIONS
  !         !    PROBLEMS AND SOLUTIONS
  !         !    LANGUAGE CHANGES
  !
  !--MONTHLY TIME AND SIZE ALLOCATIONS
  !
  !--CPS GUIDE
  !         !    DEVELOPMENT & UPDATE GUIDE
  !         !    USER'S GUIDE
  !
  !--VENDOR MANUALS
```

Figure 1. Part II Specification Structure

On a large software project, the effort required to produce this documentation can be staggering. The Boeing Military Airplane Company (BMAC), in building the B-52/KC-135 Weapons Systems Trainer (WST) prototypes for the USAF, produced approximately 1,000,000 lines of source code. This resulted in roughly 91,000 sheets of non-listing detailed design documentation. This does not include the amount of documentation produced in the generation of functional specifications, implementation specifications, or the programmers' notebooks, CPS guide, and other items of the Part II Spec. Additionally, there were in excess of 7,000 revisions to the source parts comprising the CPS. Assuming that each revision and associated document release required the modification of a minimum of three sheets (one flowchart, one narrative, and one revision status sheet), there were at least 21,000 regenerated documentation sheets for a total of 112,000 effective non-listing pages of design documents.

Naturally, there are impediments to the completion of a task of this magnitude. One of the problems with which many organizations must deal is the lack of sufficient numbers of skilled engineers and programmers to perform the designing and coding tasks. Engineering support personnel who should undertake much of the documentation task are therefore frequently utilized to perform in an engineering role. This places a greater burden of document generation upon the engineers and programmers which adds to the schedule impact.

The major issue in documenting software, even with an abundance of designers and support personnel, is the cost. A reasonable cost estimate for a delivered page of documentation is three manhours (MH).(1) It can be assumed that about one MH for one round of editing and revising with an additional 0.5 MH for typing(2) are embedded in this figure. Each additional revision of a page can then be estimated at 1.5 MH. The documentation cost of a WST-sized project could then be expected to be 304,500 MH, or approximately 1,750 man months (MM). This can be further emphasized by noting that a comparison of document generation to code generation shows that documentation accounts directly and indirectly for about 60 percent of project costs as opposed to 40 percent of project costs for coding.(3) Obviously, documentation is a candidate for cost reduction.

How can this cost be reduced? Perhaps the most apparent remedy is the application of word processing to those areas of the documents that are texual. In-house BMAC experience with word processing indicates that savings of 60-70 percent are possible when revision and retyping are undertaken through word processing rather than conventional secretarial methods. The 7,000-plus released revisions on WST could be translated to an expected expenditure of 31,500 MH. A 60 percent reduction via word processing brings about a possible savings of 18,900 MH. If the cost of revising a document page is conservatively set at one MH, the savings over the 21,000 revised pages is still 12,600 MH. Applying these possible savings to the embedded revision in the three MH per page yields a modified page cost of 2.4 MH, implying a savings of 20 percent over the basic cost of the 91,000 non-revision sheets, or 54,600 MH (still using one MH per embedded revision). When considered together, the reductions amount to about 67,200 MH or 22 percent. Of course, the *major benefit of this type of reduction* is not that the job could be done more efficiently. Rather, a less ominous spectre of the documentation cost would allow the job to be performed in the first place.

The word processor would be the mainstay of smaller projects and those supplying only the lower levels of documentation. Indeed, for the large project generating a Part II Spec. the word processor can play a very large role, particularly in supporting the CPS guide, the programmer's notebooks, and the modeling and narrative sections of the computer program descriptions. Other areas are better served in other manners, especially the module design flowcharts, interface lists, data base structure and memory allocation, and the real-time cross reference. Of these, the most extensive and time-consuming in generation are the flowcharts and the interface lists.

Flowcharting an 'as-built' piece of software is prone to similar problems as writing the narrative text – adherence to drawing standards, typing comments into the flow elements, analysis of the code, etc. An alternative is to implement an automatic flowcharting tool. Without the specific approval of the procuring agency, however, this is proscribed by data item descriptions such as the DI-H-3277/M7. Why is there an aversion to auto-flowcharting? The usual auto-flow tool has been used to generate what amounts to an additional listing of the code which fails to enhance the software's supportability. The secondary goal of an auto-flow tool then should be to chart the design in an understandable and useful form. One of the more highly acclaimed design approaches is the top-down method, where the basic programming problem is iteratively divided into subsets of less general, more detailed problems that can eventually be easily solved on an individual basis. Flowcharting a top-down design in a likewise manner greatly enhances the usefulness of the documentation and its acceptability to the user.

BMAC has an auto-flow tool in the final stages of development, the Document Support System (DSS), which performs the flowchart generation in a top-down manner thus directly reflecting the levels of the design. At the same time, the source code image is separated into design levels corresponding to the generated flowcharts and formatted to reflect the logic nesting of each level. For illustration, a simple two-design level program has been generated and analyzed. Figure 2 shows the entire source image listing of the program which has been written for a Gould SEL 32/55 using a subset of S-FORTRAN developed by Caine, Farber & Gordon, Inc.

```
*          PART NUMBER
        PROGRAM X
        DATAPOOL  LBPPHUGO
        LOGICAL * 1  LBPPHUGO
C
C          1.0 THIS IS THE TOP LEVEL
C
C          ?  SHALL WE DO IT ?
C
           IF ( L )
C
C          1.1    DO  THE  FIRST  THING
C
           I = 1
C
C          1.2    DO  THE  SECOND  THING
C
C
C          1.2.1    FIRST  PART,  SECOND  THING
C
           K = 3
C
C          ? IS INDICATION NECESSARY ?
C
           IF ( I.EQ.2)
C
C          1.2.2  SET THE INDICATOR
C
           LBPPHUGO = .FALSE.
           END IF
           END IF
           END
```

Figure 2. Example Program

Separation of the code and attendant flowcharts per design level is depicted in Figures 3 through 7. The leading block of code, used for variable mnemonic attribute generation, common area references, and data initialization has been set aside in Figure 3. Figures 4 and 5 represent the top design level of 'executable' code. In Figure 4, code subsection 1.1 is shown with a replacement statement highlighted by dashed lines, while subsection 1.2 is represented only by a comment. This makes it immediately apparent that 1.1 is not subdivided into lower design levels, while 1.2 is. The flowchart of Figure 5 shows the logical flow of the top design level. Branching due to TRUE or FALSE states of the decision is indicated by 'T' or 'FF' within the logic paths leading from the decision block. Figures 6 and 7 show the second level of design (code subsection 1.2) pictured with the corresponding comment and process block displayed in the previous design level to aid in identification of the listing and flowchart. Those separated segments of code and flowchart lend themselves quite readily to integration with descriptive text for each of the design levels.

```
REV :     STATEMENT
----------------------------------------
      :
   -  :   *            PART NUMBER
   -  :              PROGRAM X
   -  :              DATAPOOL  LBPPHUGO
   -  :              LOGICAL * 1  LBPPHUGO
   -  :   C
```

Figure 3. Leading Code Block

```
REV :   STATEMENT
-----------------------------------------------
      :
   -  :  C 1.0 THIS IS THE TOP LEVEL
   -  :  C     ?  SHALL WE DO IT ?
   -  :        IF ( L )
   -  :  C     (   1.1   DO  THE  FIRST  THING
      :        (            +---------------------
   -  :        (            !   I = 1
      :        (            +---------------------
   -  :  C     (   1.2   DO  THE  SECOND  THING
   -  :        END IF
```

Figure 4. Top Design Level Code

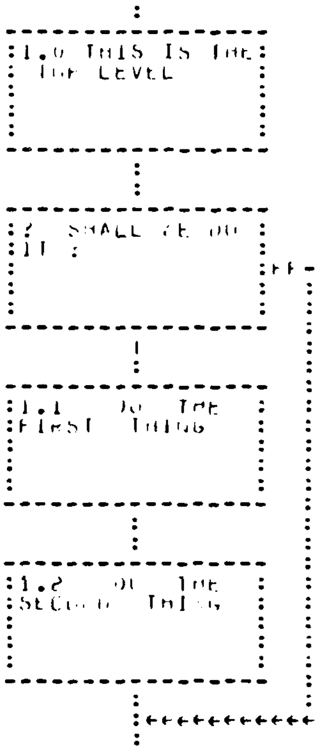

Figure 5. Top Design Level Flowchart

```
REV :   STATEMENT
--------------------------------------------------------
      :
   -  :  C 1.2    DO  THE  SECOND  THING
   -  :  C         1.2.1   FIRST  PART,  SECOND  THING
      :                    +---------------------------
   -  :                    !   K = 3
      :                    +---------------------------
   -  :  C         ? IS INDICATION NECESSARY ?
   -  :            IF ( I.EQ.2)
   -  :  C         (   1.2.2  SET THE INDICATOR
      :            (           +-----------------------
   -  :            (           !   LBPPHUGO = .FALSE.
      :            (           +-----------------------
   -  :            END IF
```

Figure 6. Second Design Level Code

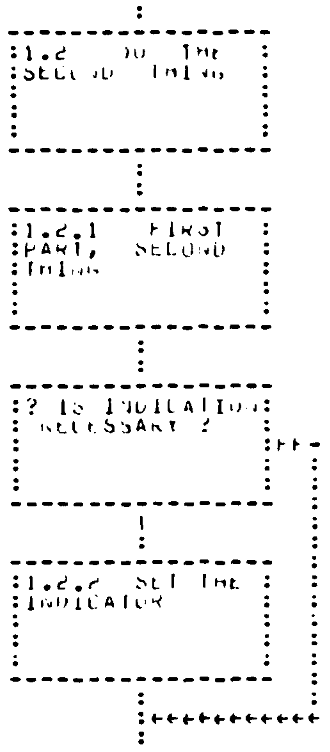

Figure 7. Second Design Level Flowchart

As evidenced, DSS can be used for analysis and documentation of existing code, provided certain coding standards have been followed. Additional applications are the generation of first-time flowcharts and the update of documentation per changes to design. Module designers generate a pseudo code of comments and generic logic structures, then use DSS to construct the design's flowchart. This gives excellent visibility to the design, its evolution, and its adherence to top-down and structured techniques. The example program of Figure 2 is in much the same format as would be generated by a designer under these circumstances. The two variables L and I have been inserted to provide proper syntax for the 'IF' logic structures, and would be replaced with proper mnemonics as they are defined.

An extremely optimistic expectation for the cost of the flowcharts and design level listings would be 1/4 MH per sheet. The amount of time required to generate all the sheets represented by Figures 3 through 7 was about 15 seconds, or 1/4-minute of real-time, leaving a great deal of spare computer time within the 15-second span. If we assume that text and 'boilerplate' comprise about one-half of each design document's non-listing pages, and the other half consists of flowcharts and design-level listings, we can arrive at a cost-savings estimate for combined word processing and auto-flowcharting. Applying the 22 percent word processing savings to one-half of the original 304.500 MH cost, or 152 250 MH, yields a savings of 33 830 MH. If we then assume the 15-second expenditure for generating the analysis of the example program applies to each sheet rather than all of them, then each sheet costs 15/3600 MH or 1/240 MH. Compared to our conservative 1/4 MH estimate for manual generation, this represents a savings of over 98 percent. The original cost of the 56.000 flowchart and design level sheets would be 14 000 MH at the 1/4 MH rate. A 98 percent reduction would be 13.720 MH for a total savings of 47.550 MH. Applied to a revised original cost of 166.250 MH (allowing 1/4 MH each for the flowcharts and design level lists assumed to comprise one-half of the 112.000 effective pages) the results are a savings of nearly 27 percent. Possibilities of this sort, especially given the conservative estimating, obviously start to bring high quality large documentation tasks into the realm of feasibility.

Documentation of module and system interfaces in a large system can be substantially more difficult than the documentation of the designs, given that many of the designs must be analyzed and correlated to give proper information for a few interfaces. This, of course, should then be accomplished in parallel with the progression of the design as the interfaces evolve. A prime candidate for support of this would be a Data Base Management System (DBMS) which correlates and maintains a data base of system interfaces. For this purpose, BMAC has instituted a DBMS with the MAXXIMUM data base manager by California Software Products, Inc., as its nucleus. This DBMS maintains interfaces which are implemented through the Gould SEL Datapool common memory facility and creates the mnemonic dictionaries used to link software load modules to the appropriate data spaces within the Datapool. In addition to the variable mnemonic, recorded data include variable attributes, dates of entry to the system and modification, logical location within the appropriate Datapool, software modules using the variable, and computers where using modules are resident. This obviously eases the pain of document generation as a great deal of this information can be gleaned from software module source code. Others, such as logical location within the Datapool, can be generated by the DBMS in response to variable attributes, unless constrained by operator input. An example of documented interface variables is given in Figure 8. Each of the two variable data entries gives the basic information stated above plus other pertinent facts such as the frequency at which the data is used and generated. Such listings can be easily generated for entire Datapool mnemonic dictionaries, or subsets thereof, to document tables and data bases according to the requirements contained within the Part II Spec.

The individual software module documentation is enhanced by the DBMS-produced module interface listing, shown in part in Figure 9. The module in question is shown boxed in asterisks on the left with individual interface linkages drawn to related modules shown boxed on the right portion of the figure. Each link shows the variable mnemonic for the data space that it represents, the type of data space (i.e., integer byte, logical byte, etc.), the data space array size, and the relative flow of data depicted by an appropriately oriented caret.

Interface documentation on the part of the DBMS is top-down in

```
                              KC-135 NAVIGATOR STATION PRIVATE MEMORY CPU 04 (QTP 14 / 03/06/81)

IBPMFZRQ  MASTER FREEZE REQUEST                                                              DATE CHANGED 12/31/1980
          -UNITS-       -RANGE-        -ACCURACY-      -RESOLUTION-        -TYPE-     (REF PAGE K0999)
          N/A           0-255          N/A             +-1                 1 INTEGER BYTE
          DATE ENTERED 24 MAY 1978
                         -MNEMONIC-   -MODULE NAME-             -PART NUMBER-       -FREQ- -MODE- -CPU- -DATE ENTERED- -DATE CHANGED-
          GENERATED BY   RNIBSEPS     OPSYS/CPU 4 ST EX PC    291-47104-1      F   20 HZ  ALL      4     05/25/1978      02/19/1980
          USED BY        RWIBPRSS     PROCESS SIMULATOR ST    291-40230-4      A   20 HZ  BOTH     4     02/25/1981      12/31/1980
                         RNIBSEPS     OPSYS/CPU 4 ST EX PC    291-47104-1      F   20 HZ  ALL      4     05/25/1978      02/19/1980
          DETAIL DESCRIPTION :    (BASE801)

IBPPOSPT  POINTER TO THE ARRAY POSITION OF    ELAPSED FRAME TIME; VALUE IS RELATED TO CPU   DATE CHANGED 12/31/1980
          -UNITS-       -RANGE-        -ACCURACY-      -RESOLUTION-       -TYPE-     (REF PAGE 00999)
          TBD           1-7            TBD             TBD                1 INTEGER BYTE              INITIALIZE TO ZERO
          DATE ENTERED 26 SEP 1977       CPU INITIALIZATION REQUIRED
                         -MNEMONIC-   -MODULE NAME-             -PART NUMBER-       -FREQ- -MODE- -CPU- -DATE ENTERED- -DATE CHANGED-
          GENERATED BY   CPU INIT     CPU 05 INIT DATA        291-47100-9      -   N/A    N/A      5     12/31/1980      02/24/1980
                         CPU INIT     CPU 04 INIT DATA        291-47100-8      M   N/A    N/A      4     12/31/1980      02/24/1980
          USED BY        MWOBINIT     INITIALIZE MAINT. EX    291-40726-2      -   N/A    ALL      5     03/03/1980      04/01/1980
                         MWIBEXEC     MAINTANENCE EXEC        291-40726-1      D   20 HZ  ALL      5     11/06/1978      02/27/1981
                         RWIBPEXX     OPSYS/CPU EX NUC PEC    291-40229-1      E   20 HZ  ALL      4     05/25/1978      03/13/1980
                         CPU INIT     CPU 05 INIT DATA        291-47100-9      -   N/A    N/A      5     12/31/1980      02/24/1980
                         SWOLIS       INSTRUCTOR STA CONT     SWOLIS           J   BKGRD  ALL      5     02/14/1978      02/24/1980
                         CPU INIT     CPU 04 INIT DATA        291-47100-8      M   N/A    N/A      4     12/31/1980      02/24/1980
                         RWIBPE05     OPSYS/CPU EX NUC PEC    RWIBPE05         C   20 HZ  BOTH     5     08/26/1977      02/02/1980
          DETAIL DESCRIPTION :    (BASE803)
```

Figure 8. Interface Data Base Documentation

```
******************                                                                    ******************
*                *                                                                    *                *
* RL3B02RG KF  3 *                                                                    * LNKR      KF  0 *
* 291-48402-1    *------*                                                      *------* REDIFON        *
* REVISION:  F   *      :                                                      :      * REVISION:      *
*                *      :                                                      :      *                *
******************      :                                                      :      ******************
                        :                                                      :
                        :<-S<-S<-S<-S<-S<-S   IBSX02SA   <-S<-S<-S<-S(IB     1)<-:
                        :<-S<-S<-S<-S<-S<-S   IBSX02SC   <-S<-S<-S<-S(IB     1)<-:
                        :<-S<-S<-S<-S<-S<-S   IBSX02SN   <-S<-S<-S<-S(IB     1)<-:
                        :<-S<-S<-S<-S<-S<-S   LBSDILSA   <-S<-S<-S<-S(LB     1)<-:
                        :<-S<-S<-S<-S<-S<-S   LBSDILSN   <-S<-S<-S<-S(LB     1)<-:
                        :<-S<-S<-S<-S<-S<-S   LBSFMFKA   <-S<-S<-S<-S(LB     1)<-:
                        :<-S<-S<-S<-S<-S<-S   LBSFMFKN   <-S<-S<-S<-S(LB     1)<-:
                        :>-S>-S>-S>-S>-S>-S   RBSPOPF2   >-S>-S>-S>-S(F*     1)->:
                        :
```

Figure 9. Inter-Module Interfaces

essence, starting with the contents of the data base and moving down to the module interface level. On the other hand, DSS has an interface documentation capability that starts with the module internal interfaces and moves up to the system level. An interface analysis of the brief example program is shown in Figure 10. The variable mnemonics I, K and L are shown to be unique to the module, while LBPPHUGD has been found in a predesignated common memory data base, thus allowing DSS to obtain array-size information and the variable's description. Mnemonic 'I' is shown to be an output of level 1.0, by virtue of an 'O' in the left column of the I/O matrix in the right portion of the figure. The right-hand column (for level 1.2) has no entry, indicating the 'I' is not used on the second design level. DSS has obviously shown us that the module is suspect, since a unique variable is generated as an output in one design level, but is never used as an input. Similarly, mnemonics are shown to be inputs by the presence of an 'I' in the design level column of the matrix, and mnemonics both used and generated are represented with a 'B'. As DSS analyzes modules, external interface information may be retained and later used to document interfaces between modules within a system, and between different systems of multiple modules. This difference in approach between the DBMS and DSS is summarized in Figure 11. The redundant aspect of system interface documentation makes an excellent cross-check mechanism, and helps to ensure data base and interface integrity.

```
                                                          1  1
                                                          0  2
                                                          0  0
                                                          0  0
                                                          0  0
                                                          0  0
                                                          0  0
                                                          0  0
                                                          0  0
                                                          0  0

I           (****)  **** LOCAL VARIABLE        ****       O  I
K           (****)  **** LOCAL VARIABLE        ****       O  O
L           (****)  **** LOCAL VARIABLE        ****       I
LBPPHUGD    (001 )  PHUGOID FLAG                          O  O
```

Figure 10. Example Program Interfaces

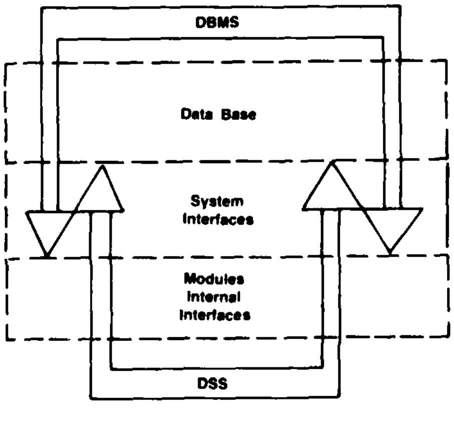

Figure 11. DBMS/DSS Perspectives

As with DSS, the DBMS process has the added benefit that discrepancies can almost always be detected and brought to light as soon as the offending source code is analyzed and its interface expectations are compared to the data base the DBMS produces an output that documents these discrepancies, as depicted in Figure 12. This particular example indicates that the module RO2BBAOU has defined several mnemonics to be in a common memory area, but never references these mnemonics in executable code. Additionally, the mnemonics are shown not to exist within the data base. This has probably arisen from a previous deletion of the mnemonics from the data base and executable code, while a somewhat careless change implementation has allowed the common definitions to remain. Two other variables are shown to disagree in array sizes between those expected by the module and those implemented by the data base.

While cost estimates for the preparation of interface documentation are not really available, it should be apparent that the process is certainly no easier than manual design documenting. Suffice it to say that the process which generated the information, of which Figure 9 is a part, took less than four minutes of computer real-time. The possibilities of savings should speak for themselves.

In order to efficiently perform these flowcharting and interface documenting capabilities, some standards and conventions should be imposed upon the software to be documented. In the instance of the interface DBMS, variable mnemonics are required to utilize the first three characters to show variable attributes of type and size, and whether they are to reside in a particular region of the Datapool common area or are unique to the module. DSS requires that the code follow structured precepts and be designed in a top-down fashion. Submodules and design levels within the code must then be commented with a numbering system that indicates to which submodule and design level a segment of code belongs. Figure 13 illustrates the hierarchical numbering of the example program processed by DSS. It can be successfully argued that other benefits of such practices (e.g., increased reliability) far outweigh the trouble of standards implementation, without even considering the applications to documentation.

The basic requirements of a general Part II Spec can be satisfied with the word processing, auto-flowcharting, and auto-interface-documenting described above. Other items such as the Real-Time Cross Reference can be completed with an extension of the DBMS source code analysis. Once these or similar mechanisms are implemented, however, there is still room for improvement. Correlation of documentation is a consideration, as are consolidation of document integration and generation of such items as test discrepancy reports, change requests, etc. Document correlation may well take the form of a DBMS function that maintains data on functional requirements documents, implementation requirements documents, and design and test documents. A change to a functional requirement paragraph could then be linked to subordinate implementation requirements and design and test documents, generating a 'need to change' list. Likewise, a module design change could be picked up by the DBMS and result in an output indicating a need to change the appropriate text through word processing

```
*** MODULE RO2BBA00  291-43172-1     R  06/26/1982 EMPLOYS 11  DATABASE VARIABLES IN THE FOLLOWING
CPUS -   9
THIS REVISION ( R) HAS PREVIOUSLY BEEN VERIFIED
VARIABLE IBPA0010 SHOWS UP IN COMMON BLOCK / EXTENDED MEMORY OF PROGRAM BUT IS NEVER SET BY PROGRAM
VARIABLE IBPA0010 DOES NOT APPEAR IN DATA BASE
VARIABLE IBPA0020 SHOWS UP IN COMMON BLOCK / EXTENDED MEMORY OF PROGRAM BUT IS NEVER SET BY PROGRAM
VARIABLE IBPA0020 DOES NOT APPEAR IN DATA BASE
VARIABLE IBPA00CD SHOWS UP IN COMMON BLOCK / EXTENDED MEMORY OF PROGRAM BUT IS NEVER SET BY PROGRAM
VARIABLE IBPA00CD DOES NOT APPEAR IN DATA BASE
VARIABLE IBSA00PR SHOWS UP IN COMMON BLOCK / EXTENDED MEMORY OF PROGRAM BUT IS NEVER SET BY PROGRAM
VARIABLE IBSA00PR DOES NOT APPEAR IN DATA BASE
VARIABLE IBSATGTT IN STATION BO - ARRAY MISMATCH (MODULE=    1) (DATA BASE=  200)
VARIABLE LBPPCDPA IN STATION BO - ARRAY MISMATCH (MODULE=    3) (DATA BASE=    5)
```

Figure 12. Interface Discrepancies

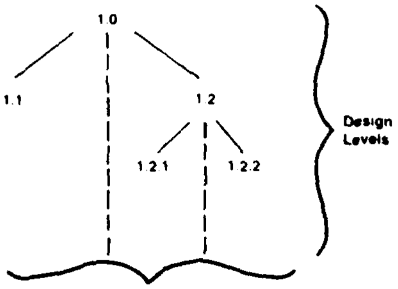

Figure 13. Example Program Design Levels and Submodules

Document integration could entail consolidation of the output of these various processes in order to avoid the manual sorting and shuffling of papers. Use of laser printers, plotters, and the like, if available, is not out of the question. With the obvious savings involved, the automatic processes explored can make giant strides toward high-quality, reasonably priced documentation.

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2 ibid p 572

3 ibid p 574

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SOFTWARE PROGRESS TRACKING SYSTEM

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ABSTRACT

The increasing complexity of software systems combined with the requirements for structured and modular designs have increased many fold the number of software elements developed and delivered on recent simulator programs. The increased number of elements plus the traditionally "soft" milestones used to measure progress has made monitoring software development and predicting future progress time consuming, subjective, and often unreliable.

A software progress tracking system which uses an earned point scheme has been successfully used to monitor software development on several large simulator programs. Points are assigned for each step in the software development cycle on a per element basis. The steps are "hard" milestones in which a generated product is accepted by program management. As the products are accepted the associated points are earned. The ratio of earned points to total possible points is compiled on an element, functional area, or total software system basis to determine progress achieved. A report generator program, usually resident on the simulator computational system, tabulates the data in a variety of management reports.

The system as implemented is flexible, highly automated, and is closely coupled to configuration management systems and software quality assurance procedures to ensure validity of data. The accumulated point values are quickly ascertained, objective, and based on the current state of program development. Simple calculations or comparisons of the accumulated point values provide an accurate measure of progress, deviation from schedule, and prediction of future progress,

INTRODUCTION

A large body of literature addresses the functions of planning, organizing and directing software development projects. Many texts and articles comprehensively discuss the initial stages of a project. The need for detailed requirement specifications, development plans and development specifications are well documented. The importance of clear organizational structure and team responsibilities are well supported. The techniques of top down, stepwise refinement of design and the requirement to review and validate designs early in a program are well known. Conscientious application of these management tools help ensure that the completed software product will meet its performance requirements in a timely manner.

These tools and techniques emphasize functions performed early in the life of a project. Less information is available on the on-going management function of control. Control can be thought of as a three step process: an attribute or characteristic of interest is measured, the measured value is compared with an expected or baseline value, and an appropriate action is taken if an unacceptable deviation exists. Any number of items of interest during software development may be controlled in this manner. Development time, development costs, computer memory usage and computer time are some of the more common items.

The purpose of this paper is to describe a method of measuring performance of the software development team and comparing the measured performance to a baseline schedule. Performance here refers to the effectiveness of software development personnel in meeting established schedule and cost targets. By providing an objective, timely measure of actual performance with a comparison to expected performance, project management will have the means to pinpoint schedule and cost deviations thus enabling them to take action to assure schedule and cost targets are met.

A performance measurement scheme should meet several criteria. First and most importantly, the scheme should be objective. The person claiming performance should not be required to estimate degree of completion. Likewise, the person monitoring performance should know exactly what a performance measurement represents. Ideally, the state of development should be sufficiently visible and the measurement means sufficiently clear to enable any project member to make the actual measurement.

Secondly, the scheme should measure performance in accomplishing the real task, i.e., the development of deliverable software. Further, the resolution of the measuring scheme should be sufficiently fine to measure incremental progress on a weekly or monthly basis and the measurement should be timely in that it measures the current state of development. Providing accurate, current performance information on a periodic basis can be a positive motivating factor for a programming staff.

Lastly, the scheme needs to be efficient. It should require minimal resources to collect, collate and report performance data and should require minimum time to interpret the results. Systems which require constant inputs from the programming staff, updates by clerical personnel, or integration of large amounts of data by management are not used.

TYPICAL METHODS OF MEASURING PERFORMANCE

Performance in software development is measured typically either by estimating percent completed of a task or by counting the number of predetermined milestones which have been reached. In either method a schedule of tasks and/or milestones is used as a baseline with which measured performance is compared.

In the estimate of percent completed method the person actually doing the work estimates the percent of the work which has been accomplished in reaching a milestone or completing a task. The percent completed method has several faults. The major fault is that the measurement is subjective. The manager is asking a person with a vested interest in completing the task as early as possible to make an educated guess as to how nearly complete he is. Most people tend to be optimistic in their ability to complete a task - particularly if their manager subtly encourages optimism. The old bromide of a task being 95% complete for months is all too true.

While not necessarily a characteristic of the percent completed method, a potential shortcoming of this method when used with tasks rather than milestones, is the definition of completion is not always stated. Therefore, the person making the estimate may have one perception of what the task includes, while his manager may have another. Hence when the programmer states the task is 100% complete - written, tested and documented - the manager may have an unpleasant surprise when he asks to see the Installation Guide. Therefore, since the end of the task may not be clearly defined, the estimates of completion may be quite inaccurate.

Since the estimates are subjective, the interpretation of the results may also be subjective. In trying to ascertain the degree of completeness of a job, a manager may ask who made the estimate and then apply a "correction factor" to the estimate for that person to get a number he feels comfortable with.

The second method, or milestone method, attempts to alleviate these problems by defining specific milestones which must be met and measuring performance by summing the number of milestones which have been met. This method is much more objective, tends to describe the overall task more fully and as a result is easier to interpret. The shortcomings of this method are more in the area of resolution of the measurement versus the efficiency of collecting, collating and presenting the results in a meaningful way.

In order to get the resolution of measurement fine enough to show incremental progress on a periodic basis, a large number of milestones need to be defined. However, the large number of milestones makes it more difficult to collect and present the data in a timely and meaningful way. A common method is to present the data on bar graphs, but on a large project with thousands of milestones, the upkeep of bar graphs can be a slow, expensive effort.

Another potential problem is that the milestone may not accurately reflect the real task. If care is not taken to define the milestone, the milestone may not be based on deliverable items but based on something which appears to show progress such as lines of code generated. Also, if the milestones are not carefully chosen, it may be difficult to determine if the milestone has been reached.

POINT SYSTEM

A method of overcoming these problems is a point system, which has been successfully used on several large simulator programs. The point system is really an extension to the milestone system which lends itself to automation. In its simplest form it is assumed that each software module goes through a similar development process and there are a number of clearly identifiable milestones within that process. For the purpose of illustration, assume ten modules will be developed and four milestones will define the development process. The milestones may represent design reviewed and accepted, code walkthrough complete, test results verified, and module released.

In the simple case each milestone for each software item is worth a point. In the case of the system with ten modules forty (40) points can be earned. As part of each design review, code walkthrough, test verification or release audit, the milestone is achieved and the corresponding point earned. By listing all of the modules and milestones achieved (points earned) in a computer file, and creating a few simple report generators, an objective, accurate, and timely measure of performance can be acquired. Figure 1 shows what a simple status report might look like.

SOFTWARE STATUS REPORT

	DESIGN	CODE	TEST	RELEASE	POINTS EARNED
Module A	1	1			2
Module B	1				1
Module C	1				1
Module D	1	1	1		3
Module E	1	1			2
Module F	1				1
Module G	1	1			2
Module H	1	1	1	1	4
Module I	1				1
Module J	1	1			2
TOTALS	10	6	2	1	19

PERCENT COMPLETE = 19/40 = 48%

Figure 1. Simple Status Report

This simplified scheme works well for a homogeneous set of modules where all modules are of the same complexity and each of the milestones represent an approximately equal amount of work. Through an introduction of weighting factors, modules of varying complexity or milestones representing unequal effort to complete can be easily handled.

Before this and other extensions are discussed, however, a brief description of implementation is in order. The heart of the system is a computer data file and a few simple report generators. The data file is simply a collection of records, one for each item which is to be tracked, which contains fields to indicate whether a particular milestone has been met or not. Usually, it is advantageous to include fields that allow for description of the item, responsible analyst, work package identification and various file identification fields. Figure 2 shows a sample record layout. Often such a file will serve multiple uses particularly if a few additional fields are added. Typical uses are Family Tree Definition, Specification Cross References, Configuration Control List, Documentation Cross Reference, and any one of a number of uses where a comprehensive list of deliverable software items are needed.

Layout

FILE NAME	SR NAME	RA	WP NUMBER	TREE DESIG	DCTR
DESCRIPTION					

File Name = Name of File as it exists on disk
SR Name = Name of Subroutine as it is called
RA = Responsible analysts initials
WP Number = Work Package Number
Tree Desig = Software Family Designation
DCTR = Status for Design, Code, Test and Release Milestones

Sample

FILE NAME	SR NAME	RA	WP NUMBER	TREE DESIG	DCTR
F.UDHEAD	UHEAD	MKM	17A	113206	11
DESCRIPTION					
PRINT HEADING FOR LISTING					

Figure 2. File Layout

Maintenance or updating of the file can be as straight forward as modifying records with a line editor or as complex as building a special purpose, interactive update program. Some means of limited access should be used to restrict unauthorized modification of the file, particularly if some of the other uses of the file are sensitive to change.

Once the file is updated to include an entry of the module under development, the milestone status fields are updated as the milestones are met. In some cases this may be a manual process, whereby once an event has occurred and the milestone achieved, a program librarian or other authorized person updates the status file. In other instances, in a more sophisticated system, a computer program could determine that milestone event has occurred (error free compilation or successful test run) and automatically update the milestone status.

After the file has been built, report generator programs are written to print the status.

For smaller projects, a program which simply prints each record, sums the earned and points defined, and calculates the percent points earned, may be sufficient. Larger projects may need several reports for different subsystems or summary reports which emphasize change.

EXTENSIONS

A number of extensions can be added to the scheme as described so far. The first is to add a method of weighting modules and/or milestones. While weighting all modules equally on a large program, where many (over 1000) modules exist appears to give good results, smaller programs with few modules may need to weight the modules to give a sufficiently accurate measurement of performance. Also, depending on the level of visibility of the measuring system and the attitude of the personnel involved, there may be a tendency to do all the "easy" modules first to show early performance.

A similar argument can be made for weighting milestones. Depending on the acceptance criteria to meet a milestone, some milestones may involve more work than others, therefore achieving those milestones represents accomplishing a greater amount of work than in meeting other milestones. Further, there may be instances where a combination of module weight and milestone weight may interact. An example is a module which was previously written on another project in a different language. The amount of design work for that module may be considerably less than a module designed from scratch, but amount of effort to code the routine might be more since an unfamiliar language may be involved.

The weighting scheme is easily implemented by assigning points to each milestone for all modules. Then as a milestone is earned, the assigned points are added to the totaled earned and divided by the total defined points to compute percent completion. The number of points assigned to each milestone is in proportion to the difficulty in achieving the milestone, and, in fact, relates directly to the estimated number of hours needed to complete the milestone. In assigning points it is recommended that points first be assigned to each of the modules and then reapportioned to the milestones.

A second extension is to add selecting and sorting options to the report generator programs. Selecting options allow the user to select all entries in the file by some field such as work package number, file name, software family tree component, or responsible analyst. Once the entries of interest are selected, the sort option allows the user to order the entries by some key. The points earned and points defined are summed from the selected entries and the percent complete calculated. Therefore, reports can be printed listing all modules and percent complete for a certain analyst, work package, or other selected criteria. It has been found valuable to allow boolean operations on selection fields (Analyst A AND Subsystem B) and to provide for major and minor sort fields (List modules in alphabetic order by analyst).

A third extension which has been useful is to add target dates and actual completion dates to each module record. In this extension the individual milestone status fields are replaced by two dates. The first date field is a target date as to when the milestone should be met. The target dates do not have to be used for all modules or milestones but are useful where an interdependency exists between a particular module milestone and some other element in the system. These interdependencies may exist in the design stage to some extent, but they become very important during the integration phase of a project.

The actual completion date field becomes a flag as to when the milestone is achieved. By adding up the points assigned to a milestone that have an actual date entered in the file the percent complete can be computed.

Using the two date fields has two advantages: schedule interdependence can be monitored and a historical record exists for future analysis. By making the date fields selectable and sortable, additional interesting reports can be generated. Assuming that an integration milestone has been identified, a list of all modules of interest can be selected by WBS work package number, family tree identification or individual module name. Target dates for the milestone of interest can then be entered. As the date of the integration milestone comes closer, lists of all modules of interest which have a particular due date and have not been completed can be provided to the responsible analyst or work package manager. Judicious use of these lists on a periodic basis can be used to monitor and motivate the programming staff to assure the milestone is met. Usually, several of these lists in various stages are active at once as key milestones are coming up. It has been found that choosing approximately one major milestone a month and starting the list several months in advance of the target date is very effective. More milestones than this tends to set up multiple or conflicting goals for the individual analysts. Also the lists need to be started well enough in advance to allow suitable time for the work to be completed and institute work-arounds if problems arise.

It should be noted that the meeting of these interdependency dates is really separate from performance measurement. It is possible that in a given subsystem the performance may be fully adequate, say 75% complete, but a key integration event may have been missed. The manager must be aware of both elements. If performance is where it should be, but an integration event has been missed, it may mean his people are not concentrating on the right items and need to be re-directed.

ROLLING BASELINE

A potential problem with the point system described thus far has to do with an effect known as a rolling baseline. The rolling baseline occurs over the life of a program as new items are continually defined and added to the status file. This has the effect of changing the baseline which causes percent complete to vary independently of milestones earned. During periods when few new items are added to the file, the percent complete accurately reflects real performance. At other times, as new items are added as quickly as previously defined milestones are met, reported progress tends to flatten out. In some instances where more new items were added than old items completed, negative progress is reported.

This problem is overcome by freezing the baseline for a unit of work or work package basis and reporting progress on the unit. That is, once a package of work is defined, no new points are allocated to the package. If for some reason it is decided certain modules have to be split up for sake of modularity or computing efficiency, the points are likewise split up in a replanning effort. In the instances where the scope of work changes due to an oversight or contract change, the effort is reprogrammed and either new work packages are created or existing work packages are expanded with a corresponding increase of points.

This has the effect of measuring performance on active or open work packages only and not on the system as a whole. However, since performance is being compared to an established schedule which is also made up of units of work, the comparison is valid and useful.

REPORTS

Several informative detail reports and summary reports can be generated from the data file. The most encompassing detail report, of course, is a listing of all elements. Such a list may be useful in creating inventory lists of software items to be delivered and might be used during Physical Configuration Audits. Other lists may be sorted and/or selected by work package or family tree identification number. Such lists show status of specific modules within subsets of the Work Breakdown Structure or functional items of the system. Other sorts or selections by a responsible analyst shows status of a particular individual's effort. Figures 3 and 4 show a sample detail reports.

The summary reports function as its name indicates. They sum up the information generated by the detail reports and simply total the items in each selected category. For example, a detail status listing of all elements within a work package can generate a summary that indicates the total number of elements and the number of elements that have met each milestone. Each of the milestones can also be expressed as a percent. The summary reports can then be used to report performance by whatever category is needed, i.e., work package, family tree element, responsible analyst, event milestone, etc. Figures 5 and 6 show sample summary reports.

Collecting data from several summary runs allow rates of completion to be calculated upon which trends or predictions of future performance to be made.

INTERDEPENDENCY STATUS REPORT

FILENAME	ID	RA	CLASS	DESCRIPTION	DESIGN	CODE	TEST	RELEASE
F.UDHEAD	DF-U150	MKM	U	PRINT HEADING FOR DELTA LISTING (CONFIG)	--/--/-- 01/27/83	--/--/-- 02/08/83	--/--/-- 03/15/83	04/15/83 04/21/83
F.UDLIST	DF-U151	MKM	U	PRINT DELTA LISTING (CONFIG)	--/--/-- 01/31/83	--/--/-- 02/10/83	--/--/-- 03/15/83	04/15/83 04/21/83
F.UDLTST	DF-U152	MKM	U	START UDELTA SUBTASKING (CONFIG)	--/--/-- 01/31/83	--/--/-- 02/15/83	--/--/--	04/15/83
F.UDMAT	DF-U153	MKM	U	CHECK BUFFERS FOR MATCH (CONFIG)	--/--/-- 01/14/83	--/--/--	--/--/--	04/15/83
F.UDMOVE	DF-U154	MKM	U	MOVE DATA INTO MEMORY (CONFIG)	--/--/-- 02/02/83	--/--/-- 03/01/83	--/--/-- 04/04/83	04/15/83 04/11/83
F.UDOPT	DF-U155	MKM	U	SET OPTIONS IN DELTA (CONFIG)	--/--/-- 02/01/83	--/--/-- 02/28/83	--/--/-- 04/14/83	04/15/83 04/11/83

Figure 3. Detail Interdependency Listing

```
                                   WORKPACKAGE STATUS REPORT

WP:  TACTICS LIBRARY SOFTWARE

MANAGER:  NFB

                                      ----------MILESTONES----------    ----------MODULE STATUS---------
WORK PACKAGE   FILENAME    WEIGHT    DESIGN   CODE   TEST   RELEASE    STATUS CODE    SCORE   % COMPLETE

    173F       F.LEDCPY         8         2      2      2        2           3           4         50
    173F       F.LEDEL          8         2      2      2        2           3           4         50
    173F       F.LEDFIL        44        11     11     11       11           1          11         25
    173F       F.LEDINF        20         5      5      5        5           1           5         25
    173F       F.LEDPRT        12         3      3      3        3           7          12         75
    173F       F.LIBEDT        16         4      4      4        4           3           8         75
    173F       F.LIBGEN        28         7      7      7        7          15          28        100
    173F       F.LTACGN        16         4      4      4        4           3           8         50
    173F       F.LTACID         8         2      2      2        2          15           8        100
    173F       F.LTASTA        32        16      0      0       16           7          16         50
    173F       F.LTCMPR        16         8      0      0        8          15          16        100
    173F       F.LTCMST        56        28     14     14        0           0           0          0
    173F       F.LTCVRT        12         3      0      0        3           0           0          0
    173F       F.LTGNUM        12         3      3      3        3           0           0          0
    173F       F.LTINIT        12         3      3      3        3           0           0          0
    173F       F.LTMDID        16         4      4      4        4           0           0          0
    173F       F.LTREC         32         8      8      8        8           0           0          0
    173F       F.LTSSTM        48        24      6     12        6           1          24         50
    173F       F.LTUCHK         8         4      1      2        1           3           5         63
    173F       F.LTUCVT        12         6      2      3        1           7          11         92
    173F       F.LTVALU         8         4      1      2        1          15           8        100

               --------       ---       ---    ---    ---      ---                     ---        ---
TOTALS:            21         424       106    106    106      106                     168         40
```

Figure 4. Detail Status Listing

```
                                             STATUS SUMMARY

WORK PACKAGE:  1234

                                  DESIGN         CODE           TEST        RELEASE       TOTAL

      TOTAL ITEMS                24            24             24            24            96

      TARGET COMPLETE            10   42%       7   29%         3   13%       0   0%      20   21%

      ACTUAL COMPLETE             9   38%       5   21%         1    4%       0   0%      15   16%

      LATE                        1    4%       2    8%         2    8%       0   0%       5    5%

      LESS THAN 1 WEEK LATE             0             1             0             0

      1-2 WEEKS LATE                    1             0             2             0

      2-4 WEEKS LATE                    0             1             0             0

      4-8 WEEKS LATE                    0             0             0             0

      MORE THAN 8 WEEKS LATE            0             0             0             0
```

Figure 5. Summary Report

WORK PACKAGE SUMMARY REPORT

WORK PACKAGE	DESCRIPTION	MGR	WEIGHT	--------MILESTONES--------- DESIGN	CODE	TEST	RELEASE	-----WP STATUS---- SCORE	% COMPLETE
173G	SCAN LIBRARY SOFTWARE	NFB	480	120	120	120	120	150	31
173H	PPG LIBRARY SOFTWARE	NFB	296	74	74	74	74	74	25
173K	EMITTER SCRIPTING: EMTR 1-50	NFB	2500	2250	250	0	0	1055	42
17A1	TD REPORTING CPPS	TJR	310	155	155	0	310	310	100
17A3	TD REPORTING SW DEVELOPMENT	TJR	1230	375	375	240	240	575	47
17A4	SCAN PROCESSOR DOCUMENTATION	TJR	1078	863	215	0	0	0	0
17A5	TIMS, DEBUG, SVL DOCUMENTATION	TJR	7420	6550	870	0	0	3465	47
17A7	SOFTWARE DEV TOOLS DOCUMENT	TJR	4818	3563	1255	0	0	3563	73
			18132	13950	3314	434	434	9192	51

Figure 6. Summary Status Report

SUMMARY

The point system for performance measurement during software development provides an objective, accurate, efficient means of collecting and reporting performance data in an engineering field which often lacks visibility. The method uses data which is based on deliverable software items and which is collected as a normal part of the development process. The results are easily interpreted and can be presented in a number of formats and subdivisions. The scheme is flexible and can be modified to meet the needs of projects both large and small.

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USER-FRIENDLY SOFTWARE: THE ROLE OF THE USER

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ABSTRACT

This paper presents a definition of the term "user-friendly" as it relates to computer software-human interaction. The software generation process, the various types of computer software users, and the role users should play in the software generation process are described. The author strongly recommends direct involvement on the part of the user(s) of computer software systems.

INTRODUCTION

Effective and efficient system operation is a function of good communication between the various parties that make up the system. Interfaces that contribute to good communication between parties should be the goal of system designers. Poor human-computer interface can be the result of inadequately or inappropriately addressing user friendliness of the device or the system equipment during design. Many systems currently in the DoD inventory which support weapon systems, simulators, training devices, and administrative systems have computers at their foundations. These systems have direct human-computer interface requirements. On-board computers for aviation weapons systems are common in today's inventory. Aircrew members operate computer-based flight systems for navigation and fuel management. They also operate mission-related systems that are partially or fully automated. Most modern simulators, trainers, and training devices are computer-driven or are in someway integrated with computer technolgy. Even electro-mechanical maintenance simulator devices are incorporating a computer to control system operation, student performance recording, and other training requirements. Several automated administrative and management information systems exist or are currently being developed. The U.S. Navy has automated aviation student records in the ATSS, and is in the process of developing a system to support undergraduate jet pilot training student performance recordkeeping, scheduling, etc.

Military personnel need to interface with computers directly or indirectly on a day-to-day basis at all levels. Managers and administrators receive computer-generated and computer-formatted outputs which they must analyze and upon which they make critical decisions. Operators and maintainers of actual equipment, training devices, and administrative tools are being introduced to computer-controlled or computer-integrated systems with which they must interface to successfully accomplish their job. Therefore, the computer systems designed for military use should be user-friendly if they are to be readily and properly adopted by the military personnel who must operate and maintain them.

In general, there are four aspects of the human-computer interface that are related to user-friendly characteristics of a system. The four aspects are:

1. Hardware interface
2. Patterns of usage
3. Purpose(s) of the system
4. Software interface.

The hardware interface focuses on input and output devices and how they are used and designed. User friendliness is typically addressed through the hardware interfaces of a system. Computer hardware designers have replaced complex keyboard input devices with fingertip control trackballs or touch-sensitive CRT screens and have reduced human-computer interface difficulties.

The patterns-of-usage aspect of user friendliness relates to the level of interaction, direct or indirect, between the user and the political implications of the human-computer interface. System patterns of usage should be based upon requirements of the user. Systems can be based on an established periodic pattern of usage, a constant and dynamic pattern of usage, or an aperiodic pattern of usage. User friendliness in regard to patterns of usage is dependent upon the level of agreement between the user's equipment and the pattern established for the system.

The purpose(s) of the system involves the intended and real world use of the system in the environment. The purpose of a flight simulator is inherently twofold: (1) to provide an environment similar to actual flight experience for training and proficient skill development, and (2) to provide a means to safely replicate aircraft disasters and emergency situations for analysis. To be user-friendly, the multileveled purposes of a system should be addressed.

The software interface, the subject of this paper, centers around the design and use of the means of communication between the user and the system computer program. Software engineers have taken a more critical perspective on the degree to which the human-computer software interface is user-friendly. The problem of poor software interface persists because the software engineer's perspective represents only half of the relationship.

What a software engineer or designer deems intuitively obvious from his/her perspective is not necessarily based on a common frame of reference with system users. The vernacular of software engineers and designers is not that of the user. Instead of learning to use or maintain a system, the operator or maintainer must first learn to think like a software engineer or designer. This situation is unsatisfactory for a military, or for that matter any, system which requires a human interface. The purpose of this paper is threefold: (1) to help define what user-friendly software should be, (2) to identify who the various users of computer software are, and (3) to describe the role of the user in the development of the human-computer interface which assists the user to do his/her job in a natural way that is easy to understand and easy to use.

DEFINITION

What does the term user-friendly mean? Some would claim that user-friendly implies simplemindedness; some would claim that it means that the system should interact on a personal level with the user; and some would claim that a user-friendly system is a system that humans, rather than some other species, can operate. Each of these definitions is inadequate. It is not desirable to reduce the relationship between man and computer to the lowest and most banal level of communication to achieve user friendliness. Nor is it necessary for a computer to communicate with humans on a first name basis or to completely simulate human interpersonal behavior. Computers have inherent and man-made limitations that are unavoidable. The user-friendly system capitalizes on system inadequacies rather than highlighting such deficiencies. User friendliness is more than providing for any human interface; it is the capability of the system to interface specifically with the level and type of user. User friendliness is a function of the system hardware, software, and human interface that leads to increased effective utilization of a system.

This paper is concerned with computer software, particularly training and training equipment related software. The role of the user should be investigated in relation to the hardware interface, the patterns of usage, and the purpose(s) for which computers are used. However, the focus of this paper is to provide information on the much neglected and poorly emphasized relationship between the user and the computer software he/she must use. The following list, generated from literature research on user friendliness (reference 1-4), provides criteria for evaluation of the level of user friendliness of computer software:

- A model of the user
- A discourse language which is comfortable for the user
- Responsiveness to user vagueness, imprecision, error, and status
- Level of effort exerted in performance activity results in a proportional required response
- Display device characteristics.

User-friendly computer software should be based upon a model of the user the system is designed to support. A maintenance trainer should contain within its memory the fault isolation logic that an expert maintainer would follow to fault-isolate a problem. For novice pilots the scenarios contained in flight simulator computers should be primative and less complex than the scenarios available for advanced pilots. Computer-assisted systems should have the capability to monitor student performance and respond on an individual basis to the needs of the particular student. Without the thinking and acting processes of the user incorporated into the system software, a disparity will exist, and frustration on the part of the user will be increased. The flight simulator student comes to the simulator environment with a set of cues and responses from the aircraft that he/she expects to have replicated in the simulator. The degree to which the aircraft world and the simulator world diverge is the amount of negative, and potentially dangerous, learning that can occur. Training time is negatively affected, and frustration due to the student's need to eliminate the incongruencies or to diminish their effect has its impact on learner motivation.

A user-friendly computer software system should communicate with the user in the common vernacular of that user. Language aimed at one level of user may be inappropriately targeted for users at a different level. A system that places a burden on the user to increase human memory requirements to understand the meaning of the language being used offers the user no incentive to efficiently use the system. It may be in the software engineer's common parlance to use such terms as DUMP, EXIT, BACK, etc., but these terms are not typically defined in the same way for weapon system operators or maintainers. Yet one finds software systems directing operators and maintainers to respond to such terminology. Software engineers, like the military, attempt to be parsimonious with their language and tend to abbreviate words, names, and sentences. Since the military has for some time been the leader in providing the English language with acronyms and abbreviations, is it not prudent for the software to use the existing, yet shorter, vocabulary of its user, rather than contributing further to the alphabet soup problem? The amount of confusion over whose definition is appropriate in a particular case could be reduced.

User-friendly software should provide a means by which the user can determine what has been accomplished; what is the current status of the interaction; what needs to be done to recover from an error, a miscalculation, or an imprecision; and how to maneuver to continue to communicate with the system. The user needs to know what has transpired to a given point in time to determine what response is required. In order to determine what is required of him/her, the user needs to know whether the computer is processing a response or expecting a response. It is necessary to embed in the human-software interface the information provided in human-to-human interactions that defines the activity and attention levels at a given moment in time. A very annoying characteristic of some computer-assisted instructional (CAI) software is that no overt indication of activity or attention is indicated on the output display device. The student (unaware that the computer is busily working an algorithm or processing some data) depresses a key that the computer interprets as an additional request; the computer thereby initiates processing on a redundant task or marks the student wrong for not following a procedure. A simple means for eliminating unnecessary processing and errors of this type is to provide a clear cue to the student that the system is responding. The user needs to have a means to recover from errors and a means to direct recovery efforts. It is insufficient to merely supply a means to erase an input or change a value; the user needs to know how to proceed, or the means to correct errors should be obvious to the user. Performance interruption or recovery in a simulator is principally the task of the instructor; however, this is not the case with trainers and CAI devices. The computer in a part-task trainer or a CAI system frequently takes on the role of the instructor and must be able to assist the student in the event of student error. Otherwise, the student could be lost in limbo for considerable time periods. This does not imply that the student be coddled through procedures when he/she errs. Rather the student should be informed of what the system requires to continue the training, particularly since the trainer may require specific actions that are not the same actions required to recover from a similar situation with the actual equipment. For example, when configuring a radar system for operation, there is typically a minimum warm-up time required with the actual equipment. The trainer probably would not require the warm-up time since it would be inefficient in part-task training; however, the student would need to step through some mini-procedure after committing an error that would indicate to the computer that the warm-up period requirement had been met. This would allow the student to continue without receiving warnings or alerts that the warm-up time was not met. Some means by which the user can elicit information from the system when the user in unsure of how to accomplish an objective should be directly accessible. Prompts and cues are often used in software programs to assist the user in following the procedure or logic pattern and to thereby provide a means by which the user can clarify what is required to proceed. Help functions should be available upon user request to meet anticipated user problems. The following are examples of cues, prompts, and helps.

- o Cues and Prompts:
  - * Press NEXT to continue
  - * Answer the question with an A, B or C
  - * Press HOOK VERIFY
  - * To begin another scenario press START.
- o Helps:
  - * The term Help means to provide the learner with assistance upon request.
  - * The critical attribute is color
  - * The proper indication should be 350 psi.

A user-friendly computer software system should follow the axiom that the level of effort required by the user to accomplish the objective of the interaction is proportional to the response. If the user has to exert more effort to ask the computer for the time of day than it would take to look at a watch, the interaction process is inefficient and will most likely not occur. The U.S. Navy found that the instructor stations for highly complex and integrated weapon system trainers required quick and ready access to scenario modifiers. The instructor for the S3A weapon system trainer, for example, needed quicker access to target data in order to modify course, speed, and location during student prosecution of the target than the original simulator software provided. A menu-driven target data access program was designed to provide more immediate access to modify the target's data base; the instructor was thereby provided with greater control over the evolving training situation.

In summary, to achieve user-friendly software, designers and users must work together on multifaceted levels. The software should accommodate who the user is, how he/she is to interact with the system, what peculiar or unique requirements he/she has in relation to the system, and the benefit gained by the user from the human-computer software interface. All relationships fit a cost-benefit equation. If the cost, in effort, time, or anxiety, exceeds the benefit of using a system, the possibility of effective and efficient system utilization is diminished.

SOFTWARE GENERATION PROCESS

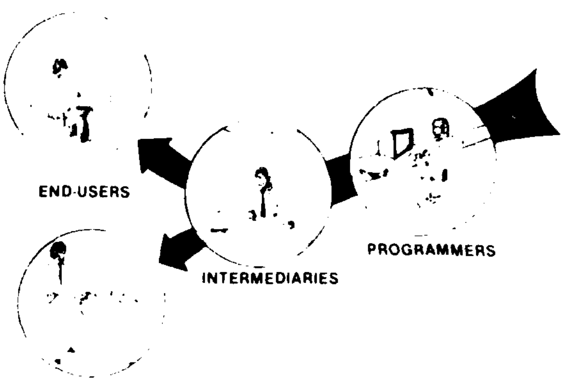
Computer software program development is typically, and most efficiently, conducted through a systematic process. The user should have knowledge and an understanding of the software development process to comprehend his/her role and to appreciate the job of the software engineer. The closer the user's frame of reference is to that of the software engineer's, and vice versa, the more friendly the system interface should be.

Software generation typically follows a seven-stage process. Stage 1, planning, involves the determination of system requirements and the preparation of software development, quality assurance, and configuration management plans. The product of the planning stage defines the problem and the expected/anticipated means to attain usable software at all user levels of the system. Stage 2, analysis, involves preliminary designing efforts for the system, program performance specification, and software test plans. During this stage the end-product software is specified at a very general and functional level. Stage 3, design, involves program design specification, software module or data base specification, and software test procedures. During this stage the software design is further refined, and a more detailed performance specification is developed. At this point in the process, no actual coding or programming has occurred. The products to this point are documents providing information for user and developer review to ensure that the design meets the requirements of the system. Stage 4, production and test, involves the coding effort for the individual software modules or units and the verification that each does what it was designed to do. Software to support a system is typically subdivided into several distinct and testable units, each of which is first debugged independent of the others to reduce troubleshooting when all units are integrated and tested during Stage 5. Stage 5, integration, involves a total system test on the functional configuration of the system. That is, unlike the tests conducted during Stage 4, the tests and operation conducted during Stage 5 must simulate or closely resemble the system's actual environment. Stage 6, acceptance, involves acceptance testing of the system, including all software, support publications, and operating procedures. During this stage the adequacy of the software to meet the stated requirements of the system must be determined. Stage 7, support and control, involves the continued software support required to modify and update the system software for the life of the system. This stage covers change procedures; it covers the means to identify software, documentation, design, or logic inconsistencies; and it covers the means to manage the configuration of the system software and support documentation. The typical path through the software generation process is not a smooth or straight-through stepwise advance. Several interactions within steps and revisiting of prior steps are often required before all parties involved can and will sign-off on progress throughout the generation of the software. For example, the impact of decisions arrived at during the design of the software may alter the software development plan established during Stage 1, planning. Before actually committing to production, the software engineers and planners will revisit the development plan and ensure that the software generation process does not lack continuity. In another case simultaneous efforts within a specific step, such as the development of operator manuals and the final acceptance testing results, feed one to the other and require continuous interchange to ensure valid end products.

This seven-step software generation and follow-on process ensures a controlled and systematic process to oversee the software development. The user has a significant role in this process from assisting in planning to providing inputs for engineering changes to existing software.

TYPES OF USERS

There are basically three types or levels of users: end users, intermediaries, and programmers. End users are those humans who interface with the computer at the data manipulation and presentation levels. Intermediaries are those humans who interface with the computer at the intermediate level of input and output. Intermediaries are involved in physically affecting the arrangement of data and data files via input and output devices. Programmers are those humans who interface with the computer at the most complex level of input and output. Programmers write software code to control the means by which intermediaries enter, exit, and move within confined areas of the computer memory. The programmer also provides control for the highest level input and output for the end user. Frequently, one individual may simultaneously, or in a series of events, interface with a computer at various user levels.



End users can be students, managers, administrators, letter writers, or data analysts. Intermediaries can be instructors, word processors, data processors, terminal operators, or weapon system operators. Programmers can be very high level software language coders, CAI developers, or machine language coders.

ROLE OF THE USER

The level of attention that is focused on the process of eliciting and incorporating user requirements into the specification, and ultimately into the implemented system, is a direct correlation with the degree to which the system is user-friendly. The user has a critical responsibility to engage in interaction with the software engineers as early in the process as possible. The user should provide inputs to the process from the planning stage through to ultimate long-term support of the system. Software generation is a cumulative process, that is, latter stages rely on assumptions and constraints underlying the products that preceded them. Each stage uses the previous stage as a starting point and should user inputs and involvement be overlooked or ignored during early stages, significant impacts to system design at implementation may result. Meeting user requirements should be an essential part of determining the overall system requirements. The user needs to assist at the inception of the software generation process to outline the activities he/she is capable of participating in in support of software generation.

In two aviation system procurements, the VTX and the E-6A, the U.S. Navy is involved in the development of computer software to support emerging aircraft systems. The VTX program is a procurement to support naval undergraduate jet pilot training. The VTX training system is comprised of four major elements: the T45 aircraft; the simulator suite of an operational flight trainer (OFT) and an instrument flight trainer (IFT); an academics system relying heavily on computer-assisted instruction (CAI); and a recordkeeping, student tracking, and resource scheduling system called a training integration system (TIS). The E-6A program is a procurement to support Take Charge and Move Out (TACAMO) operational commitments. The E-6A has a training requirement for a crew and maintenance personnel. The program currently calls for the procurement of E-6A aircraft, a flight simulator specification, and front-end analyses to establish specific training requirements. NAVAIRSYSCOM, the U.S. Navy's Aviation Systems Command and the procuring agency of these emerging systems, has considerable experience in working with the software generation process as it relates to training and training equipment. Their experience has led them to work with their sponsor in the development of Fleet Project Teams and Special Program Offices to provide direct input into the system from the user communities. The U.S. Navy also was involved in the development of computer software to support the S-3A training-related data base system. The S-3A is an anti-submarine warfare (ASW) aircraft, which the Navy felt needed a front-end analysis update to support their fleet readiness squadron (FRS) training system. The front-end analysis data was generated in an electronic format and controlled through computer software. The user community was invited to participate throughout the system development; however, the invitation was informal, and the program suffered due to a lack of experience in handling user inputs. This section of the paper will describe the role of the user during each stage of the software generation process, and will refer to the NAVAIR experiences to provide lessons learned.

User inputs during the planning stage with regard to user requirements, to user resource allocation for product review and in-process review, and to other planning concerns are integral to ensuring that end-product software is user-friendly. Users should ensure that they are to be involved throughout the software generation process, and that their level and degree of involvement is explicitly stated in planning decisions and documentation. The user should ensure that adequate time, resources, and occasions for review and acceptance are allotted. Merely acknowledging that the user should be involved does not guarantee user involvement. Higher eschelon management must be made aware of such requirements early on so that adequate foundations for manpower, budget, and support are available when required. Also during planning the user should provide, as appropriate, inputs on the problem; on similar systems; on the system being replaced; and on the intended purpose, environment, and personnel for the system. If possible, face-to-face interface should occur during the planning stage. This type of interaction will provide the user with a better understanding of the limitations and constraints under which the software engineers labor, and vice versa. The user should endeavor to become better familiar with the software engineer's frame of reference and language. A person's frame of reference is made up of those events, experience, and knowledge he/she has been exposed to that shape his/her perspective on reality and in particular on the task to be accomplished. Language in this context refers to the communication means and modes of an individual and covers verbal and nonverbal communication as well as subtlety of the common vernacular. The closer one's frame of reference and language are to another's the more precisely they can communicate.

User inputs were elicited during the planning stage from the S-3A community. Unfortunately, the user's stated requirements exceeded legal boundaries and common procurement practices and had to be ignored. This apparent "snub" led to difficulties throughout the program. User inputs have been elicited during the planning stage for the two emerging systems, and management has been in support of Fleet Project Team participation. In all cases the user has seemed very eager to provide inputs to the analysis of the problem and to the resolution of the problem. The user has been in direct contact with the software engineers, and a give-and-take and nonantagonistic atmosphere has been established. Personality differences can be skillfully controlled, but not necessarily eliminated. Success in establishing and maintaining a relationship that generates a user-friendly system seems to be dependent upon the presence of a free and open environment for discussion with a single moderating body in attendance. Someone with authority and a "big-picture" perspective needs to be involved directly to keep discussions from getting out of hand, either on a personal level or into a dream world.

User inputs during the analysis stage are probably the most critical of all inputs throughout the software-generation process. It is during this stage that the user friendliness of the system is first defined, and it is from the end-product of analysis that deviations are made at latter stages in the process. The user should ensure that the following items, synthesized from available literature (references [1]-4), are addressed in the functional description of the system which is generated during the analysis stage.

- User language
- User logic (psychology or pattern of thought)
- Means to recover from user error
- Help available
- Level of effort estimated to achieve tasks
- Amount of training required
- Data configuration
- Data access procedures
- Security procedures
- Human factors related to the man-machine interface
- Use of CGI (graphics)/visuals.

The functional description of the system software should describe the language the system will use to interface with the user. As stated earlier, unfamiliar language usage leads to a burden on the part of the user to acquire new terminology, jargon, and subtleties of the language. A model of the user, how he/she accomplishes a job using the system, should also be contained in the functional description. Flow diagrams, logic trees, and other pictorial descriptions should accompany any textual documentation concerning the user's logic in problem solving or system use.

In face-to-face communication it is possible to get lost or lose a train of thought; the human-computer interface should provide obvious means of recovery from such a disconnect eventuality. Interruptions, memory lapses, daydreaming, and other mental and physical occurrences can lead to communication interruption. The functional description should provide data on how the system will indicate status to the user, how the user will be able to recover from errors, and what assistance the system will provide when the user is unsure of functions, how to proceed, etc.

The functional description should also include an indication of the average level of effort, the number of actions, the total amount of time, etc., estimated to achieve tasks. The level of effort should directly relate to the difficulty of achieving the task and the complexity of the subtasks that make up the task. The user should make sure that simple tasks, as defined separately from the computer, such as a simple multiplication task, require a simple-action instruction on the part of the user. This does not mean that complex tasks should require complex user action or instruction; rather the system should simplify for the user, whenever possible, the procedural, instructional, and interpretational requirements of the system. If a task can be automated, and the user need not be directly involved, then the system should not require anything from the user.

The functional description should contain an estimate of the amount of training required for the user of the system. This estimate should cover initial training and follow-on training requirements. Software trade-offs are often made at the cost of additional training. The user should be aware of the impacts of such trade-offs, and the software engineer should be forced to define up-front the basis upon which future trade-offs will be made. Data configuration, data access, and security procedures should be delineated in the functional description to ensure that all will be properly and adequately addressed in the design. The configuration of the data can have an impact on how the data is manipulated and formatted for ouput. Assurances should be made at the analysis stage that the activities of the user can be accomplished given the data configuration. The user should probe the functional description with the same questions and activities expected of the end-product system to determine the limitations and/or inadequacies of the analysis. In this regard the user should ensure his/her involvement in testing the system throughout the software-generation cycle. The user should ensure that adequate time and test points are identified in the acceptance plan. If possible, the user should encourage test trials of part or the whole of the system software interface to coincide with software engineering and testing activities.

User inputs were elicited during the analysis stage from the S-3A community, and a functional description was produced for the system. However, the list of items described above as areas to be addressed in the analysis stage was not developed. The user had a poor conceptualization of what was needed and what the system was to provide. The users' review comments reflected a lack of understanding in that their major concern was where the system would be sited rather than how it would operate. The VTX user-community has been intimately involved in the analysis stage of software generation to support the simulators, the TIS, and the academics subsystem. Specifications have been written to functionally describe these three subsystems. Again, the list of items to be addressed in the analysis stage was not developed prior to eliciting user inputs. Nevertheless, the users and the software engineers have had several face-to-face formal sessions to interact and to discuss how the software can best support the needs of the users. The E-6A user-community is in the process of meeting with the software engineers to discuss the software analyses to support E-6A requirements. The E-6A Fleet Project Team will use the list of items to be addressed in the analysis stage during their evaluation of the flight simulator functional specification.

The design stage is an extension of the analysis effort. During design the user should strive to ensure consistent application of the analysis stage outputs to the design of the software. The user should revisit the analysis data to determine whether all requirements in fact were addressed. Modification to the basic analysis data is most easily accomplished prior to entering the production and test stage. If possible, the user should evaluate software procedures and system displays and cues on mock-up or paper product versions of the intended end-product system. Flipping through sample menus as they would appear during software interface can provide a general level of appreciation for what the end-product will look like. At this stage in the process trade-offs will begin to arise. Software trade-offs are the result of hardware constraints, operating software constraints, lack of engineering creativity, and the cost of generation. It is often during design that a distinction is made between "need to have" and "nice to have" or "whistles and bells" requirements. All trade-offs, whether they fit "need" or "want" criteria or they are due to system or fiscal constraints, should be documented and justified. This information provides support data for future funding requests and provides the basis for future system enhancements.

The S-3A user-community was provided with an opportunity to review the design of the data base system on a paper product set of example menus. These sample menus took the reviewer through all modes of operation and demonstrated step-by-step the procedures the user would go through to accomplish activities. Since the user was not really cognizant of the purpose of the analysis and how it fit with the design, no consistency evaluation was made by the user. The result was that the concept changed as the system evolved without any audit trail back to the original analysis. Trade-offs were made and were not well documented, mainly because at the time no requirement was levied on the software engineers to provide such documentation. The VTX and the E-6A programs have not fully evolved to the design stage of the software-generation process. However, it is anticipated that during design reviews the user-community representatives will evaluate the design for consistency and will request documentation of all deviations from the original analysis.

The production and test stage of the process involves software coding activities that result in actual, visual products that the user can interface with. The user should push and probe the software to its limits. A user unfamiliar with the system can provide better insight to interface problems and can directly assist in the debugging effort. This increased faculty is a result of user-naivete with regard to how the system was evolved from the design. The errors and bugs discovered during production and test are those most likely to be repeated in the final product if the user is not involved in the interim testing. The user can also assist in identifying design inadequacies or design-production inconsistencies with respect to the human-software interface.

Constraints in the S-3A program limited production and testing to non-users and contractor personnel. The program ran into hardware and software operating system constraints that affected schedules and resources to complete the program. Testing by operators was not conducted in a systematic manner until the integration stage was complete. The VTX and E-6A programs have programmed time into their schedules for user-community representatives to be directly involved in quality assurance during software production and unit testing. It is anticipated that full-time personnel, exclusively assigned to support the E-6A program development, will be available to provide user inputs during production and testing.

Typically, the user is not involved with system testing during the integration stage. If provided with the opportunity, however, the user should test the entire system as an integrated whole during integration and during acceptance. The difference between tests conducted during integration and during acceptance is a matter of the timing and the expected level of quality control. The testing conducted during integration should elicit more programming errors yet to be debugged than the testing conducted during acceptance. The system should be installed on-site or should be ready for packing and shipping at the completion of acceptance testing. Integration testing, on the other hand, can be accomplished in the lab. The user should validate the procedures and other information defined in the operations and maintenance manuals, user manuals, and training materials to verify that the support documentation supports the system beyond acceptance and implementation. During acceptance the user also has a responsibility to review the specification requirements and all trade-offs made during the software-generation process. The user should ensure that all deviations from the original requirements and all trade-offs are adequately documented with justification for each.

The S-3A user-community was not involved in integration testing or acceptance of the training-related data base system. This lack of involvement has led to a lack of interest in using, and possibly maintaining, the data base system. Integration testing and system acceptance was conducted by Navy personnel familiar with the program and the system design. The VTX and E-6A programs will have user-community representatives directly involved with acceptance testing. As in the case of the production and testing stage, full-time personnel will be available to support E-6A quality assurance testing throughout the integration stage.

The final stage in the software generation process has an ongoing, everpresent requirement for the user to actively participate in the maintenance and improvement of the system software. The user should document system errors or bugs, identify any inadequacies of the system, and provide constructive inputs to enhance the system. Constructive feedback to software engineers, programmers, and management provides important information for further system development and development of similar systems. The user should also assist in the development of a software configuration managment instruction (CMI) that: 1) governs the establishment and provides a charter for a Software Configuration Change Board (SCCB) and 2) identifies the means to ensure reliable and valid software at all times.

A CMI was written to support the S-3A training-related data base system. However, funding constraints and apparent lack of interest on the part of the users have led to almost complete neglect of the system. Other naval communities and industry have expressed interest in the underlying concept of the system. The S-3A user-community, having never taken ownership for the system, may never realize the full benefit of the system. A significant lesson learned from the S-3A program is that the user's inputs cannot be sacrificed for expediency. The system eventually must pay for its lack of attention to user friendliness. The VTX and E-6A programs require configuration management planning as contract requirements. Hopefully, user involvement in these programs will continue to be supported throughout the system generation process and on into the out years of the system life cycle. With the VTX and the E-6A programs the U.S. Navy has an opportunity to demonstrate that user involvement contributes to a more user-friendly system and thereby to demonstrate that user friendliness contributes to efficient and effective training.

SUMMARY

User-friendly computer software is software that adapts to the user's perspective and allows communication to occur between the computer and the user. User-friendly software speaks the same language as the user regardless of the type or level of user. The only way to ensure user-friendly software in the end-product is to ensure direct user involvement at the initial step of the software-generation cycle and continued interaction throughout the subsequent steps of the process. This interaction does not occur spontaneously. Adequate funding and authorization from procuring agencies and high eschelon management must be secured. Extensive travel is typically a requirement of user support to the software generation process. Additionally, front-end money to develop adequate functional descriptions and to perform the necessary analyses is required. Moreover, time must be made available for dedicated-users to support review activities. These requirements can appear to be costly; however, the benefit gained through more efficient, effective use of the system resulting from user acceptance and a feeling of mutual understanding of the user with the computer system far outweighs the initial investment to ensure a high degree of user friendliness.

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PASSIVE WEAPON TRAINING SYSTEM

German Von Thal
McDonnell Aircraft Co.

NOT AVAILABLE FOR PUBLICATION

COFT—A NEW CONCEPT IN TANK GUNNERY TRAINING

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Simulation and Control Systems Department
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ABSTRACT

The problem of developing and sustaining armor crew gunnery proficiency has become increasingly challenging in recent years due to operational and training costs and limited range availability for realistic gunnery training. The Unit-Conduct of Fire Trainer (U-COFT) was thus developed to provide armor force commanders the capability for improving and sustaining crew gunnery combat readiness between range firing periods. A total training system consisting of crew station, visual, and instructional subsystems, the U-COFT is housed in three environmentally controlled shelters that afford limited mobility and self-contained operation. It will be deployed with armor and infantry battalions in 44 locations throughout the free world. The U-COFT instructional system features an extensive library of exercises which train all the gunnery tasks required of a crew in combat, plus an adaptive training management function that permits each crew to improve its proficiency at a rate commensurate with its ability. This paper briefly describes the unique instructional features incorporated in the U-COFT training system.

INTRODUCTION

With the largest training device contract ever awarded, the U.S. Army is sponsoring the manufacture and fielding of nearly 300 Unit-Conduct of Fire Trainer (U-COFT) systems configured for the M1 Abrams and M60A3 tanks, and M2/M3 Bradley fighting vehicles. Employing computer image generation, digital control systems, and computer aided instruction techniques, the U-COFT is designed to train armored vehicle commanders and gunners in basic, intermediate, and advanced gunnery skills. Providing crew compartments that closely replicate actual turret interiors, generating high resolution full-color imagery viewed through sights and periscopes, and accurately simulating the sight, sound, and "feel" of fire control system and weapon operation, the U-COFT demonstrated training effectiveness during operational testing by the U.S. Army. A key factor in its capability as a training device is the instructional subsystem used to direct, evaluate, and monitor the training process. Highlights of the U-COFT development and operational testing, system characteristics, and instructional subsystem features are provided in subsequent paragraphs.

PROTOTYPE DEVELOPMENT AND VALIDATION

In September 1979 the U.S. Army awarded contracts to two contractors for accelerated development, over a 21-month period, of prototype versions of an M1 configured U-COFT on a competitive "best-effort" basis. That is, both contractors were allowed maximum latitude in design of the trainers, so long as certain minimum performance requirements were met. Government evaluation and selection of the production contractor was to be based heavily on the training effectiveness demonstrated during field testing. At the end of the contractually fixed development period, only one contractor successfully fielded an operational system. Development of M2 and M60 versions was continued with the winning contractor, General Electric. A production award followed in September 1982.

Assessment of the training capability of the General Electric U-COFT occurred during a full-scale operational test at Fort Hood, Texas, involving a battalion of M1 crewmen and vehicles. The test was designed to measure the capability of, and differences between, two training programs developed to train crew gunnery. Training effectiveness was measured within each program, in terms of skills developed and increased proficiency. Transfer effectiveness was measured in terms of crew proficiency — either sustained or increased — resulting from the training programs as demonstrated on the actual M1 tank.

In the test plan devised, one armor company was to train using the actual M1 tank together with other conventional training aids; two other companies were to receive gunnery training exclusively on the U-COFT yet perform all other normal crew tasks during the three month training/evaluation period. Prior to start of the training period all three companies participated in a range firing test to assess basic crew proficiency levels. At the conclusion of training a second range firing exercise was conducted and graded, and the results compared to the pretraining scores.

Final test results concluded that both training programs sustained proficiency; each provided a satisfactory level of transfer effectiveness. Additionally, the U-COFT was found to be training effective in that as a training medium it sustained and in some cases improved gunner and tank commander skills in all areas measured. Moreover, a supplementary test designed to assess the ability of both tank and COFT-trained crews to operate with malfunctioning fire control equipment indicated that crews trained on the COFT were, in fact, clearly superior. This was not unexpected since crews training on the U-COFT experience programmed malfunctions as part of the exercise matrix and hence become more familiar with procedures to follow when confronted with failed or degraded weapon system components. A fourth M1 tank company newly formed immediately prior to the start of the test, and which could not be "officially" included, was also involved. This company was largely but not entirely composed of personnel untrained on the M1, and due to the non-homogeneous mix did not represent a true transition group. This company was, however, trained solely on the COFT with a course of instruction designed for transition training, the length of which was approximately three times that of the sustainment companies. Approximately two thirds of the way through this train ing the skill levels demonstrated on the COFT were beginning to match those achieved by the sustainment crews; at the completion of the test, the skill levels of the transition company, demonstrated on the COFT, equalled or bettered those of the sustainment companies. These findings are expected to be verified by planned testing when the U-COFT reaches field units.

PRODUCTION SYSTEM DESCRIPTION

As illustrated in Figure 1, the U-COFT is composed of the following hardware elements:

- A crew station in which the appearance and functions of training-critical vehicle operating controls, indicators, and weapon sights are replicated.
- A computer image generation (CIG) visual system that produces realistic, full-color action scenes allowing crew members to view and interact with a broad range of target situations.
- An instructor-operator station (IOS) through which the instructor (a master gunner or platoon sergeant) initiates the computer-selected exercises and monitors crew performance. He can freeze action, replay all or part of a particular exercise, select remedial exercises to suit specific crew needs, or obtain soft or hard copies of crew performance. Color displays included in the station let him view all visual scenes as presented to the trainees.
- A general-purpose computer which provides the control interface between system elements, as well as manages the total U-COFT training, scheduling, and performance/proficiency evaluation.
- A shelter subsystem composed of three air-transportable MIL/ISO standard containers, with two of these housing the trainer equipment and the third providing space for crew briefing/debriefing and maintenance. Environmental conditioning, power distribution, and fire protection is self-contained.

The special-purpose computer image generator provides three-dimensional color daylight, reduced visibility, and night scenes with various terrain and topographical backgrounds, manmade structures, moving targets, projectile tracers, and special effects (round impact, missile signature, artillery fire — both friendly and enemy, smoke grenade explosion, etc.) that allow tank crews to develop gunnery proficiency in a variety of simulated battle conditions. Correct visual perspective is instantaneously computed and maintained for all orientations of the simulated vehicle targets and overall data base. The 10km-by-7km data base around which the training exercises are developed is composed of eight separate data blocks; six of these can be moved or interchanged to provide scene flexibility. Ownvehicle can be programmed for movement through seven of the eight blocks; targets can be placed anywhere in the data base. Weapons simulated include the 105 mm main gun, 7.62 mm coaxial machine gun, .50 caliber machine gun, and smoke grenades used on the M1 and M60 tanks, and the 25 mm automatic weapon, 7.62 mm machine gun and TOW missile system used on the M2/M3 fighting vehicles. Data bases are available for both visible and thermal engagement exercises; in the latter, thermal signatures of scene objects and targets are taken into account to assure realism.

Over 500 tactical exercises, each approximately 10 minutes long, are available for the M1 U-COFT. The M60 version will be equipped with a comparable number, and the M2/M3 will have more than 350. These exercises range from a three-hour introductory session for trainee familiarization with the U-COFT and orientation in basic elements of tank gunnery, to complex multiple-target air/ground exercises which test the mettle of even the finest tank crews. Ranking of the exercises is in order of increasing difficulty in each of three skill areas: target acquisition, reticle aiming, and systems management. By a systematic method of butting and stacking, these exercises form a three-dimensional matrix through which a student advances— on an exercise-by-exercise basis—toward certification levels established for basic,

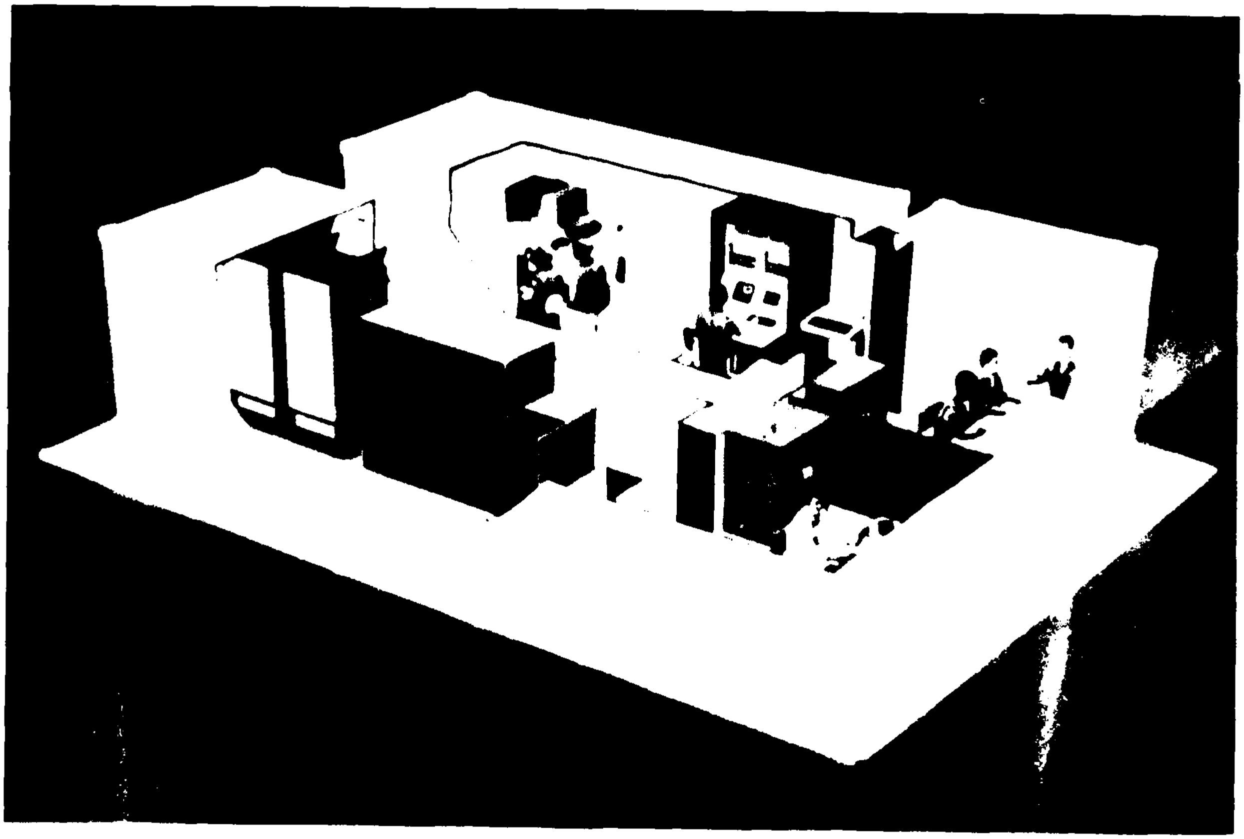


Figure 1. Unit-Conduct of Fire Trainer (U-COFT)

cross, transition, and sustainment courses of instruction. Ranking the exercises according to difficulty makes "controlled adaptive learning" possible, in that the student progresses to the next successive exercise (or level of difficulty) only if his current and/or previous performance justifies it. He either advances, regresses, or remains at the same level in accordance with pre-established matrix movement rules and conditions that will be discussed later. For each exercise in the commander/gunner and commander matrices, there are either two or four repetitions of that exercise available. In the case of stationary ownvehicle exercises, each exercise has four repetitions in which the situation conditions are the same but the order of appearance of the targets is changed. For moving ownvehicle exercises, there are two repetitions, each of these being a unique exercise since in a moving exercise merely changing the order of appearance could mean that the target would not be visible due to ownvehicle position at that time. The repetitions are utilized when the computer recommends "no advancement" and the crew is required to retrain at that same difficulty level. The repetition capability also serves to deter crew memorization of exercise content and target appearance.

As students progress through the matrix, they move from simple stationary owntank-stationary target engagements to increasingly difficult conditions involving various combinations of moving ownvehicle, moving targets, multiple stationary and moving targets, reduced visibility, malfunctioning fire control components, and incoming enemy fire. Overall, an extremely realistic, effective, and stringently controlled training environment results.

INSTRUCTIONAL SUBSYSTEM

The instructional approach employed in the U-COFT has evolved as the result of inputs from tank crewmen, engineers, educators, training psychologists, training managers, project managers, and other sources, and has proved to be extremely effective to date in achieving the Army's goals for this trainer. The U-COFT instructional subsystem consists of a library of preprogrammed exercises for teaching gunnery skills, an adaptive evaluation system for evaluating crew progress, a training management system to process student records and assist in scheduling, and an Instructor Operator Station (IOS) to provide the instructor with real-time instructional feedback and control features to aid in monitoring and critiquing student actions.

Training Matrix

As discussed earlier, the training exercises form a matrix, as illustrated in Figure 2, that is organized according to target acquisition, retical aiming, and systems management levels of difficulty. Ranking exercises in this manner makes possible an adaptive learning process that is controlled by selection of exercises of known change in difficulty based on trainee performance on previous exercises. Target acquisition levels of difficulty cover a range of target exposure, visibility, lighting, friendly and enemy fire, and various distracting conditions such as thermal clutter, friendly and enemy fire, and friendly vehicles in the target areas. The reticle aim levels are ranked by difficulty by forc-

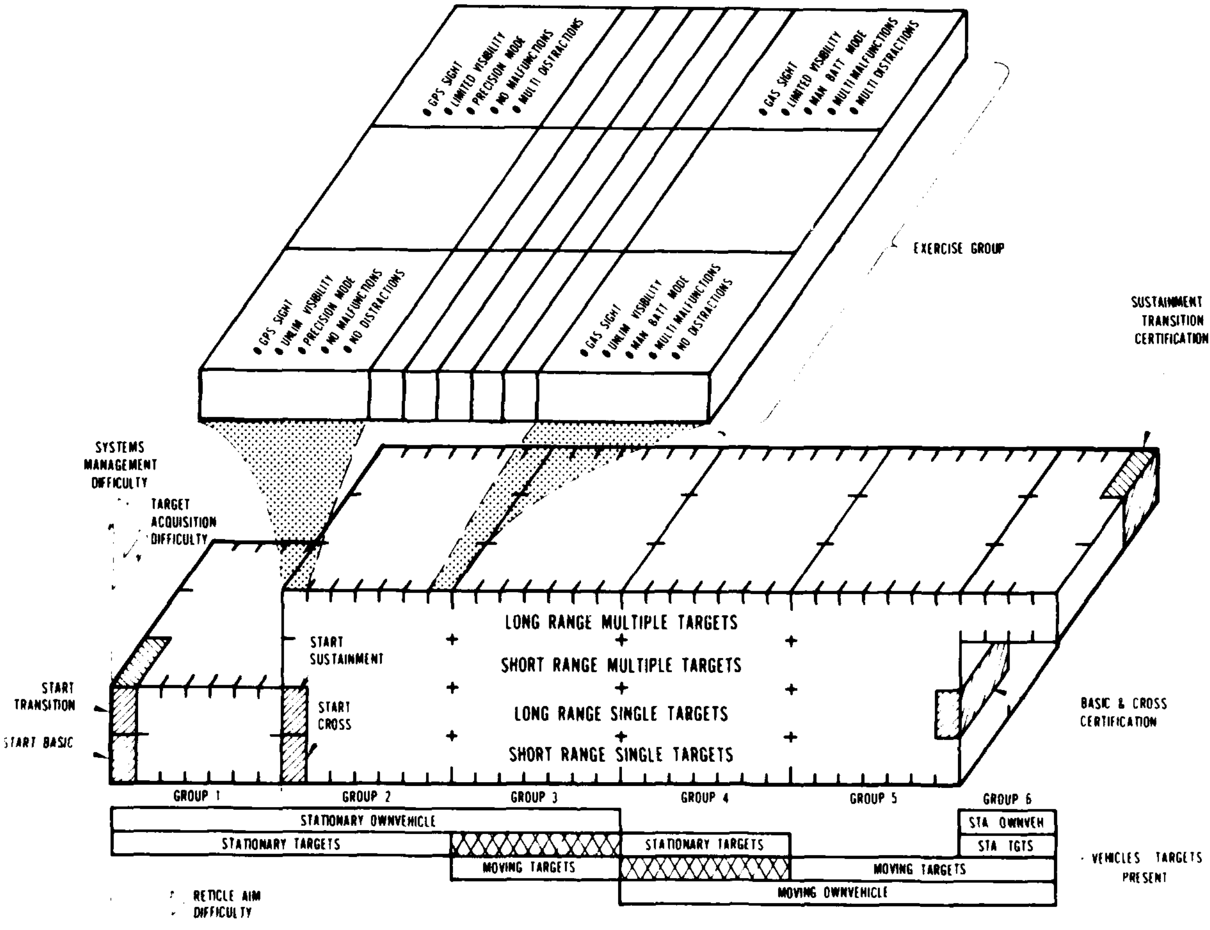


Figure 2. Commander/Gunner Training Matrix for M1

ing the use of primary and auxiliary gunsights either with or without fire control system malfunctions present and required use of NBC (Nuclear, Biological, Chemical) equipment by the crew. And finally, systems management levels are layered according to whether single or multiple targets are present, and to respective target range. There is a similar but smaller matrix which consists of exercises designed specifically for the training of the tank commander (TC), and the firing of the various weapons from the TC position.

The exercises comprising the commander/gunner and commander-only matrices are organized into groups, with each group addressing a specific type of ownvehicle motion and target mix. Each exercise in the group consists of from four to ten independently scored situations with similar tactical and environmental conditions. Each group contains a mixture of target types, both friendly and enemy, including tanks, armored personnel carriers, trucks, helicopters, and area (troop fire) targets, and is structured according to the target acquisition and reticle aim levels of difficulty. In each of the first five groups or blocks of exercises shown in Figure 2, each group provides seven types of reticle aim problems, with three degrees of difficulty in target acquisition, and two or four levels of difficulty in systems management. As the crew progresses from Group 1 through Group 6, the conditions become more difficult as the owntank targets proceed from stationary to moving, and from single to multiple.

Following an orientation, trainees enrolled in the basic course of instruction enter the matrix at the beginning position shown in Figure 2. After completing an expected number of exercises, progressing along a nominally diagonal movement through the layered groups of exercises, the trainees exit the matrix at the point where certification for the basic course is achieved. That is, at that point exercises are provided which test the capability of the crew to proceed to the more difficult sustainment blocks of exercises.

Trainees in the cross training program category enter the matrix at a more advanced level than that specified for basic, but then move toward certification in similar fashion as those students in the basic course. Transition and sustainment trainees enter the matrix at yet higher levels and after completing their respective expected number of exercises achieve certification at the uppermost point of the matrix.

The training exercises provide for moving or stationary firing, ownvehicle in combination with moving or stationary targets. Target and ownvehicle motion is preprogrammed to assure that all trainees at all unit locations are measured in the same way; allowing random "wandering" may involve heavy reliance on instructor judgement and result in inconsistencies in scoring. For stationary engagement exercises, motion paths such as those representing movement from and to defilade positions connect stationary firing positions; for stationary target exercises, the paths cause the targets to move into view and then remain stationary until the exposure time limit is reached. In all cases, the targets withdraw from the scene if not hit. In no cases do targets to be engaged appear or disappear suddenly from the scene. Ownvehicle speed is specified for each exercise requiring ownvehicle motion, with both constant and variable speed and direction paths chosen as appropriate for the objectives of each exercise. Exercises provide varied terrain roughness, with ownvehicle operation in stabilized and nonstabilized conditions.

Targets in an exercise are spaced in range and azimuth to provide training in target search and acquisition. Targets become visible within two or three seconds after the start of each situation; and since each has a preprogrammed exposure time, it withdraws from the training field of view if not hit within the time allowed. Vehicle and area targets appear at any aspect angle with respect to the viewing ownvehicle, from full front to full rear and including all angles in between. All targets may be programmed for movement throughout the data base gaming area, the only restraint being the existence and location of other objects in the data base.

Target classification levels range from "most dangerous" to "friendly", with each target in a situation being ranked with respect to the other targets in the situation. Classifications are based on the following variables: target type, target range, target orientation (including turret orientation in the case of tank targets), and other targets visible. Friendly targets always receive the lowest classification value, and the levels of targets within the same lethality group are equal. Engagement in order of lethality is one of the criteria considered in the grading of crew performance.

Training the commander to fire the main gun and his own weapon involves use of the commander's exercise matrix, which is similar to the commander/gunner matrix (Figure 2), but has only two systems management levels. The exercises in this matrix are organized around specific types of ownvehicle motion and target mix, and each exercise includes independently scored situations with similar tactical and environmental conditions. Commander training occurs concurrently with crew training in that as the crew progresses through the basic, cross, transition, or sustainment programs the computer periodically recommends a commander exercise. Access to the commander's matrix is automatic and progress is based on the commander's learning progress. The first commander's exercise is automatically selected after the third computer-recommended crew exercise but thereafter commander exercises are recommended based on the commander's "lag". This is defined as the difference between his position in the commander's matrix versus the position of the crew in its matrix, and can be positive or negative. The frequency of commander exercises can vary from one exercise for each five crew exercises to one for every crew exercise.

As noted previously the library also includes special-purpose exercises that are used for U-COFT introduction/orientation, calibration and zeroing, preparation for operation, acquisition and manipulation, and evaluation.

Scoring Criteria

Each U-COFT training exercise contains a minimum of four to a maximum of ten independently scored situations involving similar tactical and environmental conditions. A situation may involve one, two, or three targets which may be stationary or moving. The composite of situation scores for a given exercise is used to form a computer recommendation as to student movement in the matrix.

Each situation is scored, on the basis of predetermined criteria, for performance by the trainees in the requisite skill dimensions of target acquisition, reticle aiming, and systems management. The measured state for each dimension is determined on the basis of the criteria listed in Table 1.

Skill Dimension	State Measurement Criteria
Target Acquisition	● Time to acquire target ● Number of identification/classification errors
Reticle Aiming	● Time to first round burst ● Time to hit ● Magnitude of aiming error
Systems Management	● Number of switch setting errors prior to firing ● Number of switch setting errors at time of firing

Table 1 Situation Scoring (Measured State) Criteria

To illustrate how scoring occurs within each skill dimension the measurement of reticle aiming error is used as an example. This error, which is evaluated for main gun rounds only, is defined as the total distance that the reticle is displaced from the centroid of the target or from the correct aiming point for situations requiring manual lead, wind, or cant aim-off. The correct target aim for all point targets is within a 0.67 mil circle of the target centroid. A target hit plate is designed for each target type such that the portion of the target outside the 0.67 mil circle but within the target silhouette is designated as sensitive to hit damage. The reticle aim error evaluation is based on the criteria indicated in Table 2.

Following measurement of student performance in each skill area the evaluation function of the instructional subsystem formulates recommendations for action by the instructor. These are displayed on the IOS terminal CRT at the conclusion of each exercise. At the same time, a disk file of crew performance is automatically updated; this file is catalogued by crew member, student name, and training program type (i.e., basic, transition, sustainment, cross). Access to student records is under strict password control.

Progression through the commander/gunner and commander exercise matrices is guided by matrix movement rules designed to prevent critical levels of training from being passed over, and to present exercises of remedial content to students for whom "reduction in standing" is recommended by the computer. The rules also assure that key exercises which train the critical tasks associated with a reticle aim group are not passed over as a result of a "rapid advancement" computer recommendation. After an exercise is completed and the scores for each of the three skill dimensions have been calculated, the system checks the movement rules against the computer recommendation criteria before recommending the next exercise. The matrix movement rules are shown in Table 3.

Round No	Reticle Error	Evaluation	Grade
1	a Target hit and aim error less than or equal to 0.67 mil	4	A
	b Target hit and aim error greater than 0.67 mil but within the hit plate area	3	B
	c Target missed and no second round fired	1	F
2	a Target hit and aim error less than or equal to 0.67 mil	3	B
	b Target hit and aim error greater than 0.67 mil but within hit plate area	2	C
	c. Target missed	1	F

Table 2. Reticle Aiming Error Evaluation

To assure that crews do not progress out of an exercise group prior to demonstrating proficiency in the critical tasks required of that exercise group, the following special rules are enforced:

- In each reticle aim group a specific exercise at a designated position in the matrix must be completed and the crew (or commander) must achieve at least a "normal advancement" recommendation in all three skill areas.
- A minimum acceptable proficiency level is established for system management and target acquisition skill areas during the conduct of exercises with malfunctions.
- Crews will be designated as certified upon obtaining at least a "normal advancement" recommendation in all three skill areas in specific certification exercises in sustainment, transition, basic, and cross training.

Skill Dimension	Matrix Movement Requirements		
	To Next Higher Level	To Next Lower Level	To Skip a Level
Systems Management (SM)	Two or more successive "normal advancement" recommendations in conjunction with a "normal" or higher recommendation for reticle aim on the last exercise fired.	Two or more consecutive "reduced" recommendations for either systems management or reticle aim	Two-level increase or decrease is not allowed
Target Acquisition (TA)	"Rapid advancement" recommendation for the last exercise fired, or two consecutive "normal advancement" exercise recommendations	Two or more consecutive "reduced" exercise recommendations	Not allowed
Reticle Aim (RA)	"Normal advancement" except in certain special cases.	Not allowed. Reduction in systems management level is recommended instead	Rapid advancement exercise recommendation (In certain special cases, movement to the next level may be recommended)

Table 3. Matrix Movement Rules

INSTRUCTIONAL FEATURES

The U-COFT instructional subsystem is characterized by an extensive range of capabilities, selectable at the instructor's option, that enable him to efficiently and effectively control and manage the overall training process. These capabilities, which are implemented through data collection, performance evaluation and analysis, and training management functions embodied within the subsystem, are summarized in Table 4.

Exercise Selection

In the training mode, exercise selection may be accomplished by the instructor in three different ways:

- By computer recommendation, in which the computer assesses the crew's matrix position, evaluates the results of computer-recommended exercises previously completed, and selects the next exercise for the crew to perform. Each training session begins with the last computer-recommended crew exercise performed during the previous training session; this helps account for any performance loss since the last session. The instructor can accept the computer's recommendation, or based on his personal assessment of crew performance he may select an exercise by content or by specific exercise number.
- By exercise content based on descriptors including ownvehicle speed, target type, target speed, initial target range, crew member firing, weapon selection, sight selection, visibility conditions, and malfunctions. Successive content selection pages for each of the descriptors are presented to the instructor and, via a "selection by elimination" process, a listing of those exercises in the library which contain the selected descriptor elements is displayed to the instructor by exercise number. Upon selection of an exercise from the list, a detailed description of that exercise is presented; at this point the instructor may opt to run that exercise or he may select another.
- By exercise number, based on instructor apriori knowledge or selection via his field manual which lists and describes all exercises available for use.

Although the instructor has the option of ignoring the computer recommendation for the next crew or commander exercise, progression through the matrix will not be affected by his selection. For example, if at the conclusion of an exercise the computer recommends exercise "12345" but the instructor decides to select exercise "98765", the system would run exercise "98765". At the conclusion of this exercise and regardless of

FUNCTION	PURPOSE	RESULT EFFECT
Mode control	Select and terminate specific operational mode (i.e., training, training management, daily readiness check, diagnostic test).	Mode selected is executed.
Exercise selection, preview, briefing	Provide instructor with exercise description for briefing to the crew.	Description of exercise and initial tactical environment is displayed to instructor after exercise is selected.
System setup	Perform automatic check of crew compartment switch settings (by trainees) for correctness.	Exercise will not start if check fails. Incorrect settings are displayed to instructor, who will inform crew to correct settings.
Performance monitoring and analysis	Convey *trainee* performance data to instructor during exercise, during playback, and on completion of exercise.	Displays via situation monitor page: ● Current ballistic computer data ● Operational mode ● Current switch positions ● Current exercise and situation numbers ● Elapsed exercise time ● Current and past engagement data ● Engagement results/scores
Session summary	Summarize overall crew performance for each training session.	Session summary is displayed and/or printed.
Shot pattern (For 105 mm main gun only. No shot pattern for area fire weapons, i.e., coax and cal .50	Provide graphic view of shot patterns for up to two rounds per target in the exercise.	Shot pattern reflecting hit data relative to center of mass of the target, accurate to 0.1 mils in azimuth and 0.2 mils in elevation is printed.
Exercise control	Provide instructor with comprehensive control of exercise.	Selected controls are executed. ● Exercise freeze/unfreeze at any point. ● Record/playback of visual scenes and aural cues for current exercise (no voice communication). ● Exercise repeat. ● Logging of verbal commands by crew during exercise (i.e., gunner identified, from my position, driver stop/go, cal. 50). ● Ammo selection input. ● Printout of situation monitor, performance analysis, and/or shot pattern pages. ● Input of identification (ID) error.

Table 4. Instructional Features Summary

how well the crew performed, the computer would once again recommend "12345" as the next exercise. This process would continue regardless of the type or number of exercises selected by content or number by the instructor. The intent of the rule is to prevent situations in which critical skill elements may not be exercised if instructor manipulation of crew progress was allowed, and to standardize crew instructional content which could be compromised by instructors having different levels of skill. It is entirely probable, however, that by exercising crews in specific exercises selected by content or by number the instructor may bring about a more rapid advancement once the system and exercise selection is returned to the computer.

Performance Monitoring

An instructional feature that is expected to be highly critical to training is the situation monitor page, displayed on the IOS display terminal CRT, that conveys student performance data to the instuctor both during and immediately after the exercise. This page, a typical example of which is shown in Figure 3, contains information such as current ballistic computer data, operational modes, current crew station switch positions, current exercise number, elapsed exercise time, current situation number, current enemy target and past target engagements (in terms of weapon firing, target type, main gun round number or machine guns burst number, reticle aim error in azimuth and elevation), and results for the engagement. While the situation monitor page is updated once each second, aiming errors are updated as each round is fired. Data for the current engagement is highlighted on the display to distinguish it from previous data and data for upcoming targets; the latter is listed for each target in terms of seconds before target appears, target bearing, and target type. Also included is the situation letter grade system status prompt, and keypad options prompt. Letter grades are interpreted in relation to the student progress recommendation; i.e., "A" for rapid advancement, "B" for normal advancement, "C" for no advancement, and "F" for reduction in standing (regression).

In the example provided in Figure 3, eight of the ten situations have been presented to the crew. In situation No. 1, the crew engaged a fully-exposed T72 target, fired cue round and missed due to an elevation aim error of 21.10 mils low. In situation No. 5, the crew engaged troop (area) targets with the coax machine gun, fired 128 rounds, hit 38% of the target and received a "miss" because 75% coverage is required for a "kill". In situation No. 9, a HIND-D helicopter will appear in 35 seconds at a position five degrees to the crew's right. Situation No. 10 will be a T72 tank which will appear in 83 seconds at a point directly in front of the present viewing point. Additional information presented on this page is the true range of the target and the range input to the computer by the crew's ranging to the target, the mode of operation is normal (no malfunctions), laser is set to First Return, the gunner has main weapon selected and SABOT indexed. SABOT is loaded. All of this data is available to the instructor and is updated in real time. He may use it to cue or assist the crew, or not, as he sees fit.

Exercise Control/Monitoring

The instructor utilizes dedicated keys on a VT-102 auxiliary keypad to control the exercises and the overall conduct of the training session. The auxiliary keypad, shown in Figure 4, allows the instructor to accomplish the following functions:

- Freeze/Unfreeze - Interrupt an exercise at any point in its execution and resume the exercise at the point of interruption. At this point the instructor may critique the crew and then proceed; repeat the exercise from the beginning; playback all or part of the exercise; terminate the exercise; display the performance analysis page at the situation monitor; or print the shot pattern.

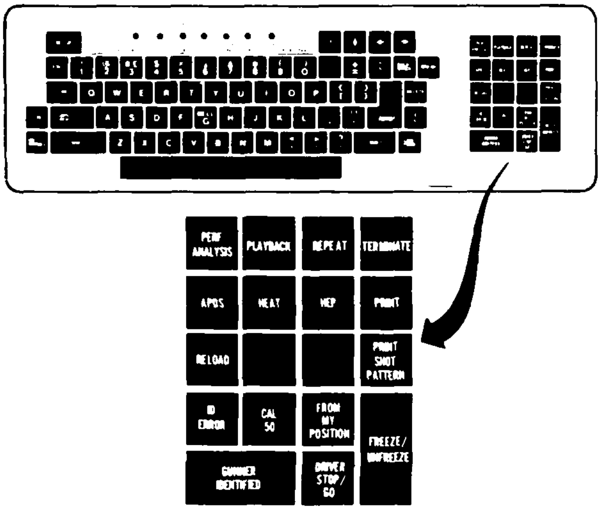
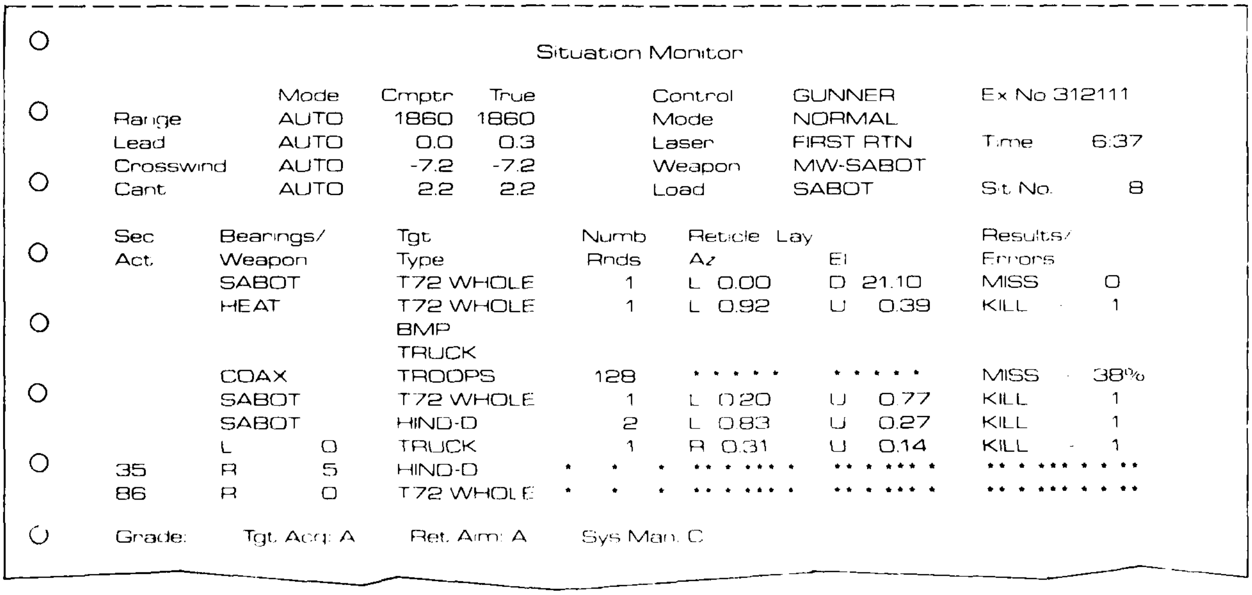


Figure 4. IOS VT-102 Terminal Keyboard Arrangement



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                                Situation Monitor

            Mode    Cmptr   True          Control   GUNNER       Ex No 312111
Range       AUTO    1860    1860          Mode      NORMAL
Lead        AUTO     0.0     0.3          Laser     FIRST RTN    Time      6:37
Crosswind   AUTO    -7.2    -7.2          Weapon    MW-SABOT
Cant        AUTO     2.2     2.2          Load      SABOT        St. No.      8

Sec     Bearings/     Tgt          Numb    Reticle Lay            Results/
Act.    Weapon        Type         Rnds    Az         El          Errors
        SABOT         T72 WHOLE      1     L 0.00     D 21.10     MISS       0
        HEAT          T72 WHOLE      1     L 0.92     U  0.39     KILL       1
                      BMP
                      TRUCK
        COAX          TROOPS       128     * * * * *  * * * * *   MISS     38%
        SABOT         T72 WHOLE      1     L 0.20     U  0.77     KILL       1
        SABOT         HIND-D         2     L 0.83     U  0.27     KILL       1
        L        0    TRUCK          1     R 0.31     U  0.14     KILL       1
35      R        5    HIND-D     *   *   * ** * *** * ** * *** *  ** * *** * * **
86      R        0    T72 WHOLE  *   *   * ** * *** * ** * *** *  ** * *** * * **

Grade:    Tgt. Acq: A    Ret. Aim: A    Sys Man. C
```

Figure 3. Typical Situation Monitor Page

- Record/Playback - Playback all or part of the last ten minutes of all of the visual and aural events for that exercise period
- Exercise Repeat - Repeat the selected exercise from the beginning
- Command Logging - The instructor can log various target identification commands by the crew members during the conduct of an exercise. These include:
  - Identified (gunner response)
  - From my Position (commander response)
  - Driver STOP/GO. In this way the instructor acts as the driver to move the tank to and from defilade, or to halt and resume movement in a moving exercise
  - Cal .50
- Ammo Selected Keys - The instructor may act as the loader by pressing either the APDS, HEAT, or HEP keys when the tank commander announces the round type.
- Reload Key - Removes round currently in the breech and reloads a different type round if so designated by the tank commander. A suitable delay is initiated before the next round can be fired.
- Print - Will print situation monitor or performance analysis page as selected.
- Print Shot Pattern - Prints page containing shot patterns for up to two main gun rounds for each target in the exercise. This pattern will reflect the reticle lay error for each round indicator to an accuracy of 0.1 mil in azimuth and 0.2 mil in elevation.
- ID Error - Allows the instructor to assess a penalty against the crew if an improper target identification has been made.

The U.S. Army is closely monitoring the development of voice recognition technology with an eye toward utilizing this technique to accomplish some or all of the instructor monitoring noted above. Exploratory evaluation of existing voice recognition systems has shown that U-COFT needs for connected/continuous voice recognition cannot be fulfilled at present. However, the software currently used for implementing the various keyboard functions is designed to easily accept the addition of voice recognition when such technology is sufficiently advanced to warrant it.

[illegible]

[illegible]

But the [illegible] training [illegible] the computer [illegible] handling and record keeping task.

When field deployment of the U-COFT begins in [illegible] Army Armor and Infantry battalions will have a trainer that has been found to be effective at developing, improving and [illegible] crew gunnery proficiency. Most significantly, any increase in combat readiness that results will be gained with substantially fewer dollars -- dollars saved in ammunition, fuel, range space costs, and vehicle maintenance.

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INCREASED READINESS THROUGH MODULARITY

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ABSTRACT

A current DOD thrust to develop and apply modularity approaches, tools and standards to training simulator development and acquisition is expected to yield benefits in reduced cost and acquisition time as well as improved supportability. Top-down functional design of stand alone modules and well-defined interfaces will enhance simulator system designs. This paper examines the effects and benefits of modularity which are expected to increase readiness through earlier trainer availability dates and increased supportability. The derivative effect of modularity appears to provide new options that can operate to support increased defense readiness.

INTRODUCTION

The U.S. Government has recently launched a modular simulator design development program. The present effort focuses on aircrew training simulators. Several factors and considerations appear to have influenced this initiative.

Emphasis on ground-based training for the full military aircrew complement has led to the development of complex training systems. In turn, technical and management challenges for procurement agencies, and the simulation industry have resulted, such as:

- Trainers cost more than expected
- Trainers take longer to develop than expected
- Trainer supportability does not meet expectations

Seeking ways to meet these challenges and in light of the success of the Air Force's Modular Automatic Test Equipment (MATE) program, a government decision was made to investigate the advantages of modularizing simulators starting with aircrew trainers. DOD procures, operates and supports a large number and a wide variety of training equipment and could conceivably benefit from the establishment of modularity standards. Envisioned is a program conceptually similar to the current MATE program. Potential benefits include:

- Reduced cost
- Reduced development time
- Improved supportability
- Improved modification capability

If these benefits are realized with the eventual development and application of modular simulator design standards across industry, then it appears likely that another important benefit will result—defense readiness will be increased.

As an example, in a related program the readiness benefit envisioned by the contractor responsible for the MATE program was that the defense mission is better fulfilled through

- Simpler skills and training because of computer-simplified test procedures, common hardware, procedures, and documentation
- Reduction of false rejects
- Eliminating unneccessary troubleshooting

These benefits are for MATE but do indicate general readiness improvement potential for application of modular principles to simulator development.

DEFINITION OF TERMS

Modular simulator design, or modularization, is defined as the organization of subsystem/hardware/software components into standard units. This involves breaking the flight simulator package down into cohesive blocks (modules) of equipment or software with standards for control of design and acquisition of the modules. Using this approach, any number of modules can be readily integrated to form a new simulator, thereby using known hardware and software with performance results predictable in advance.

Readiness is a complex term and implies different things under different conditions. For our present purpose, readiness is defined as the state of being prepared and able to do the assigned mission without serious limitations. That is, whatever the organizational level or military service, the equipment is ready, the crews are trained and the logistics support is available. There are states of readiness such as "day-to-day" readiness and "crews sitting on the runway." There are levels of readiness such as employed by SAC. But what we basically mean by readiness is "ready and able."

ANALYSIS OF MODULARIZATION BENEFITS

What usually motivates investment of time, energy, or money is the potential payoff. We can better visualize this payoff for the eventual application of the modular simulator design approach as shown in Figure 1. That such benefits can be realized from using the modularization approach is supported by the relative benefits achieved from modularization in an Automatic Test Equipment (ATE) product line, as shown in Figure 2.

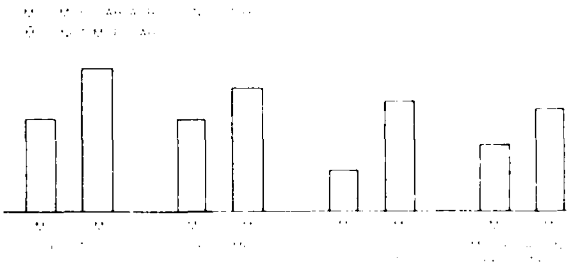

Figure 1 Relative Benefits of Modular Simulator Design Approach Application (Conceptual)

The favorable influence that modularization of training simulators could have on readiness is shown in Figure 3. However, modular simulator design does not automatically buy improved readiness. To realize such improvements will require some consideration for factors that link potential modularity benefits with readiness improvements. This consideration will involve both the government and industry. To illustrate: The involvements and benefits expected from the MATE

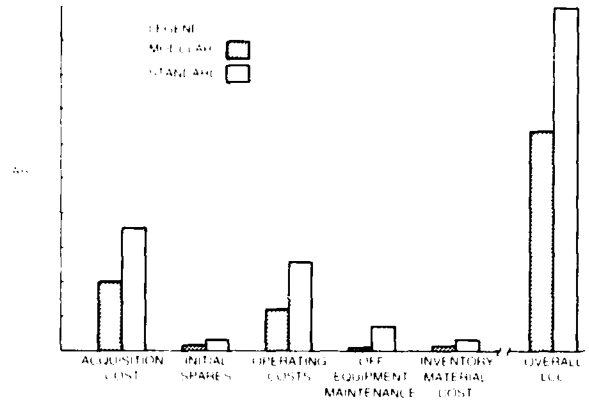

Figure 2 Relative LCC Comparison of Modular vs Standard ATE Design

SOUGHT BENEFIT OF SIM MODULARITY	RESULT	POTENTIAL IMPACT ON READINESS
REDUCED COST	AVAILABLE FUNDS OPTION	OPTION FOR REALLOCATION OF FUNDS TO FURTHER IMPROVE OVERALL DEFENSE READINESS
REDUCED DEVELOPMENT TIME	EARLIER DELIVERY OF TRAINING SIMULATOR OPTIONS	SYSTEM PERSONNEL READY TO PERFORM MISSION SOONER, BETTER AND MORE SAFELY
IMPROVED SUPPORTABILITY COMMON HARDWARE, PROCEDURES AND DOCUMENTATION REDUCED PARTS INVENTORY TRANSPORTABILITY REDUCED SKILLS REQUIRED	OPTIONS TO 1 REDUCE SUPPORT PERSONNEL SKILL LEVELS AND NUMBERS 2 STREAMLINE PARTS SUPPLY SYSTEM 3 INCREASE SUPPORT FLEXIBILITY 4 INCREASE TRAINER AVAILABILITY FOR TRAINING 5 REDUCED SUPPORT COSTS	BETTER SUPPORT — MORE AND BETTER TRAINING + LESS PRIMARY SYSTEM USE REQUIRED FOR CREW TRAINING — PRIMARY SYSTEM IN BETTER CONDITION FOR DEFENSE MISSION ALERT
IMPROVED MODIFICATION CAPABILITY	OPTIONS FOR SIMPLER, EARLIER AND LESS EXPENSIVE SIMULATOR UPDATES FOR CURRENCY WITH PRIME SYSTEM CHANGES	CREWS ORIENTED QUICKER TO SYSTEM CHANGES PROVIDING IMMEDIATE IMPACT OF CHANGE FOR UNINTERRUPTED READINESS

Figure 3 Modular Simulator Benefits Lead to Options Having Potential Impact on Readiness

program is exemplified in a 1980 AIAA paper by WPAFB logisticians, Lt. Col. Byrne and Capt. Allen, where they, in part, conclude:

> "MATE can make affordable automatic testing a reality for the Air Force and offers numerous collateral benefits. However, standardization, especially during this transition, will not come easily."(1)

These authors enumerate many expected benefits from the point of view of government and commercial developers, the military user, and the logistics supporter. In order to see the origin and sequence of the development of benefit options better, we will next look at one approach to the modular simulator design concept development program.

MODULAR SIMULATOR DESIGN APPROACH

This approach employs a disciplined systems engineering structure to take full advantage of the value of this process as a means of providing an unbiased, logical framework for conducting the modular simulator design concept definition (Figure 4). The approach is divided into five broad functional areas (Figure 5):

- Design concept definition
- Design concept application
- Impact definition
- Implementation planning
- Concept documentation

Design Concept Definition

The concept definition begins with a top-down functional analysis that considers existing functional groupings, identifies operational performance requirements and determines the specific capabilities needed to satisfy the functional requirements. The output representing an aircrew simulator functional analysis, is utilized to formulate the preliminary modularity concept in concert with the initial module selection criteria. Special emphasis is placed on the resolution of hardware/software module levels that meet the functional performance requirements yet minimize any effects of modularity on technological innovation and development.

Design Concept Application

The preliminary module selection criteria, developed during design concept definition, is applied to selected Weapon System Trainer (WST) programs to provide additional design insights and validation opportunities. The physical and functional interface definition is explored in terms of establishing a concept that will standardize and simplify both the physical and functional aspects of a modular design. The preliminary output is tested by further application of these concepts to the selected WST. In addition, an existing set of physical functional interface criteria, developed in support of ongoing company modularity research and development programs, serves to further refine the candidate approaches for an industry-wide application.

Impact Definition

During impact definition, the impact on module testing/qualification, Higher Order Language (HOL), logistics, aircraft equipment and existing simulator modularity elements are assessed. Knowledge of military systems and proven logistics models are applied toward an objective evaluation of the modularity impacts. This approach to module testing and qualification is refined through development of a list of requirements based on the final selection criteria and the selected interface approach. Development of implementation tools parallels this activity. The output is a plan that clearly defines the path to module qualification. An assessment of the interrelationships between the modularity concept and related support elements is conducted with impacts being defined and quantified in terms of cost, availability and manpower. Additional impact assessments are conducted relative to the use of HOL and Ada languages on military simulators. Cost data generated in the preceding areas is used to assess the impact of the modularity concept on aircraft equipment and the results quantified in terms of capabilities which may be built into aircraft systems to support simulator modularity as well as any impact on acquisition and life cycle costs.

Implementation Planning

Recognizing that the success of the simulator modularity concept is dependent on an effective and appropriate management system, planning is developed that establishes a viable schedule for phase-in/out of simulator modules/standards, the required management structure and modularity tools. Close coordination with the government is imperative in this process. Implementation costs are developed using proven cost estimating methods for development, production, and operations and support elements. A follow-on phase plan is to be developed to provide for the redesign of an existing simulator, testing/qualifications of the resulting modules, integration of modules into a training system and validation of the modularization tool system performance.

Concept Documentation

As the final action, a technical report is prepared which will present a complete and comprehensive documentation of the modularity approach. This report includes statement of work and associated specifications as well as the procedures, processes and rationale used in conducting a follow-on study.

ANALYSIS OF AIRCREW TRAINING SIMULATOR FUNCTIONS

System engineering techniques and procedures are used to conduct a top-down functional analysis of aircrew training simulators. Existing functional grouping concepts used in all levels of training devices are considered during this analysis. However, these grouping and module concepts are not considered as constraints on the functional analysis. For example, Figure 6 illustrates two potential modularity approaches to a given aircraft multifunction training application.

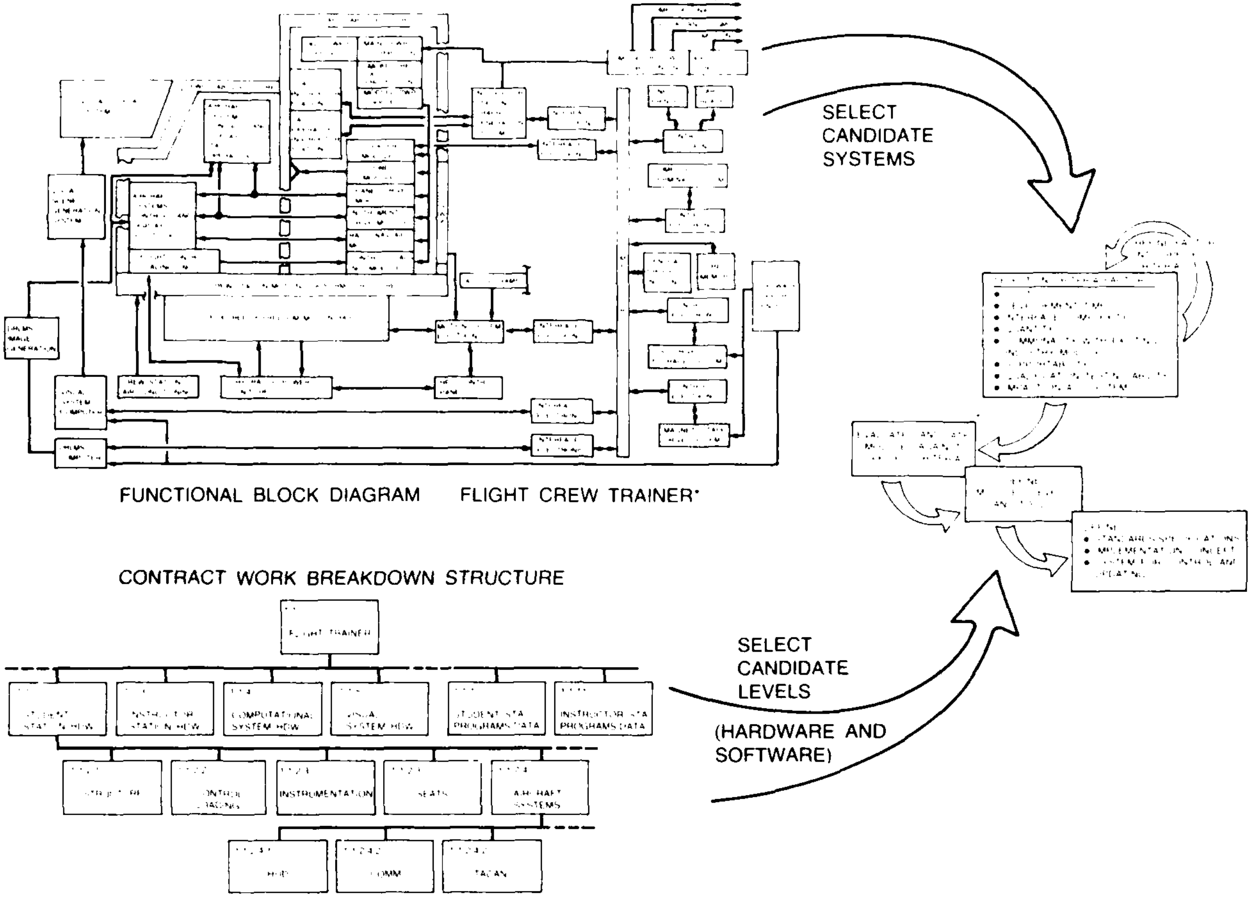

Figure 4 An Approach to the Modular Simulator Design Concept Development Program

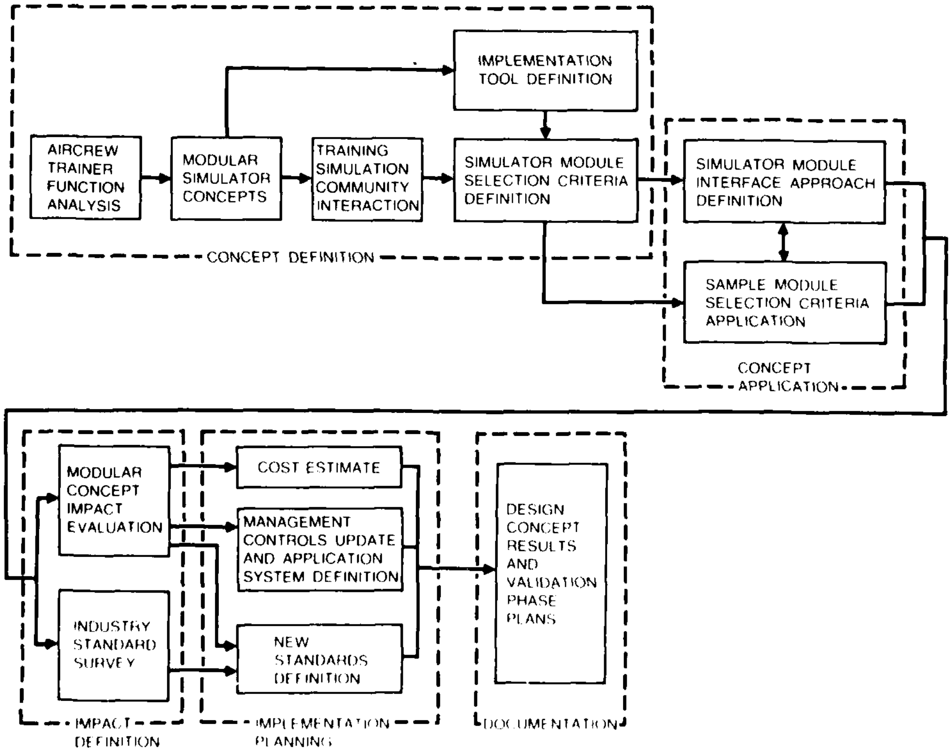

Figure 5 Modular Simulator Design Concept Development Road Map

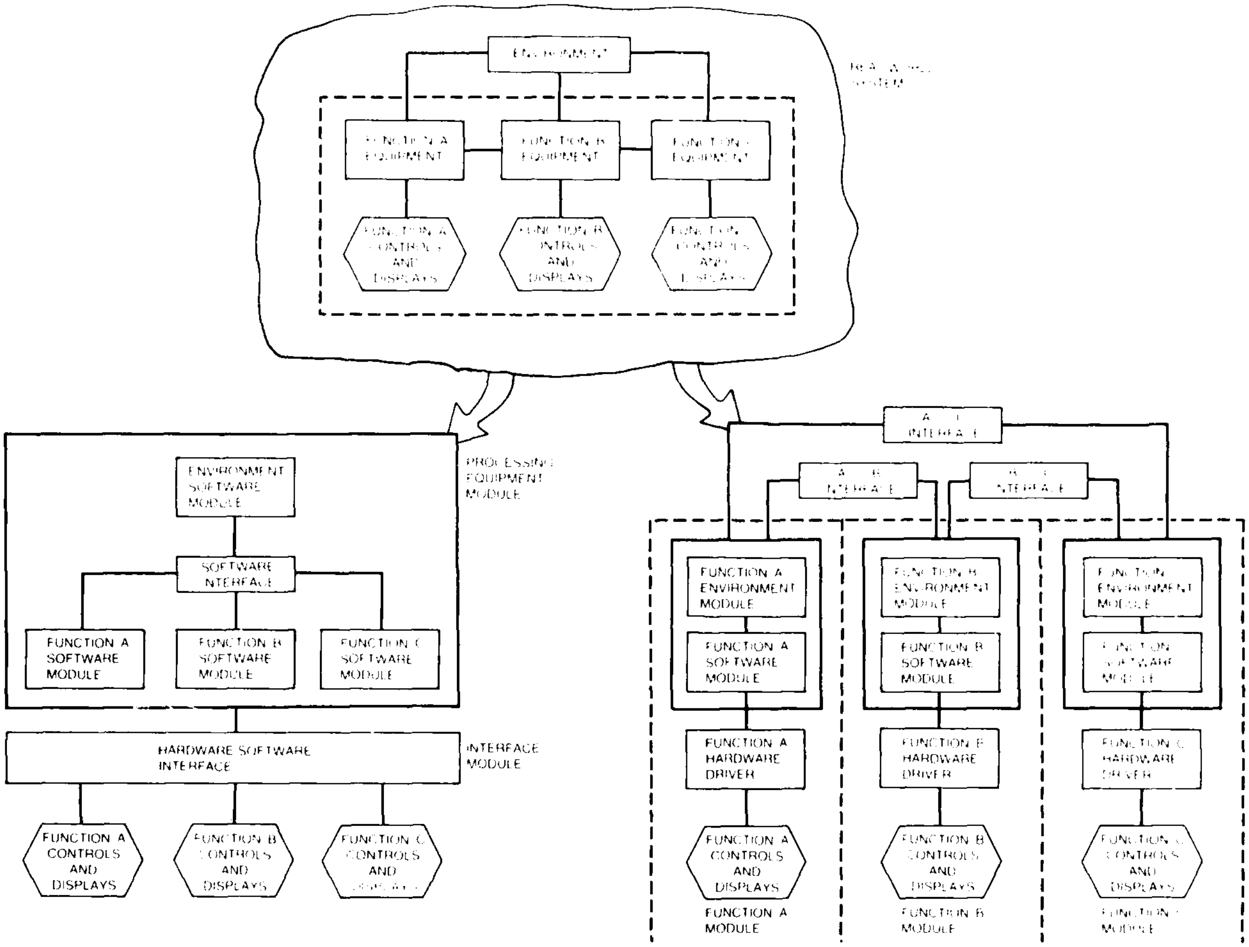

Figure 6 Two Potential Modularity Approaches

The first approach is representative of current training simulation technology. In this approach major system modules perform common simulation tasks across all simulated aircraft functions. Computational processing and hardware/software interface equipment are treated as major system modules. Individual software and hardware modules at a lower level simulate the aircraft/system functions.

An alternative approach might involve modularization by aircraft/system function. In this approach, all necessary processing hardware and software, interface and control/display capability for a particular subsystem would be contained within a given function module. In this case, it would be extremely important to identify and specify a flexible, common interface to communicate between system modules. In current applications, visual, DRLMS and motion systems lend themselves well to modularization at this level. Extension of this type of function/module allocation to other training subsystems such as instructional, environmental and aircraft systems simulation are considered.

Operational performance requirements for military training simulators are identified, including the support requirements necessary to maintain the operational capability of these systems. Operational constraints are also defined. This analysis determines how each function is performed and considers feasible alternate combinations.

Capabilities required to satisfy identified functional requirements are determined by:

- Examining each system function to determine the kinds of capabilities needed to meet training simulator performance requirements.
- Exploring possible combinations of functions which provide the required performance capability, while simplifying the interface complexity.

Potential modules and functional groups of modules are then allocated to the identified functions and required capabilities. A similar process was followed in using MATE guides to simplify interfaces as those shown in Figure 7.

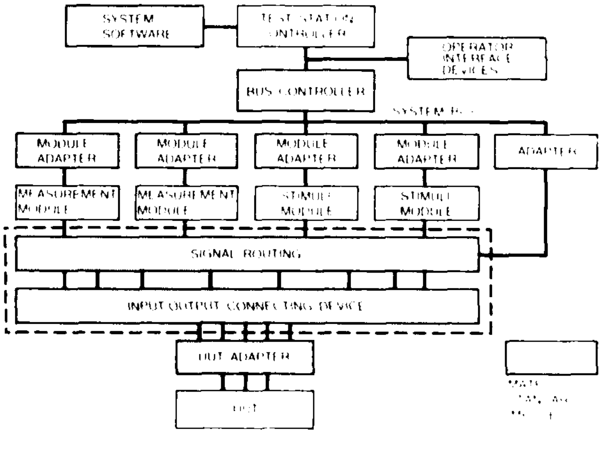

Figure 7 MATE Standard Interfaces

CANDIDATE MODULE GROUPING

Candidate groupings of potential modules are prepared from the aircrew simulator functional analysis previously discussed. These candidate groupings, taken from a cross section of simulation and aircraft industries are documented in terms of functional capability and interface descriptions. Examples of the results of such groupings are shown in Figure 8 for a flight crew trainer. Development of the candidate groupings goes hand-in-hand with development of the candidate levels discussed in the subsequent section.

Sensor simulation systems, such as visual Computer Image Generation (CIG) and Digital Radar Land Mass Simulation (DRLMS) systems, provide good examples of potential candidate modules.

Sensor simulations incorporate Digital Data Bases (DDBs) which provide a processor-compatible earth topography model to be used in generation of simulated visual/sensor imagery. Historically these DDBs have been quite different between suppliers and even between the individual sensor simulation types of a particular contract. This has been due primarily to the fact that DDBs were a result and not a requirement of the sensor simulation design process.

Improvements to digital processing state-of-the-art have removed many of the constraints on sensor simulation processing, raising the possibility that the DDB could become the standard component or module around which new CIG, DRLMS and other sensors are designed. Figure 9 shows a potential approach whereby an integrated data base generation/support system could be employed to support a number of sensor simulations.

A modularity approach whereby the DDB is considered a standard "module" may provide both training fidelity and supportability benefits. Since the DDBs for these simulations provide real-world terrain references and since multiple sensor simulations may be active simulataneously, this approach would provide a high degree of correlation between the individual simulations. Additionally, the necessity to create, maintain and support a number of separate DDBs would be reduced or eliminated.

In this example, it is important to note that any standardization of the DDB would have to be carefully applied to data base content and format and not to specific media. Advancements in laser-optical, bubble memory, and other high density bulk memories would quickly cause the obsolescence of any media standardization. Sensor simulation systems present other possibilities for modularity beyond the DDB since processing subsystems such as line-of-sight, coordinate transformation, data retrieval and memory management subsystems perform largely the same function regardless of application.

MODULAR LEVEL DEFINITION

Development of the candidate levels is an iterative process which is initially derived from the top-down CWBS examination of the typical trainers in conjunction with the functional analysis of the natural interface groupings. However, the ultimate definition of the modularity levels comes concurrently with the definition of the modules themselves through repeated refinement and application of the module selection criteria. Two considerations in level selection discussed here are (1) future industry innovation impact and (2) module complexity.

Innovation Impact

The interplay between a specific modularization concept and future technological innovation is a subject requiring special emphasis and insight. In most areas of technology the simulator industry uses the latest "state-of-the-art" techniques and will probably continue to do so; however, the industry is not generally in itself a significant technology driver. The only major exception is that of sensor system (visual/digital radar landmass simulation) in which new techniques such as laser scanners are under development. If modularity is standardized incorrectly, the ability of industry to use state-of-the-art innovations will be inhibited. Ideally, from an innovation viewpoint, the modular simulator design concept should standardize interfaces but allow total freedom of design within the module. If the standardization dictates the internal design of the ERU, innovation flexibility is lost. It appears that the most important level(s) at which to apply the innovation freedom is a combination of the system level and the ERU level.

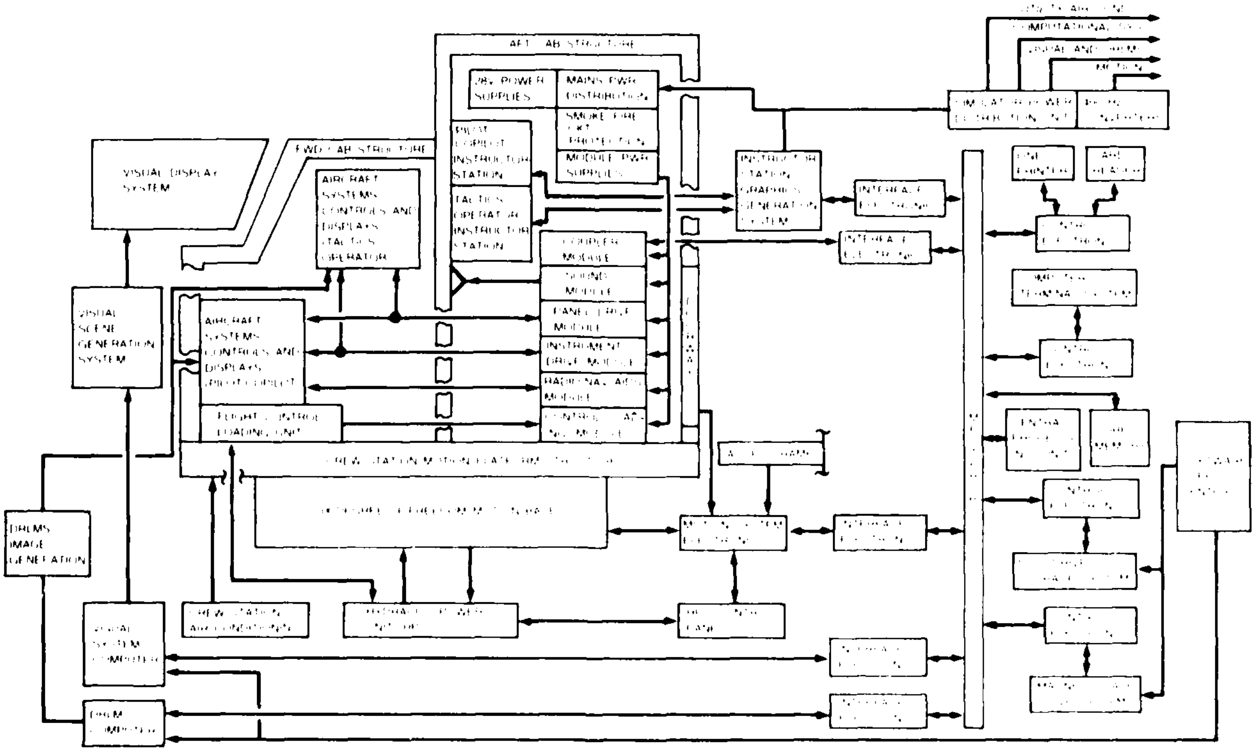

Figure 8 Flight Crew Trainer Module Grouping Example

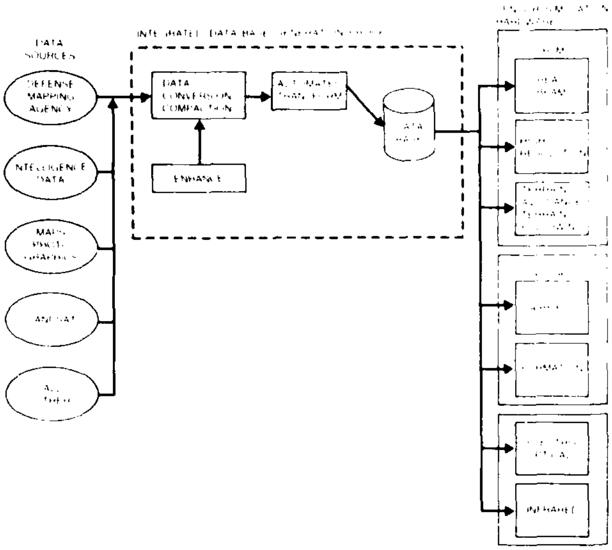

Figure 9 Data Base Driven Sensor Simulation Example

Module Complexity

Module levels are also resolved in light of both hardware and software complexity needed to meet the functional performance requirements. For example, if trainer A requires only 50 percent of the performance capability of trainer B in a particular module or module grouping, does trainer A pay the overhead of carrying the additional capability for the sake of standardization or go to the next lower level and still select standard modules to provide the required level of capability? An example of software levels is provided in Figure 10.

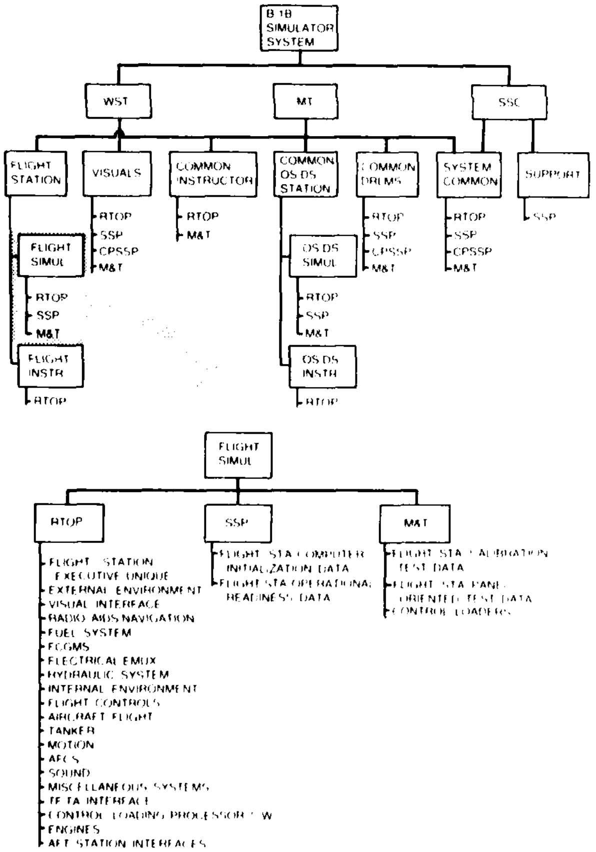

Figure 10 Example of Computer Program Modularity Levels

OTHER MODULE DEVELOPMENT CONSIDERATIONS

The purpose of this paper and space/time limitations do not allow a full description of the process of development of the modular simulator design approach. However, this approach includes

- An industry survey
- Implementation tools definition
- Module selection criteria development and use
- Modular design concept applications
- Logistics considerations
- Development and validation of modular simulator design tools

Now that we have reviewed an approach to the development, and to some extent, the application of modular simulator design concepts, we have a better foundation to visualize how modularization benefits can be linked to readiness.

ANALYSIS OF MODULARITY/READINESS RELATED BENEFITS

Some modular simulator design application benefits may well provide fallout readiness benefits without specific plans, decisions, or actions. We can be satisfied with that, or we can thoroughly analyze all potential links between modularization and readiness benefits and plan to enhance the value of simulator modularization benefits that improve readiness. The key is to recognize the improved (or increased) decision-making options in working alternatives. For example, in Figure 3 if the sought benefit of reduced cost is realized, this leads to an "available funds" option. These would be government funds that could, by decision, be left unused or used for any other purpose within the fiscal constraints. In this case, the only way to enhance readiness is to reallocate saved funds to a readiness cause. A second example from Figure 3 is the earlier delivery of training simulator option which is possible when development time of a simulator is reduced through modularization. If this benefit is expected and the decision is made to start the training simulator development later, by the number of months saved, then of course the modularized simulator trainer would be delivered at the same time as the unmodularized simulator trainer, and there would be no beneficial impact on readiness from that modularization benefit. The point is, that only if the appropriate decision-makers are aware that such options exist and that there is a plan in effect that states a requirement to weigh such factors in their decision-making consideration, will some potential readiness benefits be able to be realized from modularization.

On the whole the derivative effects of modularity appears to provide new options that can (or can be made to) operate to support increased defense readiness.

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A FOUR-DIMENSIONAL THUNDERSTORM MODEL FOR FLIGHT SIMULATORS

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ABSTRACT

The recent airliner crash at New Orleans indicates that windshears due to thunderstorm downbursts challenge the most experienced and well-trained pilots. Much controversy exists as to the correct flight procedures for takeoff and landing under downburst windshear conditions. Flight simulators provide a safe environment to test procedures and train pilots for hazardous flight situations, but in the past, flight simulators have been unable to realistically duplicate the complex changes that occur temporally and spatially in real-world thunderstorms. A thunderstorm model based upon real-world data has now been developed for flight simulators, which provides twelve meteorological flight parameters which change in three-dimensional space and over a thirty-minute time span with color weather radar representations of the storm coordinated in time and space. The storm data set (representing a 20nm x 20nm x 3200-ft volume) is based upon multiple Doppler radar analyses of a 1978 Illinois thunderstorm. This data has been supplemented by a well-documented, fine resolution, downdraft model to provide realistic values in the hazardous regions of the sudden downdraft and its resulting turbulent gust front. By selecting different downdraft intensities and storm translational speed, the instructor may simulate a mild thunderstorm or one in which it would be impossible to fly. By positioning the storm's downdraft with respect to the runway in time and space, numerous different thunderstorm situations may be simulated. This thunderstorm model represents a breakthrough in the simulation of the storm environment and four-dimensional windshear effects for flight simulation.

INTRODUCTION

Weather remains an unknown factor at all levels of aircraft operations, from the military to general aviation. Aircraft accidents result from many contributing factors, but over 50 percent of commercial aircraft accidents are weather-related. Accidents continue to occur despite many recent technological advances in storm detection equipment and despite increased knowledge of hazardous flight conditions, especially around thunderstorms. Pilots have generally gained knowledge of hazardous weather conditions through actual flight experiences rather than through flight simulator experiences, because of the inadequacies of older simulators in portraying real-world weather effects.

Flight simulators have provided a safe environment for pilot training in many hazardous situations, such as an engine out on takeoff or a blown tire on landing, and have also been used to help determine correct flight procedures for such emergency situations. Flight simulators might be used to unravel the mysteries of recent accidents such as Eastern 66 at JFK or Pan Am 759 at New Orleans, in which windshear may have worked in concert with heavy rain to produce aerodynamic penalties. Flight procedures in downburst windshear situations are presently being reviewed in light of information from investigation of recent crashes. But simulators could provide false training if inadequate or incomplete data has been used in modeling the hazards.

Real-world meteorological data at the time of aircraft accidents is always sketchy and incomplete since it is derived primarily from flight recorder data in which separation of weather effects from pilot effects on the recorded motion of the aircraft is difficult. Precipitation rates are usually estimated from cockpit voice recorder sounds, occasional eyewitness accounts, and very coarse resolution ground weather radar returns. The coordination in time and space of the many weather effects is difficult to verify, yet this is the primary type of data that has been available for implementation in flight simulators. Thunderstorm windshears are very complex, yet most thunderstorm simulations have consisted of one-dimensional data along fatal flight paths.

The recently developed multiple Doppler radar techniques have begun to unlock our understanding of the complex internal circulations of thunderstorms. By combining the radial wind components from two or more Doppler radars which are scanning the same storm volume from different perspectives, computer analysis may yield three time-variant wind components at every grid point (typically 0.8 km). Meteorologists use these winds to extend their knowledge of the thermodynamic forcing of thunderstorm circulations. Simulators could use this data to help train pilots about thunderstorms.

BACKGROUND

The complexities of thunderstorms present a substantial challenge to the training and simulation community. The thunderstorm is a dynamic, highly variable entity which translates rapidly across the ground while growing and decaying vertically and horizontally, resulting in constantly changing internal and external characteristics.

Even the simplest thunderstorm, the airmass thunderstorm, goes through a series of stages during its 20- to 40-minute life span (Figure 1). During the initial, or cumulus, stage, the storm consists primarily of a warm, moist updraft in which cloud droplets grow into supercooled raindrops as they are swept up beyond the freezing level. As the raindrops grow too large to be supported by the updraft, they fall and drag the air along to produce a strong downdraft, characteristic of the mature stage. As drier outside air is entrained, it is cooled by the evaporating raindrops, strengthening the downdraft and producing strong winds and heavy precipitation at the surface. During the dissipating stage the downdraft becomes more extensive, the updraft is shut off, and, as the storm begins to self-destruct, the precipitation soon ceases and, afterwards, the cloud itself begins to dissipate.

If the winds surrounding the storm permit, a thunderstorm may become better organized by separating the updraft from the downdraft, resulting in storms that may last 4 to 6 hours. These more severe thunderstorms usually consist of more than one updraft and downdraft pair, and often occur in a line or group of similar thunderstorms. A severe thunderstorm may produce hail and very strong surface winds, even a tornado. The supercell thunderstorm may last 5 or more hours and produce large hail and multiple tornadoes. The largest and most hazardous storms have been well studied by federally funded research projects which use ground-based meteorological networks in conjunction with research aircraft and multiple Doppler radars. But these storms are so large and infrequent that most area airports would have already been closed to air traffic.

The innocuous appearing thunderstorm can also provide very hazardous situations for an aircraft on takeoff, approach, and landing. Heavy rain produces severely limited visibility, while strong windshears and turbulence challenge the flight crew during very critical periods of decision-making. The thunderstorm downdraft (or more severe downburst or microburst) spreads out near the ground to produce a turbulent gust front which can extend 10 to 15 nautical miles away from the precipitation area (Figure 2). Strong vertical and horizontal windshears and turbulence are created as each heavy rain episode produces a surge in the gust front.

Thunderstorms develop very quickly under optimum conditions and can produce rapidly changing local effects. The innocent little shower that occurred at the loading dock may have developed

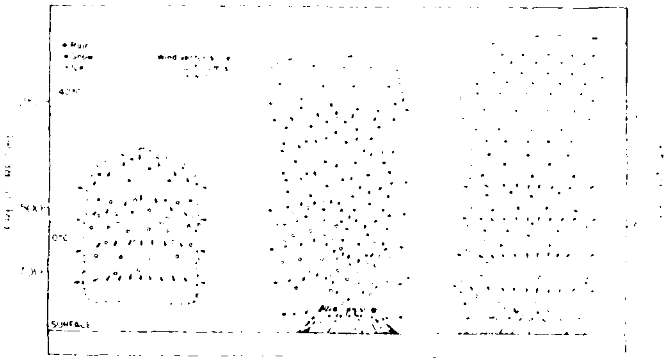

Figure 1 SCHEMATIC DESCRIPTION OF THE THREE STAGES OF THE LIFE CYCLE OF A TYPICAL AIRMASS THUNDERSTORM
(Adpated from "The Thunderstorm," U.S. Government Printing Office, 1949.)

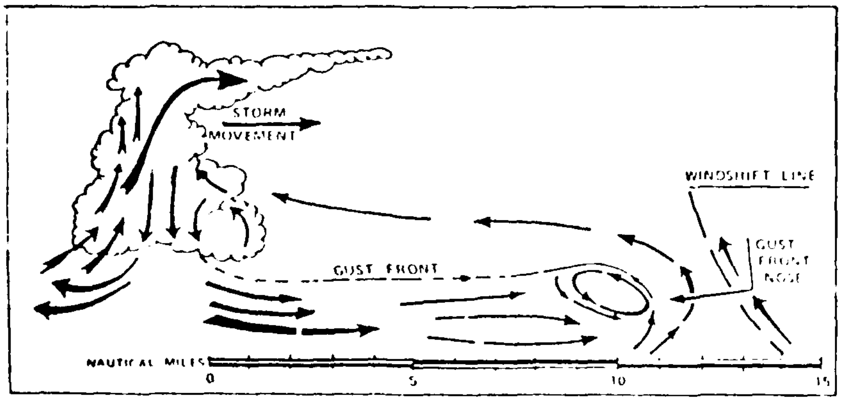

Figure 2 SCHEMATIC DESCRIPTION OF A THUNDERSTORM GUST FRONT

a strong downburst during the taxi to the end of the runway. As an aircraft begins its takeoff roll a strong gust front could be moving across the far end of the runway. A realistic thunderstorm simulation needs to account for these very localized and dynamically changing characteristics.

Real-world thunderstorms are highly varied and any simulated thunderstorm must provide enough variability to provide a challenge to a pilot's recall. At the same time, maximum training usage requires a high degree of repeatability, especially if the simulation is being used as part of a pilot's certification. The FAA, as part of its Phase III simulation certification, has required that certain weather effects be displayed visually and aurally and on weather radars used as part of a pilot's navigational instruments.

As in any simulation, all the visual, aural, and motion cues must be fully coordinated or false training will occur, but few simulator instructors have the meteorological training to control the correct timing of the many thunderstorm effects. Instructors should be allowed to concentrate on supervising the training session rather than being burdened by a complicated series of tasks to create the effects desired. For example, an instructor should just select a weather radar display of a thunderstorm without concern that the radar echo will initially appear at the correct altitude and grow vertically and horizontally in coordination with the changing updraft structure. Yet instructors need to have overall control of storm selection, initial location, movement, development stage and intensity, all of which must remain within typical real-world thunderstorm values.

Now a thunderstorm simulation model has been developed which can realistically duplicate real-world thunderstorm characteristics important to flight training and which can meet the training requirements of instructor control of repeatability and variability. This is a terminal area thunderstorm simulation suitable for FAA Phase II, III, and LOFT applications.

THUNDERSTORM ENVIRONMENTAL MODEL

The thunderstorm environmental model simulates the low-altitude flight environment of a moderate to severe thunderstorm for an aircraft on approach, landing, and takeoff. This terminal area simulation model contains a strong, small-scale downdraft which penetrates to the ground, forming a time-variant gust front which travels and grows along the ground. The entire simulation model provides outputs which vary according to the aircraft's position in three-dimensional space and time. The model is based upon triple Doppler radar observations of a typically moderate Spring thunderstorm which occurred during 1978 outside Chicago, Illinois.

This particular thunderstorm had a 33,000-foot radar top and showed reflectivities of up to 60 dbz, indicating heavy precipitation rates were present. This thunderstorm contained updrafts on the order of 40 ft/s and downdrafts of about 26 ft/s. A prestorm meteorological sounding provided the temperature, humidity, and wind structure surrounding the storm. Data tapes from triple Doppler radar analyses, containing mean horizontal wind velocities at about 2,600-foot resolution, were used as the basis of data generation.

Most radar analyses have difficulty with low-altitude, small-scale phenomena which are critically important to a terminal area flight simulation. Ground clutter destroys much of the value of the low-altitudes returns which are close to the radar. The large horizontal resolution of most radars masks many fine details in the wind structure being analyzed. In this thunderstorm downdrafts may have existed at a few locations but none were resolved well enough for simulation purposes. One of the most probable locations was selected and a mathematical downdraft model was used to provide the fine resolution required for simulation of the downdraft and its resultant gust front over a 30-minute time span.

This second-order closure turbulence model provides data which corresponds well with published real-world thunderstorm data. The downdraft model provides vertical and horizontal wind components, temperature and pressure deviations, three turbulence rms values, and a scale length at each point in the downdraft grid. The axisymmetric downdraft model extends to about 30,000 feet and resides within the larger (20 nm x 20 nm x 3,200-foot) storm data box.

Data within the storm box was derived from the triple Doppler radar horizontal wind components and the prestorm sounding. Vertical velocities were derived by integration of the inelastic continuity equation. These vertical velocities and the prestorm sounding were used to create the overall temperature and pressure deviation fields within the storm box. Turbulence was assumed isotropic outside the downdraft region and turbulence rms values were calculated by stress analysis of the wind components within the storm box.

If the aircraft is within the downdraft region, both data sets are combined to provide the final environmental data. To avoid counting velocities twice, the storm box values within the downdraft region have been adjusted so that mass continuity is maintained. Precipitation rate and visibility were derived from radar reflectivity data using a convective precipitation rate formula. Final outputs of the thunderstorm environmental model include three components of wind, three turbulence component rms values, turbulent scale lengths, temperature, pressure, precipitation rate, and meteorological visibility.

The downdraft and storm box data sets are compressed for disk storage and are accessed only as required by aircraft movement through the downdraft and storm box. The downdraft data set is composed of ten data files at 3-minute intervals and each file contains eight variables at each of the 1,024 data points. The storm box data set consists of eleven 3-minute time files, each with 4,418 data points containing 9 variables. The thunderstorm environmental model is programmed in FORTRAN.

The instructor controls the location and orientation of the entire storm box and may start the simulation during any portion of the 30-minute time period. The instructor selects the storm translational speed and direction and a downdraft intensity, which are limited to real world values. By selecting different downdraft intensities and translational speeds, the instructor may simulate a mild thunderstorm or one in which it would be impossible to fly. By positioning the storm box with respect to the runway in time and space, numerous different thunderstorm situations may be simulated. Because the model provides outputs which vary in both time and space, a pilot executing a go-around maneuver would find the storm had dynamically changed in strength as well as location. In fact, a pilot could wait before takeoff as the thunderstorm passed over, and feel the turbulence, winds, and precipitation effects change while remaining on the ground. The thunderstorm environmental model represents a major breakthrough in the simulation of the storm environment and four-dimensional windshear effects for flight simulation.

TOTAL SIMULATION

To complete the realistic simulation of a thunderstorm, other visual and aural cues are provided. Color weather radar echoes are displayed which dynamically change in size and are coordinated in time and space with the meteorological outputs. The radar echoes appear initially at the correct altitudes and grow and decay vertically and horizontally with time. The individual cell echoes may translate and rotate in real time. The color weather radar simulation includes beam spreading, and range and precipitation attenuation effects.

The precipitation rate output from the thunderstorm model is used to simulate the sound of rain or hail in the cockpit. Wind and turbulence components can be used to provide sound directionality. The sight and sound of thunder and lightning under the instructor's control are being developed. Visibility effects are simulated as the aircraft enters precipitation. A visual thunderstorm display is being developed to provide a distant view that might be observed on approach.

CONCLUSION

In order to provide correct training, it is important to use real-world data in simulation. The complexities of thunderstorms require a large dynamic data base which can coordinate the many required effects and free the instructor to supervise the training session. Recent Doppler radar analyses of thunderstorms can now provide data bases suitable for simulation, making simulator training for realistic hazardous weather flight procedures now possible. It is most important that a dynamic physical model of a thunderstorm provide outputs to other visual and aural systems in order to create a comprehensive and coordinated simulation.

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THE PROGRAM PLANNING REVIEW (PPR)

"- - MILESTONE OR MILLSTONE" ?

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ABSTRACT

Current Air Force practices invoke the Program Planning Review (PPR) and its associated data submissions and review meetings on all new simulator procurements. The PPR, as defined by Air Force policy, provides both the contractor and Air Force program offices with insight into the program plans to insure successful completion of all contract objectives.

The PPR requirements have been the subject of recent comments, studies, and reviews. The resulting opinions have consistently questioned the "need" for the in-depth planning and related data submissions required to support the PPR Milestone within the first four months after contract award. The arguments both for and against concern the quantity of data submitted, the number of reviews scheduled, and the resulting impact on the contractor.

This paper summarizes the successful completion of the PPR requirements on a current Air Force simulator contract where proper preparation and implementation of the program plans by the contractor, and prompt, explicit review by the government, resulted in a program baseline which has met all cost and schedule objectives to date.

INTRODUCTION

The Program Planning Review (PPR) -- is it a new milestone or another millstone? Technical Reviews conducted in accordance with MIL-STD-1521 to assess the degree of completion of major technical milestones, have been a normal part of Air Force procurement practices for many years. We are all familiar with the System Requirements Review (SRR), the Engineering Design Review (EDR), the Preliminary Design Review (PDR), and the Critical Design Review (CDR). Although many view these technical milestones as the most important events in a design and development project, their success can only be as good as the underlying planning leading up to their execution. The Air Force has formally recognized this planning need within the past couple of years via the implementation of the Program Planning Review milestone.

The Air Force defines the Program Planning Review as a milestone which provides executive level management, in both the Air Force and contractor organizations, with insight into the program planning and overall management approach to be utilized in executing the requirements of a particular contract. Execution of this milestone has now become a standard part of all Air Force simulator procurements. Normally the Air Force requires that the PPR be conducted early in the program, i.e., within the first 110 days of contract award. Successful completion of the milestone is normally defined as submission, review, and approval of several contract data items; the execution of a formal meeting at which the contractor presents his Program Management Plan; and the completion of an executive level session attended by contractor and government management to critique the activities leading up to the PPR Milestone.

PPR DATA REQUIREMENTS

Air Force operating instructions normally specify that certain specific planning documents be delivered, reviewed by the government and deemed satisfactory, before the Program Planning Review milestone can be considered complete. The F-16 Digital Radar Land Mass Simulator (DRLMS) Contract, executed in 1981, included a collection of most of the plans required for the standard PPR milestone as follows:

1. Configuration Management Plan (DI-E-3108)
2. Program Milestones (DI-A-3009/M2)
3. Integration Support Plan (DI-L-30318)
4. System Test Plan (DI-T-3701A/M1)
5. Technical Manual Plan (DI-M-6154)
6. Computer Program Development Plan (DI-F-30567A/M4)
7. Contract Work Breakdown Structure (DI-A-3023/M)
8. Firmware Development Plan (UDI-E-3935-ASD/M3)

9. Systems Engineering Plan (DI-S-3618/M)

10. Production Plan (DI-P-3460/M)

In addition, the Air Force may also require delivery, review and approval of additional data items involving planning, prior to closing the PPR milestone. These may include the System Safety Program Plan, Reliability and Maintainability Demonstration Plan, the Pre-operational Support Plan, and Training Planning Information.

PLANNING EXPERIENCE

The F-16 DRLMS PPR Milestone was defined to be complete by the fifth month. Although this was beyond the 110 day recommendation of Air Force operating policy, it proved to be a more suitable schedule for a development program scheduled to run for forty months. The contract also required the development and delivery of several other planning documents, in addition to the ten (10) identified above. Although these were not prerequisite to satisfactory completion of the PPR Milestone, they were scheduled to be submitted within the first five months of the contract, thus, adding to the contractor's planning workload. Of the fourteen plans specified for submission within the first five months, ten of the plans were due within the first 90 days with seven of these scheduled to be submitted within the first 60 days!

Why does the Air Force insist upon this extraordinary amount of planning? The record shows that the reason for most program failures over the past several years is due not to weak execution, but to poor planning -- unrealistic, inadequate, and insufficient planning is the most likely cause of program failure. Planning is usually cited as being the first of the five fundamental functions of management; the others being organizing, staffing, directing, and controlling. Planning is of particular importance in research and development project management because usually there is no other experience factor to rely on for comparing actuals versus experience, as there is in manufacturing.

PLAN THE PLANS

Why are so many plans required which seemingly overlap and duplicate each other? A good performance measurement plan provides a thorough definition of all aspects of the contractual effort. Scheduling is an important and integral part of the overall planning effort because the scheduling process forces people to quantify their effort in discrete terms and place their tasks in proper relationship to each other. This task identification is naturally facilitated by using a proper work breakdown structure to progressively identify each element of the item under development, as well as the activities required to accomplish the effort. Since a "Plan for Planning" is necessary to insure integration of all planning/scheduling functions with the contractual schedule constraints, which may be dictated by delivery dates, program milestones, etc., it is only natural that the Program Milestone and Contract Work Breakdown Structure data items, identified above, are usually specified for delivery early in a program.

The Contract Work Breakdown Structure establishes the framework for reporting program schedule, technical performance, and cost. It provides a basis for uniform planning and status reporting and also provides the structure for proper assignment of responsibilities within the contractor's functional areas. The Program Milestones are based upon the work breakdown structure and the contractual constraints.

These two documents provide the foundation for all subsequent planning, to insure that all contractual effort is defined and scheduled to the maximum extent possible, and the resources for accomplishing the work are properly identified and allocated. The planning within each functional discipline is then documented per the requirements of the specific data item description as noted in the previous list of PPR required data submittals.

Each plan forms the basis for effective communication, not only between the contractor and the government, but more importantly, between the responsible individuals at each level within both organizations. Effective communication will lead to effective management, and effective communication must be a dialogue between the responsible individuals within and between each organization, and not merely a series of parallel monologues. Effective plans are most efficiently prepared and reviewed when the responsible individuals within the affected disciplines perform the planning and reviewing.

TOO MUCH DATA?

Now that we understand the reason for the planning, why is it so difficult to complete? The fourteen data items which constituted the planning requirements on the F-16 DRLMS program were just the beginning. During the first five months of this contract, there were 55 data submissions, or approximately one submission every second working day. These data submittals were prepared against a total of 29 different data item descriptions, including the 14 delineated above. These submissions ranged from a relatively straightforward Agenda to, and including, a comprehensive System Test Planning document. Air Force review, comment, and approval were required on 39 of the 55 submissions. The "Plan for the Planning" worked! Over 70% of the 55 submissions were completed on, or ahead of schedule by the contractor, and only four of the deliveries which were late were delinquent by more than a week.

TOO MANY MEETINGS?

The Program Planning Review is not the only meeting scheduled to take place during the first five months of the contract. In addition to planning and preparing data for submission to the government, the contractor must also perform some "real" work. The real work is normally the output of the system engineering process conducted during the first several months of the program. The specifications must be reviewed, the functions analyzed, the requirements allocated, and a design synthesized which will lead to a preliminary system description. These events and activities must also be supported by design and trade studies, and logistics analyses. The results are then reviewed with the government during the System Requirements Review.

Successful completion of the SRR then leads to the development of conceptual design for subsystem components, with due consideration given to continuing trade studies and technical interface compatibility. Interface agreements are established during Interface Control Working Group (ICWG) meetings and a Part I Interface Spec. developed. One or more Engineering Design Reviews may be conducted following the SRR before holding the first formal Preliminary Design Review.

MEETING EXPERIENCE

During the five month period leading up to the PPR, the F-16 DRLMS Program completed a Post Award Conference (PAC), a System Requirements Review (SRR), two Engineering Design Reviews (EDR), two Program Management Reviews (PMRs), a Provisioning Guidance Conference, a Support Equipment Guidance Conference, a Parts Control Board Guidance Conference, two ICWG Meetings, a Tech Pubs Guidance Conference, a C/SCS Implementation Review, and finally the Program Planning Review (PPR). All of these meetings were completed to the full satisfaction of both the contractor and the government. Fortunately, many of the meetings were conducted "back-to-back" to minimize the impact to both organizations. The F-16 DRLMS contract also required the implementation of coproduction planning to meet the requirements of the F-16 Multi-national Agreement as governed by the Memorandum of Understanding executed in June 1975 by the United States, Norway, Denmark, Belgium, and the Netherlands. The coproduction involvement added a second level of complexity to the planning process and, in turn, required the implementation of Technical Assistance Agreements and data export licenses to ensure that all State Department provisions were satisfied.

PPR MEETING

As noted previously, Air Force operating policy requires that a formal Program Planning Review Meeting be held with contractor and government representatives to review the program management plan. In order to ensure satisfactory and timely review of the pertinent detailed plans prior to their final approval and implementation, the F-16 DRLMS Program conducted the Program Planning Review in two increments. The first increment, which was conducted in the middle of the third month in conjunction with a PMR/EDR meeting, included a review of all applicable plans submitted during the first 90 days. The second and final PPR incremental meeting was conducted during the middle of the fifth month for the purpose of reviewing the remaining planning documents and the contractor's program management plan. The typical Air Force Work Statement identifies the following topics for discussion during the presentation of the program management plan at the Program Planning Review:

1. Risk/problem identification, ranking, avoidance/reduction and control

2. Establishment of cost, schedule and performance baseline (including critical path identification and manloading)

3. Progress tracking and reporting of the baselines

4. Definition and implementation of contingency plans

5. Subcontract management

6. Government/contractor relationships

7. Contractor management information and control systems

Simply stated, these topics provide the contractor with the opportunity to outline his management philosophy and techniques for "doing business."

PLANNING CONTROLS

Program Managers must be concerned with the control of expenditures of money, time, and human resources to achieve the desired system performance. Consequently, Program Managers are interested in having visibility of the progress in achieving the desired technical performance, cost, and schedule objectives. In this effort, they are in turn, dependent upon the quality of data furnished by the management control system. The foundation of the management control system is the program management plan. The program management plan, in turn, is the collective set of functional plans which start with the Statement of Work (SOW) and:

- Determine the nature and scope of work

- Determine the resources to be applied

- Determine the results and/or output to be achieved

- Establish the procedures for consistent/systematic handling of work

- Establish the policies and rules for routine repetitive tasks

- Define the organizational responsibility/accountability for accomplishments

- Define the sequence of actions to perform the tasks

- Define the schedule requirements

Although plans provide the Program Manager with the management control device for monitoring progress, the principal mechanism for achieving an integrated plan is the work breakdown structure (WBS). Since an important aspect of program control is the proper definition of the task to be performed, the work breakdown structure is an essential device for identifying the contractual tasks. For program planning and performance measurement purposes, it is desirable that the WBS be structured in accordance with the way the work is actually going to be performed. The Air Force normally specifies that the top three levels of the contract WBS be selected from options contained in MIL-STD-881. The summary level items are normally included in the contract and should provide a useful structure for future contract status reporting. The contractor may then extend the WBS in any manner he chooses in an effort to divide the contractual tasks into manageable pieces of effort, for which internal responsibility can be assigned. Although such a breakdown is commonly used in manufacturing, it is usually more difficult to establish in engineering, where the tendency is to describe the effort in broad general terms, identifying only near-term effort in detail. This lack of task definition can easily lead to down-stream surprises on projects which appear to be doing well, simply because it is virtually impossible to determine what resources are required for unplanned work. Thus, we see once again the necessity for early, adequate, and proper planning and planning controls.

MANAGEMENT TECHNIQUES

How can the program management team develop the dozens of data submissions, prepare for and attend the dozen or so meetings, and still be able to effectively plan manpower requirements, develop comprehensive schedules and time phase budgets during the same period? They can't -- and they shouldn't attempt to! Just as the work breakdown structure is a formal method for identifying and defining the contractual tasks, so is a contractor's organizational chart a representation of the formal structure which reflects the manner in which the contractor will organize the people who will do the work. Effective program management plans are more realistic if they are prepared "bottoms-up" by the individuals responsible for their ultimate implementation. The F-16 DRLMS contractor employed matrix management techniques, with full delegation of responsibility and authority to the functional organizations and individuals responsible for executing the tasks. This technique was effectively employed during the period leading up to the Program Planning Review to insure that all plans, data item submissions, and formal meetings were properly and successfully completed. The program management staff defined the "big picture" viewpoint to insure that the planning details being implemented throughout the matrix organization were consistent with the overall contract requirements. The creation of a multidisciplined program management staff, capable of "planning the planning" and promulgating the policies, procedures, and philosophies of the program, insured that the functional area specialists worked together for the common set of program objectives.

TEAM WORK

The Program Managers must establish and maintain a relationship of trust and confidence between the government and contractor program management functions. These relationships should be built at all levels of interface between the contractor and government to insure that there is more emphasis on "what" is right, rather than "who" is right. Neither program management team can be successful if the other fails. Therefore, it is essential that the communications channels be established and kept open early in the program. Each of the meetings specified in the work statement provide a vehicle for establishing effective communications. Each of the planning documents prepared and submitted by the contractor for government review and comment, provides a vehicle for understanding by both organizations. The PPR milestone, and the events leading up to it, will be successful if both organizations are equally involved in achieving the program objectives. The contractor must understand the government's program objectives, and the government should also understand the contractor's objectives. Planning is fundamental to the program's objectives. How can you tell if you are going to achieve the program's objectives if you don't have a plan to tell where you are going?

SUMMARY

In conclusion, it is apparent that the innumerable data submissions and meetings -- squares which must be filled before the PPR is scored complete -- could easily be viewed as a "millstone" by the program management team. The F-16 DRLMS Program has proved that the "squares can be filled" with positive program impact. Proper planning will not slow down the "real" work. It will insure its success. In view of the numerous data submissions and formal meeting requirements, the contractor is likely to assign work priorities which will satisfy the most people in the near-term. In doing so, he often gives the planning process far less priority than it needs. Much to his surprise, he may soon find that temporary or inadequate submissions have become the "baseline," thus, a new problem may arise -- explaining why the measured performance does not satisfy the criteria set forth in the "temporary" (and inadequate) plan. If the contractor finds himself in this vicious circle, he may never recover enough to fully develop an adequate plan. Therefore, the Program Planning Review could indeed become a "millstone" to the program management team, if treated lightly. The F-16 DRLMS Program has demonstrated that proper program planning, by both the contractor and the government, leads not only to successful completion of the PPR Milestone, but also to successful implementation of the program and achievement of its objectives.

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SOME MANAGEMENT INITIATIVES TO IMPROVE EMBEDDED COMMERCIAL COMPUTER AND TRAINING DEVICE LIFE CYCLE SUPPORT

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ABSTRACT

This paper discusses some of the problems associated with the use of commercial off-the-shelf computer systems in aircrew training devices and offers some suggestions for improving the life cycle management of commercial computer systems in such military training devices. The impacts of commercial practices and computer capacity limitations are addressed as well as acquisition and logistics management considerations. Improved planning and management effectiveness will be needed in the 1980s to ensure that computer systems are supportable and/or replaced during the life cycle of training devices systems. Both acquisition and logistics support agencies will need to recognize that the life cycle of commercial computer systems may be limited by the lack of computer and peripheral vendor support and by the lack of expansion capability. Accordingly, training devices will need to be designed and developed to accommodate computer expansion or replacement. Computer system expansion or replacement will need to be anticipated to minimize training device to weapon system configuration differences caused by a lack of computer system supportability or capacity. This process could be termed "Pre-Planned Product Preservation (P^4)".

INTRODUCTION

Life Cycle support of commercial off-the-shelf computers embedded in training devices has traditionally been a challenge to military training device managers. Logistics supportability problems and computer capacity limitations have plagued simulator managers since digital computers were first embedded in simulators. Commercial practices, acquisition management practices, and logistics management practices have all contributed to life cycle support problems.

While advancing technology and improved management practices have lessened the impact in some areas, the overall life cycle supportability problem remains.

LOGISTICS SUPPORTABILITY PROBLEMS

On older generation computer systems, logistics supportability could be prolonged because base level maintenance had the capability for piece/part repair of the single-layer, discrete-component technology (core memory was the exception). With new technology computer systems (multi-layer, high density boards), base repair capability has become more limited with increased dependence on depot level (contractor) repair. This evolution in maintenance concept has occurred with commercial users (airlines) as well as the military. With increased dependence upon contract depot level repair, the supportability problem has changed from that of providing piece/part components for base level repair to that of finding contractors, either original manufacturers or third parties, for depot level repair and spares.

Because of rapidly advancing technology and the highly competitive environment, commercial computer companies are announcing a new product series of computers with increasing frequency (every three to five years). As new products become mature and accepted, production of the previous series is terminated. Most commercial computer manufacturers will then guarantee support of their products for five years following termination of production of a particular computer model. Some companies provide support for a longer time depending on availability of spares and components, availability of company skills, and the total computer population supported. There are indications that computer companies who are predominant suppliers of training device computer systems are recognizing the simulator user's need for longer support. Most companies, however, particularly those who do not have a large share of the simulation market, appear to be staying with the five-year support policy.

The availability and cost of depot level repair and spares from original manufacturers and/or third party repair contractors are highly dependent upon the overall demand for such services. Factors affecting demand include:

Effect of Production Status

Support is available while the product is in production and normally for at least five years following production termination. The availability of spares and repair from original manufacturers varies with company policies. Some will bid on spares and repairs so long as their products are in service, though the cost is likely to increase. Others simply refuse to bid repairs after they have discontinued guaranteed support of a product. Also, computer manufacturers may or may not maintain an in-house repair capability for their vendor-supplied peripherals. Thus, repair for peripherals may be subject to another level of availability. It has been suggested that long term computer support commitments be made a requirement in all simulator acquisitions. While this would be highly desirable, there is some question whether it could be enforced since such a commitment is dependent upon the integrity and continuity of the prime, the computer vendor, and second tier peripheral vendors.

Manufacturing Rights and Data Availability

The availability of repairs from third party repair sources is frequently dependent upon the availability of technical data. One computer manufacturer claims that the documentation furnished with each delivered system is adequate to establish and maintain a depot level repair capability. Others, however, furnish limited documentation with their equipment and consider depot level technical data as proprietary information. Most computer manufacturers contacted during this study indicated that they would consider selling proprietary data or manufacturing rights on their older systems if they could not offer repair services. It was noted during the study that third party repair is becoming more readily available for older technology systems. However, there is some question whether it will be economical for third party repair sources to develop the expertise and more sophisticated resources necessary to repair newer technology equipment.

Total Production Quantity

Larger total production quantities of an item increase the probability that enough units remain in service to economically justify retention of a repair capability for a longer period. Commercial users tend to depreciate computer systems over about five to seven years and then replace them, while the military embeds computers in equipment that is intended to be used for 15-25 years. Frequently, then, the military becomes the sole user of commercial computer repair services as commercial applications are phased out.

Equipment Reliability and Sparing

Computers are inherently reliable and are becoming more so with new technologies. Thus, the basic repair and spare demand for computer circuit boards is low compared to electro-mechanical devices such as peripherals. This inherent reliability of computer circuit boards makes the choice in sparing philosophy more difficult. Although at least one of each kind of board is spared in most commercial and military simulator applications, long term support choices involves either: (a) dependence upon contractor repair and spare support; (b) provisioning a life-time supply of spare boards; or (c) a combination of these. All three choices involve some risk. As indicated above, dependence upon contractor support is subject to limited commercial life support policies. Life-of-type sparing involves high front-end costs and less-than-perfect predictions of failure rates . A combination of contractor dependence until termination of guaranteed support, then procuring life-of-type spares is subject to planning, programming and budgeting lead time which exceeds the one year termination-of-support notice provided by some computer vendors.

Base Level Self-Sufficiency

The capability of base (organizational and intermediate) maintenance personnel to repair computer components can have a significant impact on the demand for depot repair. With older technologies (single-layer discrete component boards), both military and commercial maintenance personnel could maintain computers with a high degree of self-sufficiency. However, with newer technologies (multi-layered, high density boards), both military and commercial users lack the skills and support equipment for a repair capability.

As the older technology hardware is phased out, an increased demand for depot repair can be expected. In this respect, computer companies are limiting their field engineers to troubleshooting and board removal-and-replacement, with board repairs accomplished at centralized depot level repair facilities.

As the demand for computer spares and repairs diminishes, it understandably becomes more costly for repair contractors, whether original manufacturers or third party, to retain the skills, parts and test equipment for a support capability. The current Air Force policy of competing most computer repairs tends to discourage the commercial retention of support capability because a sustained business base is not assured. The relative cost of depot repair during a computer's life cycle is depicted in Figure 1. A similar depiction could be made to illustrate spares costs.

EXPANSION CAPABILITY LIMITATIONS

The lack of expansion capability (computational timing and memory requirements) to incorporate trainer changes has, in the past, frequently been more of a driving factor in computer replacements than logistics supportability. Trainer changes, generated by weapon system changes and by increased training requirements, place additional demands on the originally delivered computational system. Solutions to this eventual computer system saturation include: (1) expanding existing systems; (2) adding another computer system; or (3) replacing the existing system. Pertinent aspects of this problem are contained in the following discussion:

The Developers' Challenge

With a few exceptions (e.g., Singer GP-4), older generation computer systems used in simulators were not specifically designed for real-time simulation. In order to meet simulation requirements as well as government imposed spare timing and sizing requirements, simulator developers were faced with the challenge of extracting the maximum capability from the then state-of-the-art machines. Techniques used to accomplish this were (a) modification or replacement of the computer vendor's software and/or hardware, (b) use of machine or assembly language and/or more efficient software programming, and (c) designing interfaces for multiple CPUs. Even with these efforts, simulator developers sometimes had to add CPUs during development and frequently delivered less than the contractually-specified spare time and memory capacity. It may be noted that changing requirements imposed by acquisition agencies sometimes contributed to this problem.

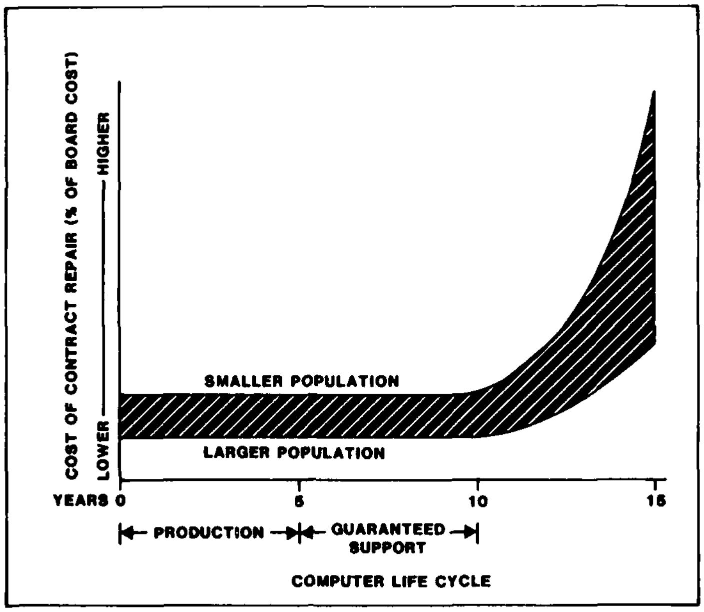
Spare Time and Size Requirements

Acquisition agencies generally plan and contractually specify spare time and size to accommodate change activity during simulator development and for delivery to the using command. Frequently, however, spare time and size is used by change activity and other factors by the time the system is delivered.

Hindrances to Computer Expansions

Attempts to expand computer capacity have been affected by the following:

a. Older generation computer systems had limited expansion capability.



RELATIVE COST OF REPAIR DURING COMPUTER LIFE CYCLE
FIGURE 1

b. Because of the Air Force's practice of "freezing" configurations, computer systems had to be updated to the latest configuration in order to add capability. Sometimes it was determined to be less expensive to replace than to update.

c. Because the computer system was obsolete (out of production), expansion kits were not available.

d. Because simulator developers had modified the computer vendor's software and/or hardware, vendor updates might not be compatible. Also, compatibility with the vendor's next generation of computer systems was diminished, making applications software less transportable and more costly in the computer replacement. More often than not, simulator-unique designs led to sole source procurement of the computer replacement with the simulator developer because of his unique design.

Technology Impact

Recent and current technology computer systems are being designed with increased capability for real-time simulation. In addition, these systems are more easily expanded by adding such things as a cache memory, a high speed floating point processor, additional CPUs , or extra memory.

COMMERCIAL PRACTICE CONSIDERATIONS

A number of practices employed by computer and simulator manufacturers contribute to the overall management problem. Some of the underlying causes of these problems are being overcome by advancing technology and improved management procedures. Other practices, however, particularly those employed by commercial computer vendors, are not likely to change.

Revision Procedures

Computer manufacturers issue service bulletins, Product Improvement Notices (PINs), Field Change Notices, Design Change Notices, or otherwise designated revision levels to a particular item of equipment and/or software. Each manufacturer has his own system of issuing revision levels; these differ (sometimes significantly) in cost, description of change, inclusion of kits, method of implementation, etc. Some manufacturers issue a revision that consists only of a drawing correction. Some affect hardware only; some affect software only; and some affect both.

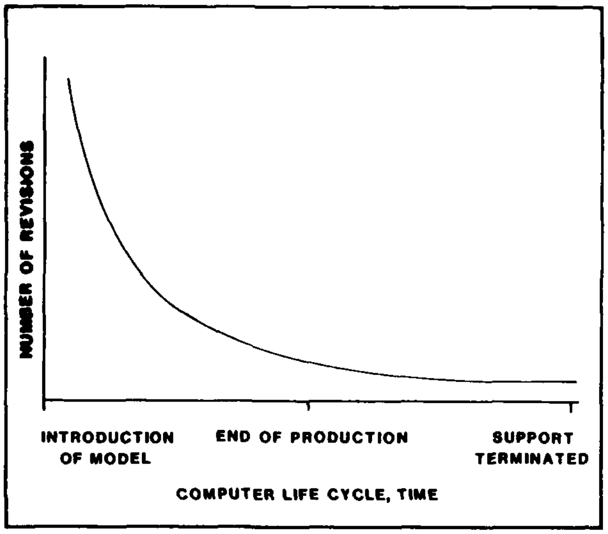
Revisions may be issued for the purpose of:

a. Improving computer system capability.
b. Improving reliability.
c. Reflecting manufacturing changes.
d. Correcting design defects or field reported problems.
e. Reflecting component or material changes or substitutions.

In turn, these revisions may or may not:

a. Affect form, fit and function.
b. Require prior incorporation of a lower level revision.
c. Be upward or downward compatible with other revisions.
d. Be fully de-bugged for a particular application.

Typical numbers of revisions versus computer life-cycle are illustrated in Figure 2, from which it can be seen that commercial computers have a very dynamic configuration baseline.



TYPICAL NUMBER OF REVISION NOTICES DURING A COMPUTER MODEL'S LIFE CYCLE

FIGURE 2

Configuration Control in Acquisition

Simulator developers have not always delivered computer systems, spares, and technical data for a given trainer type/model in a common or current configuration. Computers or spares delivered at different times could include different revision levels. In recent acquisitions, the Air Force has required that computer systems for a given trainer type/model be updated to the configuration of the last delivered trainer.

Software and Hardware Modifications

Both simulator developers and computer manufacturers advised Veda that until just recently simulator developers have modified or replaced the computer vendors' operating systems (O/S) and/or hardware in order to improve the "real-time" computational capability of the vendors' systems. This fact alone has had significant impacts on simulator management:

a. If vendor operating systems and/or hardware are modified or replaced, computer vendors cannot guarantee that their hardware updates (revisions) will not affect the simulator operation.

b. Vendors' operating system revisions, upon which some hardware revisions are dependent, may not be compatible with a modified operating system.

c. Even though computer manufacturers attempt to design for compatibility from one computer model or generation to the next, modification or replacement of the operating system and/or hardware make the applications software less transportable. Thus, software costs during computer replacements are significantly increased.

d. It is also possible for simulator developers to use the vendor's operating system intact, but supplement the O/S by using portions of the computer not used by the then current O/S, such as reserved memory words. A subsequent computer vendor revision to the O/S utilizing that portion of the computer is then not usable in the simulator application.

e. In the past, most simulator developers made at least minor hardware changes to vendor-supplied equipment. This was accomplished in one of two ways:

(1) The simulator developer would physically modify the vendor's part, making it simulator-unique and no longer an off-the-shelf item. If handled properly, a simulator manufacturer part number would be assigned to the resulting assembly and a source control drawing produced and delivered.

(2) The simulator developer would provide a modified design and/or specification to the computer vendor, who would produce and deliver the assembly with a vendor part number. Although the assembly was vendor supplied, it most likely became a vendor's "specialized product" (versus a "standard product") and thus simulator-unique.

Peripheral Equipment Modification

A related problem exists with respect to modification of peripheral equipment. Some computer manufacturers modify peripheral equipment or specify modifications to the peripheral vendor. In either case, peripheral equipment procured directly from the peripheral vendor may not always perform satisfactorily in the delivered computer systems. Some simulator developers procure peripherals through the computer manufacturer in order to preclude the above and to hold the computer vendor responsible for total computer system performance.

The Outlook

It should be noted that the problem associated with manufacturer-modified hardware and software may not be as severe in future systems. This is because currently available computer systems have been designed for real-time operations and have considerably more capability and expansion potential than previous generations. Both computer vendors and simulator developers have stated to Veda that the newer technology computer systems can be used in simulation applications without modification of hardware or software. One simulator developer, while believing this possible, suggested that modification would still be required because of cost competitiveness and the customer's desire to "push technology".

ACQUISITION MANAGEMENT CONSIDERATIONS

Some of the acquisition practices contributing to computer system management problems have been corrected in recent acquisitions. However, because of acquisition lead times, the effectiveness of these improved practices is yet to be demonstrated. Particular aspects of current versus past practices are identified in the following discussions.

The Computer Selection Process

Traditionally, computer systems in training devices have been selected by the simulator developer during the acquisition process based upon general computational system requirements specified by the acquisition agency. Generally, a commercial off-the-shelf computer system is selected either by the simulator developer's choice or because a commercial system is specified by the government. The government, however, does not normally specify a commercial brand or model. The basic rationale for selection and/or specification of commercial systems for simulation has been as follows:

a. Real-time performance and memory capacity requirements for simulation applications have required state-of-the-art computer systems designs; generally, only commercially available computer systems could meet these requirements.

b. The quantity of computers required in any one simulator system type/model has not justified the development of a military computer system that could meet computational requirements.

c. The simulation market is highly competitive; thus, cost is a prime consideration of the simulator developer. If left to the developer, then, a least-cost system meeting performance requirements will be selected.

d. Rapidly advancing technology in a highly competitive commercial computer market has made available low cost-to-performance ratio commercial systems, thus eliminating the need for high government development costs.

This method of computer system selection has, in the past, tended to proliferate the types and models of computer systems in training devices and thus aggravate the logistics support effort. More recently, however, the increased use of simulators, and more significantly, the increased use of digital computers in simulation have lead to recognition of simulation as a computer industry market. Because of this market recognition, computer manufacturers who specialize in real-time systems are designing them with a consideration for simulation requirements. This evolution has led to the present situation wherein it is likely that computer systems of the minicomputer or super-minicomputer category from one of four manufacturers are selected. Specifically, manufacturers whose systems are being selected today as mainframe computers for both commercial and military simulator applications are: Digital Equipment Corporation (PDP or VAX series); Gould SEL (32/77 or 32/87 series); Harris (800 series); or Perkin-Elmer (8/32 or 3200 series). While the current selection process has essentially reduced proliferation of mainframe computer systems to four manufacturers, there are other factors that affect, or may affect, the commercial computer selection process:

a. No single computer model within a manufacturer's product line is suitable for all simulator applications whereas a single computer of the same model could have excessive performance (and cost) in other applications.

b. Technology innovations, seemingly being introduced with increased frequency, may make the current training device computation system concept obsolete. While most simulator developers contacted believe that a mainframe computer will continue to be used in simulations, they suggested that there would be increased use of microprocessors in a distributed mode, and that the physical size of the mainframe will decrease. The management of microprocessors presents yet another challenge to simulator managers.

c. In spite of inflation, the cost-to-performance ratio has continued to decrease with the introduction of new technologies. This trend can be expected to continue for the foreseeable future. Accordingly, computational system cost (excluding applications-unique software) will continue to become a smaller percentage of the overall simulator system cost.

The Simulator Development Process

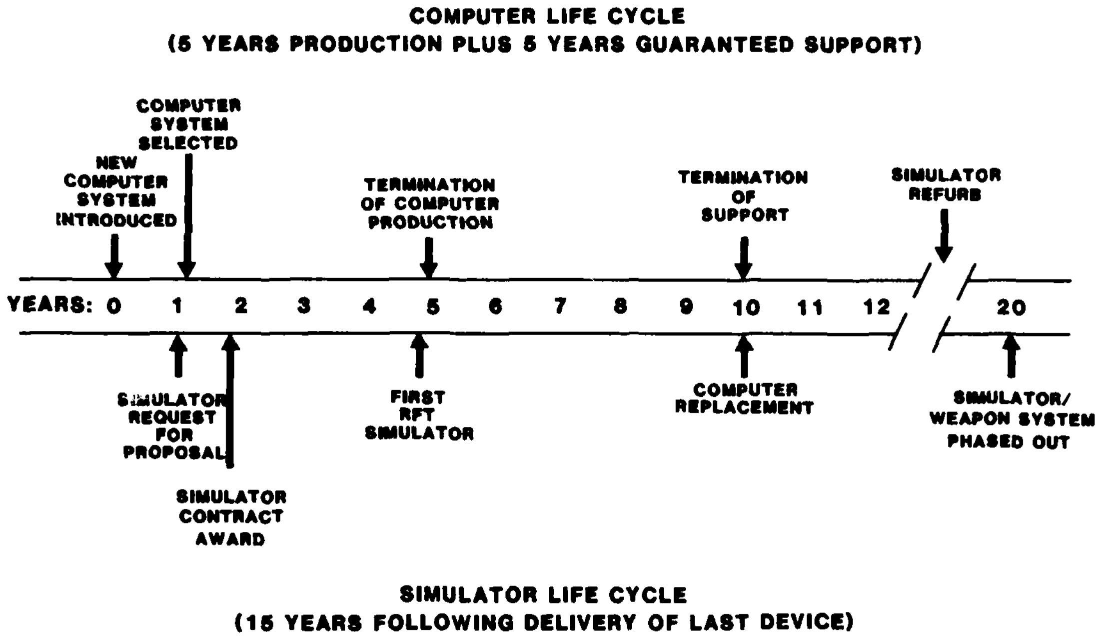
During simulator acquisition, simulator developers select computer systems during the proposal phase. In order to minimize risks to both the government and the developers, a reasonably mature computer (one to two years into production) is selected. Based upon statistics from the Air Force, a simulator development requires, on the average, 34 months from contract award to delivery of the first ready-for-training (RFT) simulator. Therefore, as illustrated in Figure 3, computer systems are four to five years into production , or perhaps already out of production, when simulators are deployed. Thus, logistics managers can expect to experience supportability problems within five years of deployment of the first training device.

For new simulator acquisitions, the Deputy for Simulators prepares a Type B1, Prime Item Development (Part I) Specification and requires a Part II Product Specification from the simulator developer. The training device is procured as a single Configuration Item. The computational system is specified by incorporating, or referencing, portions of MIL-D-83468, Digital Computational Systems for Real-Time Training Simulators. No specification per se is required for the computer system, nor are interface specifications or *interface control* documents required. Thus, there is no clear distinction between the off-the-shelf computer system and the applications (simulator-unique) hardware and software.

As indicated in previous discussions, simulator developers in the past were not required to deliver computers and spares in a common or current configuration; however, this has been imposed in recent acquisition contracts. Also, acquisition agencies have not maintained visibility and control over modifications to computer vendor's hardware and software. The Air Force has recognized this and is currently intensifying efforts to control and minimize these modifications. Finally, contractually specified spare time and size is frequently used up by change activity during development. This problem should become less of a concern with the expandability of newer technology computer systems.

Acquisition Management Initiatives

The provisions of an acquisition, of course, strongly influence the supportability of a training device. Thus, computer life cycle planning must begin with the acquisition process. If it is recognized that computer replacements are inevitable, then training devices should be designed to facilitate such computer replacement. It is suggested that preservation of the off-the-shelf nature of computer systems is essential. This translates into the following requirements:



COMPARISON OF TYPICAL COMPUTER AND SIMULATOR LIFE CYCLES

FIGURE 3

a. Commercial off-the-shelf hardware and software must be used without modification. Any deviation should be fully documented and justified to the acquisition agency. It is also assumed that applications software is programmed in a higher order language such as FORTRAN or Ada.

b. The hardware and software interface between the commercial off-the-shelf computer system and the simulator must be defined and maintained through interface control documents or other comparable means.

c. A configuration description is needed to define the commercial configuration baseline. Such a configuration description is normally delivered by the computer vendor with each system, and describes the hardware, software, and documentation as delivered. The computer vendor's current configuration of hardware, software, and documentation should be maintained during development and be reflected in the configuration description delivered with the simulator.

d. A technique that can be used to encourage simulator contractors to consider life cycle supportability is to require a Post Production Support Plan as a part of acquisition contracts. The Post Production Support Plan is described in MIL-STD-1388-1A, Logistics Support Analysis, and Data Item Description DI-P-7119. This plan requires the prime contractor to: (1) identify items that will present potential problems due to inadequate sources of supply after termination of production; and (2) prepare alternatives to satisfy support problems for the system/equipment's expected useful life.

If the above requirements can be fulfilled, a current, fully documented and unmodified commercial off-the-shelf computer system will be delivered with the simulator. Maintaining the off-the-shelf integrity of commercial systems should facilitate computer replacements since computer manufacturers try to design their next generation computer systems to be compatible with their previous generation systems. Thus, the cost and complexity of computer system replacements should be minimized. Requiring a Post Production Support Plan should greatly enhance Air Force's planning for life cycle supportability of commercial computer systems including peripherals.

LOGISTICS MANAGEMENT CONSIDERATIONS

Although there are many ramifications to the logistics management of computer systems, there are two overriding considerations: configuration management of computer systems and recognizing the limited life cycle of commercial systems.

Configuration Management

Effective logistics management of embedded computer systems following deployment of simulators has been hindered by a lack of positive configuration management. Failure to maintain computer systems at the manufacturers' current configuration levels has created mixed configurations of spares, data, and installed hardware and software within specific simulator types and also among different types of simulators. As a design goal, computer manufacturers try to make next generation computer systems compatible with their previous generation systems. This compatibility, however, is based upon the latest configuration of the older generation system. Thus, failure to update computer systems makes logistics support and replacement of computer systems more difficult and costly.

Computer Replacements

The need for computer system replacements one or more times during a simulator life cycle is not yet established as a recognized requirement. In the past, computer replacements have been driven more by lack of capacity (time and/or size) to accept simulator modifications rather than by a lack of supportability. The cost of replacing computers has been substantial because software was programmed in machine or assembly language, computer systems had not been updated, and modifications had been made to off-the-shelf software and/or hardware. In some simulator systems, this replacement cost has contributed to a significant simulator modification backlog, and thus, to degraded training because of weapon system-trainer configuration differences.

Logistics Management Initiatives

Based upon the above considerations, there are logically two logistics management initiatives to be considered: maintaining positive configuration management of computer systems and periodically reviewing supportability of computer systems.

a. Maintaining positive configuration management of computer systems includes preserving their commercial off-the-shelf nature and maintaining the systems and documentation to the manufacturers' dynamic configuration baseline. To accomplish this, more flexible procedures will have to be developed to accommodate the manufacturers' dynamic configuration baselines.

b. In order to provide adequate funding lead times, computer system supportability must be periodically reviewed. Using the Post Production Support Plan, if acquired, this review should include:

- Parent weapon system inventory plans
- Weapon system modernization plans
- Trainer modernization plans
- Computer spare time and size
- Expandability of the computer system
- Availability of expansion kits
- Vendor support policy and plans
- Availability and cost of support from vendor or third party
- Reliability
- Maintainability
- Any modifications made to off-the-shelf hardware and software
- Applications software program language
- Compatibility with currently available replacement systems

Because of the rapidly changing commercial computer market, it is suggested that a supportability review should be made on at least a biennial basis, and probably annually for older systems and peripherals.

This increased management attention to embedded computer systems should contribute to improved logistics supportability during the life cycle of the computer system and to improved training effectiveness during the life cycle of the simulator.

SUMMARY

There are many factors contributing to the problems of commercial off-the-shelf computer system life cycle support. Some of the problems are being overcome by technology while others are being corrected by management initiatives. However, full recognition of the limited commercial computer life cycle is needed, along with acceptance of computer replacement requirements.

The cost and mission impact of computer system replacements can be minimized if: (1) simulator developers can deliver off-the-shelf commercial computer systems without modification; (2) computer systems are maintained to the vendor's current configuration; and (3) supportability of computer systems is periodically reviewed to anticipate replacement requirements. This entire process could be termed "Pre-Planned Product Preservation (P^4)".

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TRAINING THE MULTIPLE-AIRCRAFT COMBAT ENVIRONMENT

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ABSTRACT

Aircrew training devices for the teaching of tactical combat maneuvering currently range from simple desk-top trainers to large weapon system trainers with limited visual systems. Still missing from the spectrum is the capability to practice full-mission multi-ship scenarios. At present such training can only be provided by major field exercises such as Red Flag, at great expense. A network of hostile-environment simulators could greatly increase the frequency of training, provide more realistic training, and keep pilots at a higher state of readiness than by using aircraft alone. The Air Force Human Resources Laboratory is exploring technology requirements for multiple aircraft simulation under Project 2743, the Combat Mission Trainer (CMT) program. The goal is to develop a full-mission combat simulator affordable at the wing level and capable of training all air-to-air and air-to-ground tasks.

INTRODUCTION

With all of man's sophisticated gadgetry and knowledge of up-to-date training methods, there still does not exist a completely adequate training environment for practicing multiple-aircraft weapons delivery. Although major field exercises such as Red Flag closely approximate the realistic scenarios needed for the training of essential combat tasks, field exercises are expensive and infrequent and do not expose pilots to actual air and ground fire. The best training environment of all is combat itself. Historical data from World War II has shown that losses decrease dramatically following the first four to five missions of a confrontation (see Figure 1). Ideally, pilots should be trained in advance to this "fourth mission" level of readiness to increase their survivability. This should be the goal of

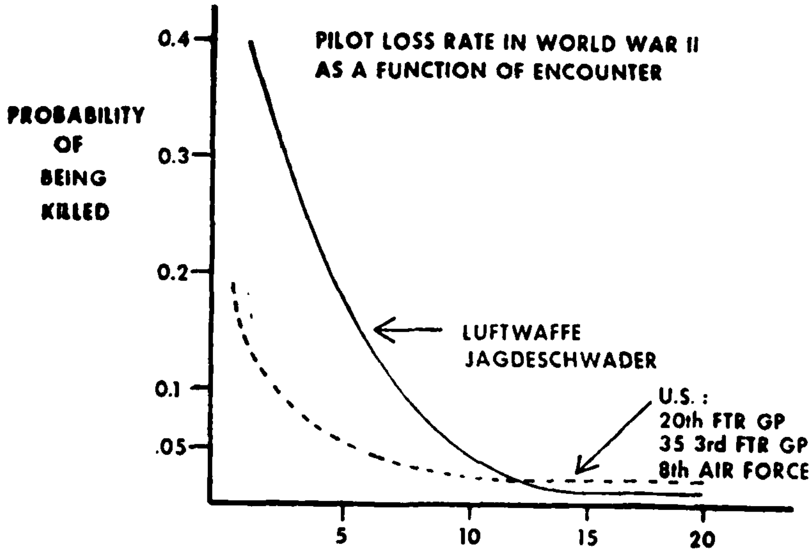

Figure 1. Losses drop remarkably following the first few missions.

day-to-day tactical training.

Flight simulators are slowly evolving into the ideal vehicle for providing the desired level of training. The use of simulators could dramatically improve the combat capability of the Tactical Air Forces (TAF), and serve as a valuable complement to large-scale field exercises (1). A Red Flag exercise, which can consist of 100 aircraft flying over 4000 sorties, is an extensive undertaking. The logistics involved in getting pilots and aircraft to Nellis AFB are of such magnitude that most pilots are able to benefit from the experience only on an annual basis. It is impossible to maintain exacting skills at a peak level when they are practiced so infrequently. If combat simulators were available at every wing, practice would be much more intensive.

Simulation can offer many other advantages. Although TAC training programs currently provide flight in the presence of threat radar emitters, pilots never see actual SAM launches, AAA tracers, etc. In the simulator, ground threats can be accurately modeled to provide striking realism for the practice of defensive maneuvers. Seeing a hostile missile approaching his aircraft will make a believer out of any pilot trying to master the art of terrain masking. Safety-of-flight rules of engagement such as those for minimum altitude and minimum separation can be varied at will in the simulator to see what the results would be in actual wartime conditions. Weather conditions can be selected for the particular area of the world for which you are training, instead of seeing only the clear dry Nevada desert air encountered in the Red Flag exercises. The experience level of adversaries can be varied to provide increasing challenges to pilots as they master new skills. Unorthodox or unusual tactics can be examined to determine their feasibility. Complex scenarios can be played back immediately for thorough debriefing and analysis. Expensive weapons such as the Maverick missile can be utilized far more frequently than during the few actual live firings permitted now.

CURRENT TRAINING DEVICES

The present-day spectrum of aircrew training devices includes, at one end, simple terminals for computer-aided instruction and desk-top trainers with interactive graphics for training specific instruments, displays and systems. The more advanced Cockpit Procedures Trainers and Instrument Flight Simulators may or may not include visual systems and are used for basic aircraft systems familiarization, instrument training, and limited visual maneuvering. At a still higher level, Operational Flight Trainers and Weapons System Trainers are now available for such front-line aircraft as the F-16, F-111 and A-10, but these also possess only limited visual systems. This spectrum must be extended to include the full-mission multi-ship environment. Some specialized simulators have been developed which provide limited interaction with another aircraft (see Table 1) but none of these devices provide a high degree of sophistication. The most seriously deficient area is that of the complex air-to-ground multi-ship mission, in which flight leads must coordinate with their wingmen and with other flights while evading multiple air and ground threats. Filling this void is the main thrust of AFHRL's Combat Mission Trainer Program.

COMBAT MISSION TRAINER

The objective of the Combat Mission Trainer (CMT) program is to develop a full-mission simulator affordable enough for widespread distribution, effective for training all air-to-ground and air-to-air tasks, and interconnectable for practicing large-scale exercises.

In its ultimate form, the CMT concept would link together a large number of simulators to provide the capability for practicing major campaigns at greatly reduced cost and without

TABLE 1
SOME CURRENTLY AVAILABLE INTERACTIVE SIMULATORS

AIR REFUELING	
Boeing C-5/C-141 Aerial Refueling Simulator	Seattle, WA
Singer B-52/KC-135 Weapon System Trainer	Castle AFB, CA
AIR-TO-AIR	
Simulator for Air-to-Air Combat (SAAC)	Luke AFB, AZ
Visual Technology Research Simulator (VTRS)	NTEC, Orlando, FL
Device 2E6	Oceana NAS, VA
McDonnell-Douglas	St. Louis, MO
British Aerospace Air Combat Simulator	Warton, England
AIR-TO-GROUND	
Advanced Simulator for Pilot Training (ASPT)	Williams AFB, AZ

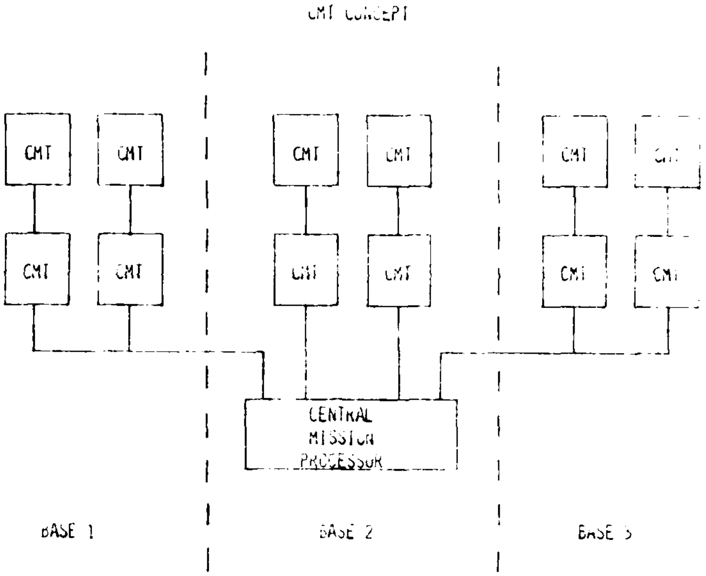

Figure 2. Interconnected simulators can provide superior multi-ship training.

loss of life or equipment. Such a system would enable pilots to interact with all other participants in the combat environment, including forward air controllers and command-and-control aircraft, as well as Army helicopters, tank formations, and other ground units (see Figure 2).

TECHNOLOGY REQUIREMENTS

Significant technology advances must be made in a number of areas before the CMT concept can become reality. A viable program for developing an affordable multiple-aircraft combat simulator must address the following design areas:

1. Visual Display
2. Image Generation
3. Data Base Generation and Update
4. Cockpit Displays and Controls
5. Basic Computational Capability
6. Instructor Operator Station
7. Multi-Cockpit Communication/Control

Visual Display

The most critical initial problem is the development of a new visual display which will provide the improved field of view, resolution, brightness, and color required for an all-purpose combat simulator. Combat simulation requires a full 360-degree coverage of the visual scene, which is not attainable in current simulators. Dome or dodecahedron simulators can provide up to 300° horizontal by 150° vertical, but do not provide the six o'clock view so critical to tactical survival. Limited field of view systems such as those proposed for TAC Operational Flight Trainers will not provide the necessary coverage for training all combat tasks.

Resolution, brightness and contrast must be adequate to support the training of tasks requiring acquisition of other aircraft or ground targets. Color could provide useful differentiation of scene details which are of the same contrast level. The display must be reduced in size from that provided by current dome and mosaic CRTs in order to eliminate the associated costs of a large, expensive supporting structure and facility.

Helmet mounted displays appear to provide a promising solution for achieving the improved capability, small size and lower cost required for the CMT application. Some current approaches being monitored for their applicability include AFHRL's Fiber Optic Helmet Mounted Display, Aerospace Medical Research Laboratory's Visually-Coupled Airborne Systems Simulator (VCASS), and the McDonnell-Douglas Helmet Mounted Visual System. For a complete description of the AFHRL approach, see the paper entitled FIBER OPTIC HELMET MOUNTED DISPLAY: A COST EFFECTIVE APPROACH TO FULL VISUAL FLIGHT SIMULATION elsewhere in these proceedings.

A typical simulator using microprocessor technology and a helmet mounted display might appear as shown in Figure 3.

Image Generation

Image generators for the CMT must provide a high-quality out-the-window visual scene and multiple sensor displays such as forward looking infrared (FLIR) and radar.

The image generator is presently the greatest cost driver of the entire system. In the near future, if image generator channel requirements can be reduced to three or four through the use of head coupled displays, then cost could potentially be reduced to $3-5 million per simulator. Systems currently in design and development by major manufacturers could be used for an interim CMT, but no real progress will be made in this area until advances in Very High Speed Integrated Circuits (VHSIC) and Very Large Scale Integration (VLSI) produce dramatic decreases in cost similar to those already achieved in the computer industry.

Scene detail as determined by edge count, texturing, and quadratic surfaces must provide the minimum essential information required for target acquisition and low level terrain cues. AFHRL's Project 2363, the Advanced Visual Technology System, will provide essential answers to the questions regarding these minimum levels following its delivery in 1984.

Sufficient moving models must be provided in the scene to handle all participants who are within visual range of each other. A moving model capability is being included in new simulators such as the General Electric C-130 simulator at Little Rock AFB, and the proposed AV-8B simulator for the Cherry Point Marine Corps Air Station being built by Rediffusion/Evans & Sutherland (2). However, more moving models than currently available on these new systems would have to be included for a realistic combat scenario.

FLIR image generation poses challenges and risks similar to that for outside visual scenery. Given appropriate algorithms for handling the unique characteristics of infrared imagery such as atmospheric and time-of-day effects, FLIR imagery can be produced by the visual image generator. Air-to-air radar is not difficult to simulate and should be relatively inexpensive to duplicate. Air-to-ground radar simulation, on the other hand, is sufficiently different from visual image generation that it requires its own separate generator, usually referred to as a Digital Radar Landmass Simulator (DRLMS). Current air-to-ground DRLMS do not readily lend themselves to the CMT concept because of their expense. Much development work is needed to provide a low-cost air-to-ground radar simulation, especially for the newer types such as Synthetic Aperture Radar (SAR).

Data Base Generation and Update

The present capability to generate and update a data base is an order of magnitude away from CMT requirements. If possible, only

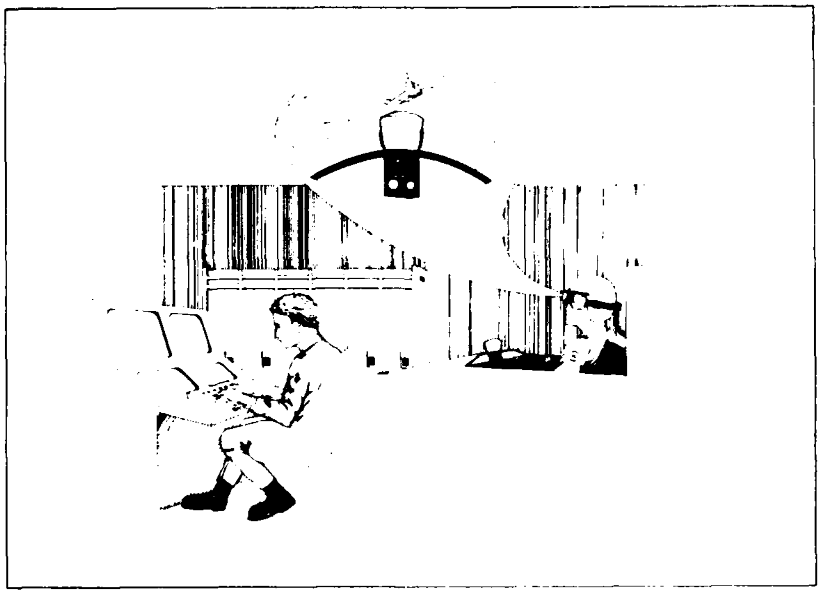

Figure 3. Compact design envisioned for a combat mission trainer.

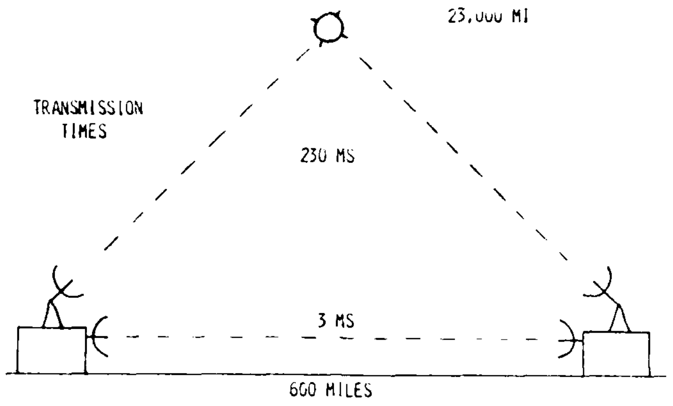

Figure 4. Satellite relay is unacceptable due to the long transmission time.

one data base should be required for storage of all out-the-window and sensor parameters required for visual representation, infrared emissivity, and radar reflectivity. Extensive hand modeling must give way to automatic techniques to greatly increase the responsiveness and flexibility of the system. Data bases must be capable of rapid update with the latest digital terrain data from the Defense Mapping Agency, and the latest threat information from various intelligence sources. Automatic input of intelligence data is a critical requirement for responding to rapidly changing threats. For best efficiency, rapid update should be limited to just threat, target, and minor terrain feature relocation.

Cockpit Displays and Controls

Development of cockpit displays and controls is a low risk area, since this technology has been demonstrated repeatedly. Fabrication of cockpit controls is a minimum cost item compared to the rest of the system, although some specialized displays such as radar warning receivers and Maverick missile displays may be required. Fixed-stick cockpits such as the F-16 have the advantage of requiring no control loading development. Newer generation aircraft are also employing multipurpose displays which will help eliminate the need for large numbers of specialized displays.

AFHRL-developed micro-linkage techniques can provide an inexpensive connection between cockpit and computers. This was demonstrated on the U-2 Cockpit Procedures Trainer (CPT) constructed by AFHRL and delivered to Beale AFB in 1982 (3). Use of micro-linkage greatly increases the flexibility of the system and lowers its cost by reducing the required hardware. Other alternatives to the linkage problem have been proposed, such as the use of separate microcomputers for each instrument (4).

Basic Computational Capability

State of the art microprocessor technology is adequate for current research efforts. A cost-effective host computer using commercial technology is practical today, although microprocessor technology is moving so fast it wouldn't pay to rush into a pre-production system before the rest of the CMT is ready. Distributed microprocessor technology was effectively utilized in the AFHRL U-2 CPT (3).

Instructor Operator Station

The CMT concept will require an extensive instructor operator station (IOS) to monitor the interaction of multiple aircraft during air-to-air and air-to-ground maneuvers. The ASPT has a very successful air-to-ground display, while the SAAC can display three dimensional air-to-air maneuvering. Neither of these designs would be adequate for both air-to-air and air-to-ground missions, so a new concept in multi-mission, multi-participant instructor operator stations must be developed.

Multiple-Cockpit Communication/Control

A number of alternative configurations exist for networking from two to fifty combat simulators. The optimum approach is to make all CMTs stand-alone capable, and connect them to a central control facility for distribution of position data, weapon status, and damage determination. Transport delay can be minimized by passing attitude and velocity data and predicting the correct actual position for the moving models.

Small-scale experience from the cross-town ASPT-SAAC linkup demonstrated the feasibility of interconnecting dissimilar simulators through telephone lines for one-on-one air-to-air combat. AFHRL will test simple two to four cockpit arrangements in-house to ascertain the feasibility of conducting multi-ship multi-mission training with more complex air-to-ground data bases. Once the concept is proven feasible the interconnection of two distant simulators can be tried using microwave links and/or land lines. The use of satellites is infeasible (5) because the average transmission time of 230 milliseconds gives a totally unacceptable transport delay for real-time interactive flight simulators (see Figure 4).

Whatever transmission method is used, security protection becomes a vital concern because classified tactics would be vulnerable to compromise during the conduct of large-scale exercises. Use of a central facility for rapid database and threat updates poses a high security risk during the transmission of new data to all interconnected simulators.

A full CMT system would also require a voice communication channel for participants to communicate with each other and with their instructors. This will further complicate the interconnection process.

CONCLUSIONS

Combat simulation is rapidly becoming a necessity for the training of future fighter pilots. A multi-cockpit, multi-mission simulator can increase readiness by improving the weapons delivery capability of the participants and by enhancing their survivability.

New technology must be developed to provide lower-cost, higher-capability simulators designed specifically for multi-ship combat interaction. The great costs associated with image generation and display must be reduced. The challenge is before industry to make lower cost image generators a reality.

As current simulators become upgraded with advanced visual systems, they can be interconnected to create a large network of interim training devices for multi-participant scenarios prior to the deployment of next-generation combat simulators.

Advances in many technical areas are required before widespread combat simulation will become a reality, but continued investment promises ultimate success and a high payoff.

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[illegible] SUPPORT - A COMPUTER MAN[illegible]

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ABSTRACT

When the Department of Defense directed that commercially available standard off-the-shelf computer systems would be used for military simulation programs in place of special militarized computers the intent was clear: Cut costs! Now, more than a decade after that DOD directive, it is possible to look back, recognize the value of the decision, and identify many of the problem areas that have been created for the military simulation program organizations. The military services have attempted to address the problems posed by the apparent conflict of needs but have met with minimal success to date. This paper is a computer manufacturer's look at some of the support problems that have been created by the use of commercially available computer systems, some of the solutions that have been considered, and some actions that should be explored if resolutions to the problems are to be achieved.

INTRODUCTION

When the Department of Defense directed that commercially available standard off-the-shelf computer systems would be used for military simulation programs in place of special militarized computers the intent was clear: Cut costs! Now, more than a decade after the DOD directive, it is possible to look back, recognize the value of the decision, and identify many of the problem areas that have been created for the military simulation program organizations.

Though the commercial computer has provided state-of-the-art solutions for the increasing demands of simulation requirements, the long term support of simulation systems has been a problem that has eluded the most conscientious efforts of the military services. The need of the computer industry to stay current with the dynamic technological advances is directly opposed to the military need to support a simulator for a useful life of up to twenty years. The commercial computer has a production life of possibly five to seven years. This production cycle is steadily decreasing. The computer system support software has a considerably shorter product life.

The military services have attempted to address the problems posed by the apparent conflict of needs but have met with minimal success to date. How then can the benefits of commercially available computers be realized without the excessive costs associated with the long term life cycle support of those systems?

This paper is a computer manufacturer's look at some of the support problems that have been created by the use of commercially available computer systems, some of the solutions that are currently being used and some future actions which should be explored if resolutions to these problems are to be achieved. The paper is broken down into three sections to discuss these support issues and their resolution in terms of Long Term Support, Software Compatibility, and Obsolescence. The three sections are Historical Problems, Current Solutions, and Recommended Solutions.

THE HISTORY OF BUY COMMERCIAL OFF-THE-SHELF COMPUTER EQUIPMENT

In the early 1970s it was mandated that commercial general purpose off-the-shelf computers be used to replace the specialized simulation computers for military simulators.

The directive was intended to reduce acquisition costs and to reduce support costs. Historically, in a training device environment, these computers which were used to simulation on-board computers have allowed cost effective performance and versatility which was not available with specialized computers or the on-board militarized computers. The on-board computers were targeted for operational environments in airborne, aerospace, surface vehicles and submarine applications and clearly had an adverse impact on simulator costs both in acquisition and support.

It was further envisioned that documentation costs could be reduced by using standard off-the-shelf commercially available documentation, i.e., operation and maintenance manuals. This is a significant cost savings in itself considering that the mil-spec documentation can cost more than the computer system it is intended to support. The use of commercially available documentation projects even greater life cycle cost savings as the computer equipment is upgraded since the associated data revision costs will be minimal.

These cost reductions also apply to the spares provisioning area. It was envisioned that the cost of procuring and maintaining spares for commercial off-the-shelf equipment would be less than both the specialized computers and for militarized computers. The plan was based on using the existing supply system.

As the directive to buy commercial off-the shelf computers began to be executed several problems arose. It must be said that the intention of the buy commercial idea was valid and appropriate. The implementation across the board however, was not as effective as it could have been.

HISTORICAL PROBLEMS

It has been field proven that commercial off-the-shelf computers can be used in production of high fidelity training devices. Major commercial computer manufacturers generally employ people who can understand military training device computer requirements and can communicate effectively in the military support environment. There are several major problems that must be addressed to field and maintain simulators with commercial computers. The three most significant problem areas are:

1. Long Term Support
2. Software Compatibility
3. Obsolescence

This paper addresses these areas from the computer manufacturer's point of view. Several beneficial results may arise if the military and the prime contractors understand the commercial manufacturer's viewpoint on these problems and how the computer vendors would propose to solve them.

1. Long Term Support. Typically a commercial system is obsolete in about five years in the commercial marketplace and as technology advances this life cycle is becoming shorter. A military simulator is not planned to be obsolete until ten to twenty-five years after initial acceptance/deployment. The wide divergence in the timframe is part of the problem. Also, the command philosophy of long term support is different in the military environment. The problem is further complicated by the nature of change in the two environments and by the methods used to address change.

If, for example, we take a commercial application which is doing engineering work, it would be expected that its useful life would be approximately seven years. At the end of this period the system will be replaced with a newer model with more capability. At the initial purchase of the system no documentation other than commercial manuals would be provided. The user of the system would opt for maintaining the system himself or would have the supplier do the maintenance. If he chose to maintain the system himself he would either buy the appropriate spares to support the system at the time of purchase or an as-required basis.

The military application for simulator work would be expected to have a useful life of approximately twenty years. At the end of this period the system would be updated or retired. Under the "buy off-the-shelf" philosophy the documentation would be standard commercial manuals or possibly modified commercial manuals. The customer could opt to maintain the system himself, have his prime contractor maintain the system or have some third party maintain the system. It should be noted that commercial manuals probably won't be sufficient since maintenance personnel are rotated through the sites at intervals which don't allow them to become familiar enough with the equipment to handle major failures.

Now, from a commercial computer manufacturer's point of view the easier system to support is the commercial application. First of all, the maintenance on the system is over a shorter period and he can keep technicians who are trained on its maintenance and who feel that they are not working on antiquated equipment. Second, he can supply the latest revision level of parts direct from the factory since he is maintaining the equipment. Third, he doesn't have to worry about the technical training and documentation since he is providing his current technical manuals and providing maintenance training to his service people on his current equipment.

The peripherals issue is also one of the areas which is effected by long term support requirements. From a military simulator viewpoint it is expected that the system, including peripherals, will have a useful life of twenty years. As with the computer, the peripherals have to be supported with spares including mechanical parts which tend to wear. After approximately five to seven years the peripheral manufacturer ceases to manufacture the peripheral and discontinues spares. If enough spares are not acquired by the user while they are available then the equipment will become rapidly non-functional.

Figure 1 indicates the levels associated with sparing peripherals. This figure indicates a simplistic view of the levels that must be addressed to obtain spares for long term support. When multiple manufacturers and multiple component vendors are considered the picture becomes extremely complicated. When multiple revision levels from multiple manufacturers are considered it becomes even more complicated.

The military simulator as viewed from a commercial viewpoint is fraught with potential pitfalls. The computer manufacturer must change the way he does business in spares, technical resources and in his change control systems. The commercial manufacturer must also change his management style instituting a program management function, and keeping product lines alive which would otherwise be terminated. This is not to say that simulator business is not profitable to the computer manufacturer, if properly managed, but is complicates matters and adds to the cost of procurement and life cycle maintenance.

2. Software Compatibility. Software is hard and hardware is soft. This statement expresses the paradox of the problem relating to commercially available software used on simulator programs. A computer manufacturer constantly produces changes to hardware which have little or no effect on the system software. However, if he changes the software, then watch out! These changes ripple through a simulator system causing repercussions randomly throughout the entire system.

The problem can be exemplified by a simulator system which is hit with a major operating system change by the computer manufacturer while in final government acceptance after two and a half years of development effort. If the simulator manufacturer doesn't provide the latest commercially available software both the prime contractor and the computer vendor may be technically in default of their contracts. If the computer vendor implements the new operating system he may not be able to pass the acceptance tests due to the systems impact, and he could then be in default for system acceptance testing. It is a "Damned if you do and damned if you don't" situation.

Even frozen configurations of software and/or hardware create problems. In this scenario the software and/or hardware configuration is frozen to specific revision levels. If a new device is added or a bug is found in the software which requires a change then the problems rise to the surface. Since the revision levels were frozen, x changes have probably occurred in the commercial releases of the software. Therefore, the simulator program is faced with either creating a non-standard, non-commercial software package which fixes the bug or having to test the latest release of the software and face the risk of incompatibilities and the potential new bugs. Yet another problem is the failure of software which works at revision X to work at Y. This may occur if programming or language standards were not followed by the programmer. This can occur when one revision of the software is forgiving in allowing the programmer to deviate from standards and the next revision demands rigid comformity to standards.

Disaster lurks in the multi-system environment when all developers are not using the same revision of the computer manufacturer's software. Software control or lack thereof is perhaps the greatest problem area. The clever programmer who gets around the software assures that future updates to the system software are not compatible with the previous release which worked. This must be handled by imposing and enforcing development standards on the prime contractor.

3. Obsolescence. The environment which is typified by the simulator world is one of constant change. By this, I mean everything is changing but not necessarily at any fixed rate. The state-of-the-art in computer hardware is changing. The software techniques are changing. The level of technical expertise and the vehicle being simulated is changing.

Hardware trends indicate that the following things will occur in the future. First, memory will become cheaper. Second, computational power will become cheaper. Third, packaging will become smaller. From a simulator viewpoint this means that in spite of long term planning, a program started in 1975 will be using a computer which is expensive to expand, expensive to maintain and technically obsolete in 1982.

This is acceptable from a military user point of view as long as spare capacity/growth provisions for computer time and memory remain and the simulator meets its operational requirements. Their viewpoint soon degenerates to unhappiness when the simulator changes eat up the growth capacity and the device can no longer meet its performance or supportability requirements. From a logistics point of view it can approach a nightmare.

How can that happen, you may ask? Well, for one thing, spares are in the national supply system at assorted revision levels. Unless spares are kept with a simulator, there is no guarantee that a board from the national supply system will work in a given system because of the revision level differences. There is, on the other hand, no certainty that it won't work either.

How did this mess come about? Simple, we procured and engineered ourselves into it. For example, Program X freezes its configuration of hardware at level B (B is made up of multiple boards at various levels). Program Y maintains its systems at current manufactured revision levels. Program Z opts to block upgrade its simulators so that the first shall be like the last in revision level and is currently halfway through a program which will field simulators for the next five years. Obviously some programs spares are obsolete and more than likely most are. There is no logistics program that crosses contract lines to assure that all parts of the same number from the same commercial manufacturer are interchangeable.

The availability of parts at some future date is also an issue of obsolescence. How many integrated circuits will become obsolete and impossible to procure, even at prohibitive costs in the future? Or, will magnetic core planes be readily available in twenty years? If they are not available, commercial computer manufacturers would probably rather give the manufacturing drawings to the government than be burdened by trying to make technically obsolete parts.

Cost effectiveness is an issue key to obsolescence. If hardware trends continue at their current rate, some systems could be replaced by a chip in the future. Would it be practical to manufacture a fifteen year old computer board when the entire computer could be replaced by a chip?

CURRENT SOLUTIONS

If the problems referenced in the previous section are to be overcome it is perhaps wise to study the current approaches being taken by today's simulator programs from both a military and commercial computer manufacturer's point of view.

1. Long Term Support. The current trend is to contractually commit a computer vendor to support the product provided to the simulator manufacturer for X years. (X means the maximum number which the computer vendor can be coerced into without extra cost) This approach is unrealistic as it really doesn't solve the problem but rather shifts the problem into the future where hopefully all concerned participants are retired, at another company, or another job. Typically, the support requirement is very vague and difficult to understand or provide.

The spares issue is also an interesting problem. Under the current system only initial spares are procured with the simulator while formal spares provisioning is performed later by another organization. This other organization is not capable of determining revision levels on cards unless they are issued an NSN (National Stock Number) on a per revision level basis. Acceptance is interesting since the spares are procured by spec control drawings. The commercially manufactured spares probably won't meet the drawings since the parts are many revision levels advanced when the procurement finally takes place.

Typically a computer supplier or a peripheral manufacturer is not interested in making boards which are at revision level B when T is the current manufacturer's revision level. Depending on when the order is placed the board may not have been in production for many years. Manufacturing to the old level would result in premium costs for special production runs. Some suppliers have an automatic upgrade to the latest revision level when a board is returned for repair. Therefore, a repaired board may differ significantly in configuration or performance from like units in the supply system.

Attempts have been made to buy the spares with the computer and hope that they will last for the life of the program. This approach will work if estimates are good, if there is enough funding to procure the necessary spares concurrently with each delivered machine, and if the spares can be controlled and co-located with the simulator. This requires that the shelf life for the spares exceeds the program requirements which may not be true.

"The first shall be like the last" approach demands that the previously delivered systems will be upgraded to the configuration of the last delivered system in a procurement. This approach also can work, but the potential problems previously indicated are still distinct possibilities. Depending on the timeframe between acquisition of the first and the last multiple sets of spares, the spares may or may not be of value when the systems are upgraded.

The block update scheme is a variation on "the first shall be like the last" approach. The first units are gradually brought up to the following units configuration as they are fielded. For multi-year procurements multiple upgrades to delivered systems are a foregone conclusion. For example, units 1-5 will be upgraded to look like units 6-11, then units 1-11 will be again upgraded to look like units 12-15. This approach is workable if managed correctly but can still be costly depending on the timeframe and operational requirements of the system.

Perhaps the most realistic approach which has been suggested is the preplanned replacement of computer hardware X years into the program. For example in a program with a twenty year life cycle which will be fielded over a period of seven years the computer system would be replaced at year eleven and spares would be procured to last the additional nine years.

2. Software Compatibility. There have been two major approaches recently to address the software compatibility problem. The first approach was the higher order language mandate. The second was use of the commercial off-the-shelf computer vendor supplied Operating System. Software Configuration Management has been required but as yet has not met with the anticipated results due to lack of enforcement on the Government's part.

The higher order language mandate proved to be beneficial to both the government and the manufacturers as Engineering Change Proposals (ECPs) are not the great mystery they once were from a software point of view. Also, it is easier to train and obtain people who are conversent in a higher order language such as FORTRAN. This will also be true if ADA becomes the standard in the future.

The computer manufacturer supplied OS software approach removed the custom tailored OS as produced by the individual simulator manufacturer. This allowed easier maintenance and easier ECP incorporation along with easier training of support and operational personnel. All is not perfect, however, the computer vendor OS is constantly changing and must be tracked via software configuration management to insure that current software and documentation are correctly distributed among the development and field systems.

Another system used for controlling the software is the software development center. On some simulators the Software Support Center concept of single point control of software change has been initiated. Under this concept, a single site is responsible for dissemination of all software, software updates and documentation. This ensures that all sites will be running the same software. This does not alleviate the obsolete software problem in regards to the computer manufacturer's latest revision level but at least it makes it more manageable.

None of the current schemes really address the issue of the compatibility between the software on a simulator system, which has been in the field for ten years, and the latest release of a computer vendor's software. This is an issue which must be faced.

3. Obsolescence. It appears that we are kidding ourselves as to the real operational life of the systems. Certain components have a fifteen to twenty year operational life but these systems change greatly. Of course, there are probably exceptions which would dispute this point. However, during these times of rapid technological change these exceptions will become fewer and fewer. As a system, the battleship New Jersey is radically different today from what it was in the 1940s. The B-52 Strategic Bomber is today radically different from what it was in the 1960s.

The average life of a computer and its associated peripherals from a manufacturer's viewpoint is about five years. After five years it is superceded by a new generation and is considered obsolete from a technology, price, or performance point of view. This does not mean that the manufacturer will stop manufacturing the machine because established customers generally buy for sometime after newer models are available. For example, the manufacturing life of a computer and peripherals would be from seven to ten years, for the computer and three to five years for the peripherals today. After ten years it probably would not be possible to continue manufacturing due to low demand and lack of availability of component parts.

Changing technology is the biggest reason for the demise of a computer. For example, computer memory technology has evolved from core to 16K metal oxide semiconductor chips to 64K chips to 256K chips and should evolve to megabyte chips and multimegabyte chips. Pricing reflects the technology. Core is considerably more expensive than 256K chip technology.

Not only does the hardware become obsolete but the software becomes obsolete. Currently there are assembly language systems and FORTRAN systems in the field. In the future ADA systems will be fielded. How difficult will it be to maintain and update the existing assembly language systems which need to be modified due to changed in the aircraft systems in the future? It will be very difficult if not impossible due to the lack of motivation for people to learn the intricacies of assembly language programming. Will the same thing be true of FORTRAN based systems in twenty years?

RECOMMENDED SOLUTIONS

There are several possible solutions which may alleviate the problems indicated in the previous sections. Whether they will be implemented will depend on how serious we are about solving the problems. The solutions as summarized in Figure 2 will necessitate cooperation between the services, the logistic portions of the services, the prime contractors and the computer manufacturers. They will necessitate a change in the way we all look at a program such that we take our special interests and set them aside in favor of realistic needs, thus providing efficient, effective, and maintainable systems. Whether this is possible or not only time will tell. If it isn't, we will all have failed.

1. The government must recognize that commercial computers and their associated spares have a maximum useful life of ten years and plan to replace them with software compatible units in the ten to twelve year timeframe. This requires planning at the inception of the program, not after it it ten years old.

This would minimize the spares, obsolescence, and the compatibility problems.

2. Change the way we handle computer spares in the National Supply System or mandate that the spares for a given simulator reside at the support center of the simulation system and be dispursed from that location so they they reflect rev levels of the cards.

3. Make the computer supplier the depot level support unit and fund it appropriately to insure a steady stream of spares flow through to the simulators and simulator manufacturer who support them.

4. Establish a review process which includes the computer manufacturer to determine the best time for major hardware and software replacements.

5. Simulators must be maintained at the current computer manufacturer's revision of the operating system.

6. Establish a interservice/prime computer manufacturer committee to recommend ways to change the way we handle support for simulators.

7. Commission a life cycle analysis of real data on simulators currently fielded to determine what is viable from the current methods and problems need to be overcome.

LAYERS OF CONTRACTORS ON PERIPHERALS

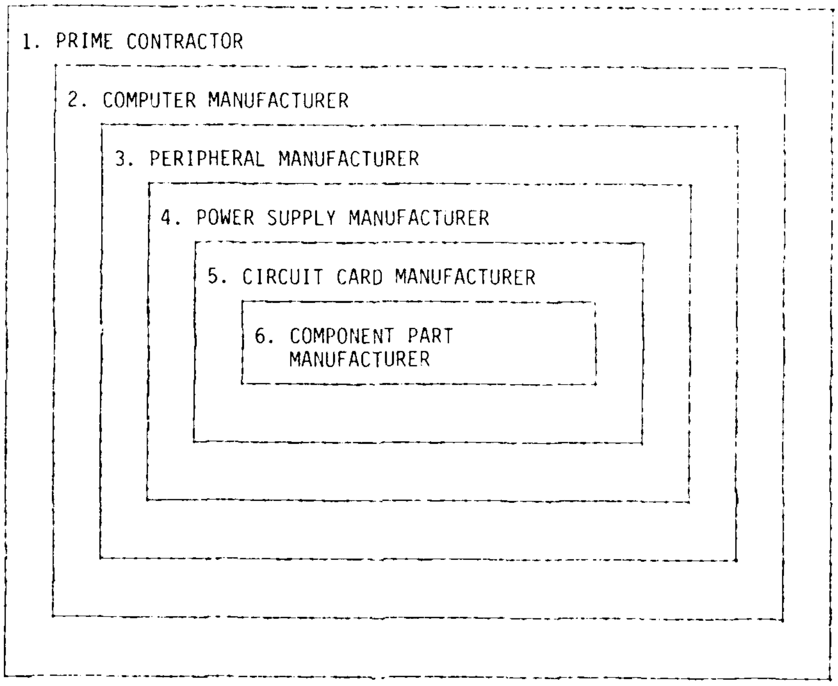

FIGURE 1

SUMMARY OF PROBLEMS AND SOLUTIONS AND FUTURE RECOMMENDATIONS

PROBLEM	CURRENT SOLUTION	FUTURE RECOMMENDATIONS
1. Inappropriate Life Cycles	Commitment	Planning Replacement
2. Incorrect Spares	Spares Stay On-Site	Change Stock System
3. Source for Updated Spares	Field Modify	Depot Becomes Computer Manufacturer
4. Software and Hardware Update Planning	Unplanned From Computer Manufacturer Point of View	Joint Effort
5. Software Obsolescence	Varies From Program to Program	Update to Current Revision Level
6. Lack of Common Interest in Problem	Adversary Role	Joint Team Approach
7. Lack of Current Data	None	Study Program

FIGURE 2

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Mr. McCaskill has accumulated over twenty years of engineering and marketing management experience in the Military/Aerospace sector. Mr. McCaskill is currently with Burtek, Inc. as Vice President of Marketing. Previously at Perkin-Elmer Corporation, he was responsible for Government Marketing. Prior to Perkin-Elmer Mr. McCaskill was employed by the Harris Corporation, he was responsible for program management for such programs as F-15, UPTIFS, B1, A4S, and B-52. At General Electric he was involved with the Poseidon and Polaris program in a Field Engineering capacity.

PROFIT RESPONSIBILITIES IN THE SIMULATION AND TRAINING EQUIPMENT INDUSTRY

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ABSTRACT

The objective of increased readiness through training can be enhanced through mutual military/industry efforts to support a viable earnings position. Strong financial health of companies competing in the market provides the resources, knowledge and systems that supply advanced technology and products that meet military training objectives.

Government agencies can contribute by providing clear definitions of the product needed, by imposing only specifications necessary to meet acceptable quality, and by contracting provisions commensurate with program risk. With firm product goals and applicable specifications, industry can minimize risk through sound planning and stable performance.

Industry can contribute by developing resources and systems that are efficient and effective in providing training products. Capability growth fosters innovativeness in advanced planning and productiveness, which are significant to providing quality products on schedule at the lowest cost possible. Industrial growth to bring this about is possible only if industry is in a strong financial position.

The government's goal is to obtain the best training possible for the dollars they spend. Industry must work with government agencies and together establish how to reach these common goals and find the most cost- and training-effective solution to each training need.

The government's needs are defined by specifications, statements of work, funding availability and weapon IOC dates. Industry is constrained by the resources, systems, knowledge, and innovativeness they have at their command. For these factors to culminate in systems that provide increased readiness through training, a significant amount of planning and preparation must occur.

To compete in the simulation and training equipment field, industry must make the investment necessary to develop the skills, provide the facilities and the design, production and management systems to effectively plan, execute, and control complex programs. These attributes are assembled over a long period of time at considerable expense. This expansion of resources and systems evolves from financing through contracted products and industry investments in research and development.

Contracted work is all important, for it not only is the source of monies to build and sustain capability, but it provides the incentive to pursue further simulation and training equipment business. Industry must see profit opportunities on current contracts and an expectation of continuing contracts to aggressively compete in the market. Profit opportunities result from a well conceived plan to produce a defined product. Ingredients of the plan include a thorough description of the objective (product), a sound conceptual approach, a complete schedule plan, reasonable cost targets and definition of potential risks. With a sound plan and good management, a reasonable profit can be achieved.

Industry investment in research and development provides the baseline knowledge to nourish the innovations that make needed products cost- and training-effective. It gives substance to the premises presented as solutions for development and design of the product. The payoff is in enhanced operational readiness resulting from advanced technology and effectual products.

The objective of training is to maintain the level of performance demanded by modern high technology. The government's tasks of defining training equipment to meet this objective continues to increase in difficulty. In the Summer 1982 DoD Acquisition Improvement Program Special Issue edition of "Concepts,"(1) authors Lieutenant Colonel Garcia E. Morram and Dr. Jules J. Bellaschi point out that, "The United States has concentrated on producing sophisticated weapon systems that have been reactive to changes in threat and technology." This approach has been maintained by using high risk technologies in the development process. An alternative that minimizes the resulting cost and schedule risk is the use of ". . . relatively mature technology and planning for the incorporation of advanced technologies after the system is developed."

Both of these approaches present problems in the definition of configuration, capability and quantities of traning devices to be employed. As the weapon system undergoes rapid design and technology changes, the government and contractors are faced with incorporating appropriate changes and reflecting actual operation of the aircraft in the simulator design. The simulation environment is impacted by more complex logistics and the probability of decreased equipment availability through changes and failures. Sophistication and longevity extends the commitment of the government and or the contractors. This commitment represents risk that each seeks to avoid and that must be equitably shared to achieve the desired objective.

In the Calspan B-1 Systems Approach to Training Technical memo Analysis,(2) of "Implications for B-1 Aircrew Training," it is stated that ". . . another important concern in establishing training device requirements is that the devices, irrespective of their capabilities, are used to their maximum effectiveness. As Micheli (1972) states in his analysis of trainer fidelity and training transfer . . training effectiveness is more a function of the manner in which the trainer is used than of the fidelity of the trainer." The relationship of weapon system sophistication and training equipment definition is stated in this writing as ". . . A common misconception with respect to training is that the sophistication of the operational system and the duration of training (along with the complexity of training devices) are positively correlated. Logically, one would then expect there to be an inverse relationship between training time and degree of sophistication (i.e., automation) of the operational system."

With the obvious significance of the need for early and complete definition of simulator application and capability, it is interesting to note that the Calspan B-1 SETA Technical Memorandum,(3) "B-1 Aircrew Instructional System Development Final Report," states, "In the past there has been little interaction between the engineers who design the simulator systems, the instructional systems development personnel who design the instructional system, and the instructors who will eventually use the system."

Training device definition also should incorporate features employed by the instructor to facilitate greater efficiency in the learning task and maximize the transfer of simulator training to the operational aircraft. Subsequent to initial student training, simulators are also used to maintain crew proficiency. Definition of application is significant to the design of capabilities that maximize the equipment's effectiveness.

Interaction of these key factions must be encouraged to successfully fulfill the DoD D-5000 2 objective contained in the section on Manpower and Training. "New systems shall be designed to minimize both the numbers and skill requirements of people needed for operation and support consistent with system availability objectives . . manpower and personnel considerations Government encouragement for the early involvement of industry in the acquisition cycle enhances the application of new technology in the final product Early interaction gives industry an opportunity to examine their options to be creative, to establish a sound resources plan, to give more realistic direction to their research projects and to develop an effective product plan that reduces industry risk.

The benefits realized by the government from early industry involvement can go beyond reduced risk The capability of industry is expanded through each commercial application of training equipment When the definition of training requirements permit the use of commercially developed and applied technology, government costs are reduced Reduced costs of basic simulator subsystems such as linkage or motion bases makes available more money to fund DoD special needs Analysis of basic training needs identifies the training objectives that require high fidelity subsystems Savings resulting from application of commercially available systems can then be utilized in the development of, for instance, Digital Radar Land Mass Systems (DRLMS), weapon system delivery systems, etc., that represent military special needs

Use of commercial technology can be encouraged through eliminating or waiving specifications and statement of work elements that limit or prohibit its application The 1982 Defense Science Board,(4) during its Summer Study, concluded that, " one particular training device has 176 top level military and Federal specifications and 954 second level specifications, whereas if it were bought to Commercial Practices, some 10-12 specifications apply" Such a proliferation of regulations is expensive to administer, may eliminate prospective contractors or subcontractors, may not be cost-effective to apply to commercial products and will complicate the contracting process. Interaction of government and industry can arrive at an acceptable compromise consistent with developing cost- and training-effective equipment.

An Air Force Systems *Command analysis* of the effects of cost growth on system acquisition identified factors that historically contribute to this growth Of the five most significant, technical problems and impact of technical advancement have declined in severity Technical complexity as a factor has grown only slightly, with less growth in the 1970s as systems become increasingly more sophisticated The analysis concluded that " The big surges since the days when systems cost less and were fielded sooner have come in external management impact and in funding instability

This study indicates that government and industry effort to define the desired product has shown progress but other disruptions have accelerated These disruptions represent a significant risk to both the short- and long-term profit objectives of industry Sound product planning and stable performance is jeopardized and capital investment is less attractive when there is insecurity in the market Unfortunately these are factors normally beyond the control of government agencies responsible for systems procurement but they must be recognized and dealt with to minimize the impact whenever possible

In order to establish the capability to bid on government procurements as a prime contractor, members of industry must invest in capital equipment, research and development, personnel and operating systems Skills required to develop, design, produce and deploy an efficient device are diverse and can be obtained only through training, experience and current state-of-the-art knowledge Dr Andrew P Mosier in his article "Enhancing Productivity Through Increased Capital Investment,"(5) states, " . . internal cash flows are the main source of funds available to defense contractors for financing investments in new technology and capital equipment Experience has shown that unless total cash flows from long-term defense contracts cover a substantial portion of the operating costs, few contractors will make capital investments to improve their productivity on defense programs." Both, new technology, especially in the areas of DoD special needs, and efficient productivity, are necessary for a firm to be sufficiently competitive to secure and maintain a military contract baseline. This process, shown in Figure 1, expands beyond a regenerative cycle as more funds become available to invest in advanced simulator technology, new manufacturing processes and modern equipment

As a firm's baseline position gains strength, its competitive proficiency increases As the contractor's baseline and cash flow grows and as he anticipates his share of the long-term training equipment market to *expand*, the firm will optimistically make the long-term investments needed to solidify their competitive position When competition sharpens, the government benefits in a number of

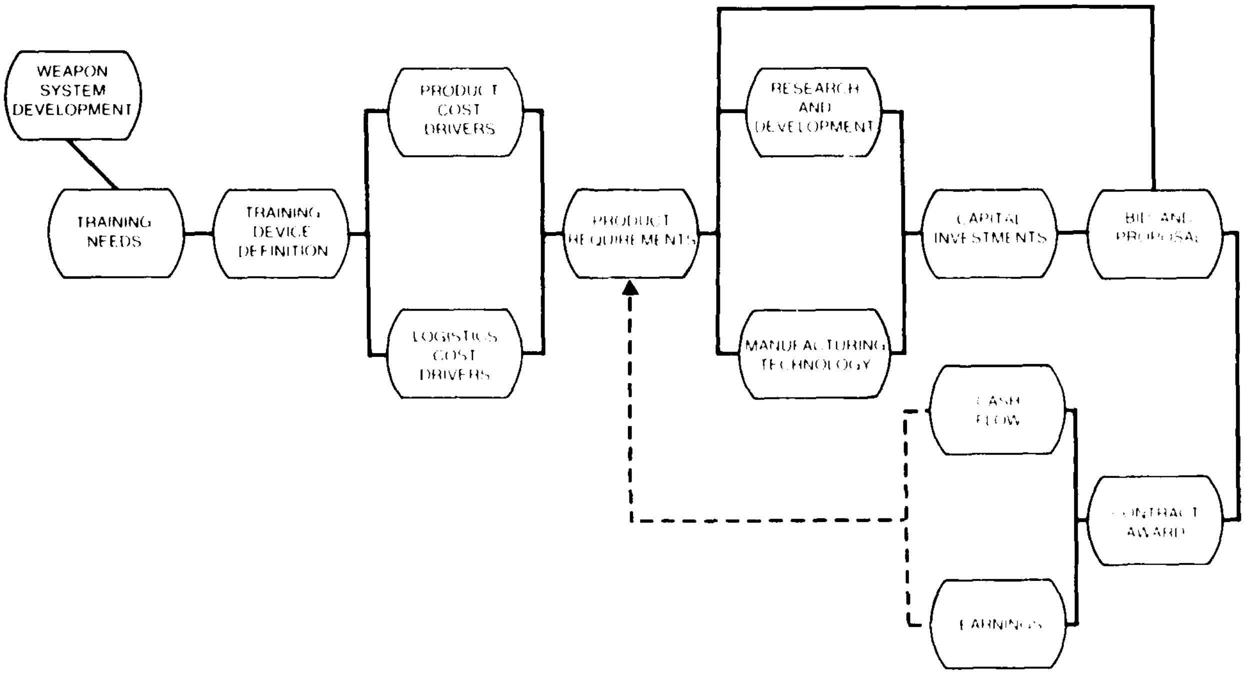

Figure 1 Government-Industry Product Development

ways. In writing about "Increasing Competition in the Acquisition Process,"[7] John C. McKeown notes this scope as, "For DoD, the benefits of competition extend beyond just cost reduction to include stimulation of innovation not only in technological and design areas, but also manufacturing, lower unit costs, satisfactory technical performance (and also quality), and a strengthened industrial base."

Contract commitments are another key consideration for industry in their pursuit of military simulator business. Specifications, statement of work and schedules establish the parameters that define the degree of risk a project represents. Contract terms and conditions determine the government/industry participation in that risk. Total risk, represented by a project, can be minimized by both participants through early preparation. The cost of initial preparation and development is a small portion of a training device. Government/industry interaction to mutually define the expanse of the program and funding, state-of-the-art technology and schedule limitations will provide the framework for a strong competition and a sound and attainable project.

Identifying risk and contractor investment associated with a project gives a firm basis for establishing a profit objective and contract type. As risk is reduced, the contract type should move from cost reimbursement toward fixed price. A profit objective should be structured to recognize assumption of risk, contractor investment and performance. Defense Acquisition Regulation (DAR) Guidelines set forth ground rules for the application of specific contract types.

The contract type should be selected to provide a maximum incentive for the contractor to perform to the desired level in the most economical manner commensurate with the circumstances of the particular procurement (Figure 2). Fixed price contracts normally provide the most incentive for contractor performance. However, degree of effective competition, extent and nature of contract performance, level of contractor experience, relationship of contract requirements to state-of-the-art, perceived accuracy of the quoted price, degree of financial risk and financial position of the contractor can influence the decision to select a contract type other than firm fixed price.

While the profit motive induces contractors to commit resources, cash flow makes these resources available. Cash flow comes from progress payments and sales. Recently, the government has recognized the contractor's need for cash flow relief. Provisions have been made for increased progress payments. When applicable, flexible progress payments can be implemented and milestone billings may be used to supplement progress payments. These cash flow reducing techniques also have aided contractors in reducing the amount of interest expense, an unallowable cost, they accrue in performing government contracts. These provisions should be a significant element in the contracting process and must be applied in an effective manner to maintain the financial health of military contractors.

In conclusion, the interfaces required to produce and maintain training devices for high technology systems are numerous and complex. Mutually acceptable results only come through the extensive effort of government and industry management in close interaction. Explicit definition of a training devices application and capabilities must be thoroughly prepared by the government. Specifications must be tailored where commercial off-the-shelf products will meet performance and maintainability requirements or where special/specific capabilities need to be emphasized to meet training requirements. Industry can help identify such areas and aid in the most effective use of available funds if brought into the procurement cycle early enough. Timeliness of funding by the government motivates industry to respond with innovation and cost-saving productivity to provide state-of-the-art training devices while maintaining earnings at an acceptable level. Industries that are not making a profit will not make the long-term investments in technology and facilities that are necessary to support government agencies in their effort to gain increased readiness through training.

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RISK	PROGRAM CONDITIONS							[illegible]
LOW	COMPETITIVE	WELL DEFINED CONTRACT REQUIREMENTS	HIGH CONTRACTOR EXPERIENCE BASE	CONTRACT REQUIREMENTS WITHIN STATE OF THE ART	COST PRICE VARIATIONS ANTICIPATED TO BE MINIMAL	LOW CONTRACTOR FINANCIAL RISK	[illegible] CONTRACTOR FINANCIAL BASE	[illegible]
MODERATE	SOME COMPETITION	GENERALIZED CONTRACT REQUIREMENTS	VARIED CONTRACTOR EXPERIENCE	MODERATE TECHNOLOGY ADVANCEMENT	COST PRICE VARIATIONS ANTICIPATED	MODERATE CONTRACTOR FINANCIAL RISK	[illegible] CONTRACTOR FINANCIAL BASE	[illegible]
HIGH	SOLE SOURCE OR LIMITED COMPETITION	VAGUE CONTRACT PERFORMANCE	LIMITED CONTRACTOR EXPERIENCE	DEVELOPMENTAL OBJECTIVES	ACCURACY OF QUOTED PRICE UNCERTAIN	HIGH CONTRACTOR FINANCIAL RISK	LIMITED CONTRACTOR FINANCIAL BASE	[illegible]

Figure 2 Contract Selection Considerations

ABOUT THE AUTHOR

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AUTOMATED SOFTWARE TESTING

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ABSTRACT

In order to obtain the enhanced testing capability required to test sophisticated trainer software and to ensure the quality of test documentation, AAI has developed an automated software testing system. Its advantages include:

1. Automatic production of all test documentation.
2. Guaranteed agreement of the values inserted into or read from memory during a test with test documentation.
3. Guaranteed consistency of test documentation with other documents.
4. The ability to compare or insert repetitively large buffers of data; testing is no longer subject to the limitations of hand-insertion of data, or visual comparison of data.
5. Simultaneous updating of both test and test documentation through the editing of test disc files.
6. The ability to save large areas of memory for future comparisons, a feature especially useful for software integration.

This paper examines the AAI software package in detail.

INTRODUCTION

Thorough testing is the only way to ensure the error-free operation of trainer software. Moreover, the ever increasing complexity of trainer software, as military systems grow in sophistication, demands a corresponding increase in the amount and effectiveness of software testing.

In view of this situation, it is not surprising that software testing represents a substantial financial burden to the development process. This burden is further increased by software standards which require thorough documentation of testing, such as MIL-STD-1644. In such cases, the problem of ensuring that the documentation accurately reflects the testing process can be difficult.

AAI has solved the documentation problem, and enormously eased the burden of testing as a whole, by developing the software package presented in this paper. The package represents a rather general, language-independent approach to the testing problem which can be adapted to the needs of almost any software development effort.

BACKGROUND OF THE SOFTWARE TESTING SYSTEM

The automated software testing system described in this paper is part of a development and documentation package successfully used by AAI in the development of the 20B5 Pierside Combat System Team Trainer. It is important to note that 20B5 software development was subject to the requirements of MIL-STD-1644, which demands thorough documentation of all development stages, including testing.

In this paper, we are principally concerned with the Computer Program Test Procedures Report (CPTP) required by MIL-STD-1644. However, the AAI package also produces the following MIL-STD-1644 documents:

Data Base Design Document	(DBDD)
Program Design Specification	(PDS)
Program Description Document	(PDD)

Indeed, it is the commonality of many components of the testing system with the documentation system which ensures the consistency of the CPTP with the other documents.

The AAI package was developed on the general purpose computer central to the 20B5 project, the SEL 32/87 minicomputer. It requires approximately 60K of 32-bit core and substantial disc space. (The amount of disc space required depends on the size of the particular software project). It is written almost entirely in structured FORTRAN, SEL version 77+.

DEFINING A TEST IN THE AUTOMATED TESTING ENVIRONMENT

The testing approach taken by the automated testing system is "black box testing". That is, the testing system neither knows nor cares how a program works; it only tests whether or not the outputs of the program are correct for given sets of inputs. Of course, if problems are detected during such testing, it may be necessary to use other methods to locate the source of the trouble.

In order to associate inputs with their corresponding outputs, tests for the automated system are defined as a series of steps. In each step, inputs are made to the program being tested by means of a specified operator action, known as the "control action". The test operator then checks that the resulting outputs of the program are as expected; if they are not, a failure has occurred. The expected outputs are known as the "expected results" of the test step and are part of the step definition.

Control actions may be either "textual" or "numerical". In a textual control action, the operator is asked to throw a switch, make a tableau entry, or do anything else which does not directly involve program symbols. In a numerical control action, the test operator is instructed to set specified program symbols to specified values.

Similarly, expected results may be either textual or numerical. In a textual expected result, the operator is asked to make an observation not directly involving program symbols (e.g., a light is on). In a numerical expected result, the operator is asked to verify that specified program symbols have specified values within specified tolerances.

It should be noted that in defining tests for the automated testing system, there is no limit to the number of symbols and/or values which may be specified in a single numerical control action or expected result. Value repetition counts and symbol subscripts are available to facilitate the definition of large data buffers for insertion or comparison.

Often the execution of the program being tested is suspended while the operator performs control actions or verifies expected results; however, this is not a requirement. Instructions for suspending or resuming program execution may be placed in the test as textual control actions.

Each test occupies a separate disc file known as a test source file. The test source file is created by the system text editor and follows the format required by the program TESTWIZ (see following section). In addition to a complete definition of each test step, the test source file contains all information necessary to produce a complete test section of the CPTP document. Included in this additional information are the test title and section number, initial conditions, and test equipment requirements.

As we shall see, our automated testing system provides automation of the numerical portions of each test step but not of the textual portions. This is not a serious restriction; the vast majority of software testing can be accomplished in the realm of program-symbol values.

THE SOFTWARE TESTING SYSTEM

The components of the AAI development and documentation package that comprise the software testing system are shown in the block diagram of Figure 1. We will discuss each of the major components in turn.

Central Data Base File

The central data base file is the keystone of the AAI package. It is a random access disc file that contains complete descriptions of every data base item (symbol) in the system under development. In particular, it contains all the information required to order data base items in common blocks (type, dimensions, equivalence, etc.). We note that the DBDD is produced entirely from the central data base file.

DATAWIZ

DATAWIZ is the program responsible for creating and maintaining the central data base file. It also generates convenient listings of data base item descriptions in which item selection can be keyed to any desired item characteristics. The "DATAWIZ INPUT FILES" shown in Figure 1 consist of programmer supplied tables fully describing the inputs and outputs of each module in the system.

FORTWIZ

FORTWIZ defines the location in global memory (common blocks) of each data base item based on the information contained in the central data base file. It writes FORTRAN specification statements (type, dimension, common, and equivalence) for use by all software modules, including the software being tested. It also outputs "global maps" or symbol dictionaries that connect symbols with addresses. These global maps are in turn read by TESTTOOL (see below). The execution of FORTWIZ is controlled by a command file, normally created with the system text editor.

TESTWIZ

TESTWIZ is responsible for processing test source files. It combines the information contained in the central data base file with the test definitions of the test source files, as well as with text files (containing introductory paragraphs) to produce the entire CPTP document. In addition, it compiles the same information into compact binary files, called "compiled test files" for use by TESTTOOL during the testing process. Incidentally, TESTWIZ properly handles classified sections of the CPTP, calculating the classification of each page and correctly labeling it with its security classification. Like FORTWIZ, TESTWIZ is controlled by a command file that is usually created with the system text editor.

TESTTOOL

TESTTOOL is an interactive program that automates the performance of memory insertions (numerical control actions) and memory comparisons (numerical expected results). It reads the compiled test files generated by TESTWIZ.

Each file contains all of the numerical operations required for one test. During testing, TESTTOOL reads and writes the computer memory used by the program being tested to perform the necessary comparisons and insertions.

The test operator is assumed to be following a procedure described in the CPTP (document output of TESTWIZ). The numerical operations of the test are referred to by the number of the test step in which they appear in that document.

TESTTOOL provides the test operator with the following capabilities:

1. The operator may perform the numerical insertions required by any step or range of steps with a single terse command, regardless of the size of the data buffers involved.

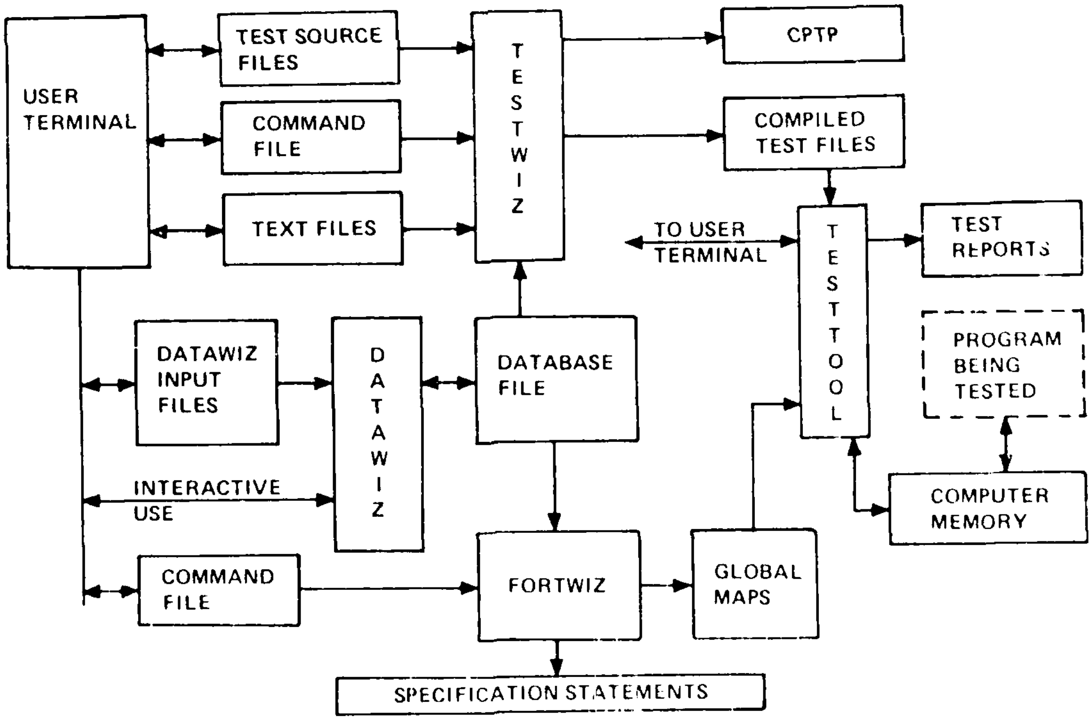
2. The operator may perform the numerical comparisons required by any step or range of steps with a single terse command, regardless of the size of the data buffers involved. The comparisons performed by TESTTOOL properly account for the tolerance specified in the test source file.

3. The operator may examine the numerical operations required by any step or range of steps without performing them.

4. The operator may save the actual values read from computer memory for a numerical comparison. Such values are written to a file in a form suitable for direct inclusion into a test source file. After such an inclusion is performed (usually with the system text editor) and the test source file is compiled by TESTWIZ, the saved values become available for use as expected results in future comparisons.

5. The operator may produce a complete hard-copy report of the insertions, comparisons, and listings during the TESTTOOL run. The report is automatically identified with the title and CPTP identification number of the test, as well as with the name and version number of the central data base file used to supply the data base information required to compile the test. The information within the report referring to each step is labeled with the correct step number. Test failures are prominently identified and the deviations from the expected results are given. The user has the option to include only failures in the report or include all values compared.

As shown in Figure 1, TESTTOOL reads the global maps produced by FORTWIZ to locate symbols in memory. This global map is guaranteed to agree with the memory assignments of the program being tested because those assignments are also made by FORTWIZ via the FORTWIZ-generated specification statements.



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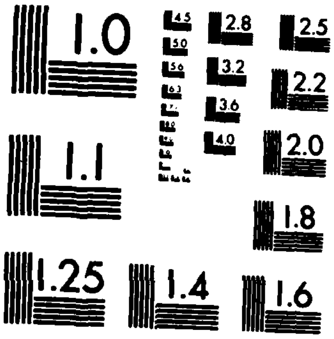

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ADVANTAGES OF THE AUTOMATED SOFTWARE TESTING SYSTEM

The automated testing system described above streamlines the performance of black-box software tests based on program-symbol values. It has the following considerable advantages over manual methods:

1. Because tests are stored in disc files that are read by the testing system, the same numerical operations can be repeated over and over again, the tests are reproducible.

2. The ability to insert or compare large buffers of data is another natural consequence of disc file test definition.

3. Comparisons are automatically performed taking tolerances into account. Memory insertions are also automatic.

4. Complete test reports, highlighting failures and showing deviations from expected results can be produced in hard copy form at the convenience of the test operator.

5. The same test definitions used to run the test are used to automatically generate the CPTP docuent. This ensures that the document accurately reflects the testing process.

6. Because the CPTP and other documents are all based on the same central data base file, the consistency of the CPTP with other documents is assured.

7. The ability of the testing system to save present actual results for future comparisons provides a convenient method of monitoring changes in computer memory as new versions of software are tested.

Under the present system, the program being tested and the testing programs are together by the automatically generated global maps and FORTRAN specification statements that serve to associate symbols with memory locations. However, it should be emphasized that FORTRAN is merely incidental to the necessary task of linking symbols with addresses; any automatic method of doing this would serve equally well. The automatic testing approach is really a language-independent testing method that can be used whenever symbol-based black box testing is appropriate.

ABOUT THE AUTHOR

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AUTOMATIC AUDIT INFORMATION SYSTEM FOR SOFTWARE DEVELOPMENT

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ABSTRACT

Management of a software development project is typically characterized by a lack of control and poor projections. Status reports are notoriously inaccurate; worse yet, the prerequisite software audits drain development resources from the design effort.

This paper describes an automated procedure for performing software audits and generating status reports. This procedure reduces the time required for both tasks significantly, and makes status reports available upon demand. Timely status reports furnish management with an early warning of problem areas so that project control can be exercised. For example, resources may be reallocated or additional resources employed where these problems are identified.

The Automatic Audit Information System for Software Development (AAIS) procedure has been implemented by AAI Corporation for the development of Device 20B5. It is based upon the following concepts:

- A central software development library
- Software development milestones and criteria
- Functional hierarchies
- A development scoreboard.

AAIS provides the 20B5 management with close project control by means of timely audits and concise status reporting.

Introduction

The technological revolutions that have yielded more powerful and sophisticated computer systems have encouraged defense contracts for more complex and higher fidelity training systems. As trainer specifications incorporate the new technology, designs such as those incorporated in Device 20B5 are often required for effective simulation and stimulation for team training. Team training implies a multi-task environment to support several operational equipments which are typically employed in cooperative roles. In this case, the simulation software developed exceeds the scope of medium-complexity software systems of the past, and becomes one of the complex software systems of the present. The development effort for complex systems is larger, by an order of magnitude, and must be carefully controlled in order to ensure its successful completion. This control must be implemented with concise and timely status reporting. However, the preparation of status reports must not interfere with the critical milestones established for design personnel. In addition, the information retrieved, analyzed and presented must accurately reflect the current status of the software development effort.

The Automatic Audit Information System for Software Development (AAIS) procedure has been developed to efficiently track software development with a minimum of design personnel interaction. The progress reports which are generated, provide both management and design personnel the information needed to monitor software progress and identify schedule and cost variances. The various report formats allow the manager to selectively scan the information and extract those items which are pertinent for analysis. The reports highlight milestone completion with regard to budget and schedule, which is of primary concern to management personnel.

The automated procedures incorporated in the AAIS program are controlled by criteria established during the infancy of the software development effort. These criteria are derived from contractual requirements such as those presented in MIL-STD-1644. In addition, documentation defined by the Data Item Descriptions (DIDs), in particular, the Program Design Specification (PDS), assist in formulating the Software Work Breakdown Structure (SWWBS) which becomes an integral foundation for the command and control facilities used to drive the AAIS program.

Design of the AAIS

The Automatic Audit Information System for Software Development (AAIS) procedure has evolved as a result of continuing efforts at AAI to track and control software development for training devices. The salient features which have emerged are:

- Software hierarchies
- Milestone completion criteria
- Software development scoreboard
- Centralized on-line development library

- Software module formats

- Automated audit and report procedure.

Each of the above features is described below in the context of its application to the development of Device 20B5. Figure 1 presents a diagram of the AAIS concept.

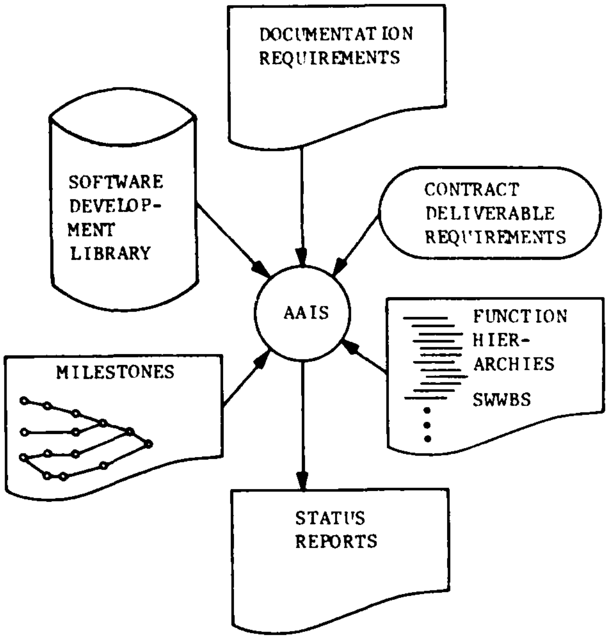

Figure 1. The AAIS Concept

The contract sponsor requires a hierarchal listing of software modules for each functional area defined in the Program Performance Specification (PPS) and detailed in the Program Design Specification (PDS). The sample hierarchy given in Figure 2 indicates naming conventions and the control structure defined for the function. These hierarchies are entered and maintained in an encoded form, known as the Software Work Breakdown Structure (SWWBS), on the computer storage media. The stored files represent a means of addressing a functional area down to the module level.

Milestones are provided by the customer in the form of contractual delivery and report dates. These dates imply that software managers must develop the necessary and detailed software development milestones required to meet the contract delivery dates. This effort amounts to critical path scheduling of available personnel within time and computer availability constraints. Five (5) software development milestones are defined as follows:

- Module design

- Module coding

- Module test driver design

- Module testing

- Function testing.

```
3.2.2.5.2       ASW ENVIRONMENT (SONOBUOY &
                AN/SOS-56 SONAR) FUNCTION SWWBS
                (PDS SECTION:  3.3.2.5.2)

SEL TASK:  NEW              COMPUTER:  OWNSHIP

NO2NEXEC                    NEW TASK EXECUTIVE
   NE4EXEC                  ASW ENVIRONMENT (SONOBUOY
                              & SOS-56) EXEC
      NE5WKMSK              WAKE MASKING CONTROL
         NE6WMREF           WAKE MASKING DATA FORMAT
         NE6WHERE           WAKE SEGMENT POSITIONS
         NE6STATS           SENSOR STATUS AND WAKE
                              POSITION
         NE6STREN           WAKE SEGMENT STRENGTH
      NE5DOPRT              DOPPLER RATIO
      NE5OPL56              SOS-56 OCEAN PROPAGATION
                              LOSS CONTROL
         NE6INTRP           PROPAGATION CONTROL
            NCZINTP2        TWO-WAY INTERPOLATION
      NE5SNBWO              SONOBUOY WASHOVER
      NE5OPRLS              OCEAN PROPAGATION LOSS
                              CONTROL
         NE6OPLRT           OCEAN PROPAGATION LOSS
                              RETRIEVAL
            NCZINTP2        TWO-WAY INTERPOLATION
      NE5AMBNS              AMBIENT NOISE
      NE5KBSHD              KELP BED SHADOWING
      NE5TCNIM              TCNI MANAGEMENT CONTROL
         NE6HARME           HARMONIC FAMILY DATA
            XDZDSCIO        DISC I/O QUEUING
         NE6RECRD           RECORD NUMBER
            XDZDSCIO        DISC I/O QUEUING
         NE6VALID           VALIDITY CHECK
            XDZDSCIO        DISC I/O QUEUING
            NCZBSRCH        BINARY SEARCH
      NE5RVERB              REVERBERATION
```

Figure 2. Sample Function Hierarchy

The completion criteria for each milestone is provided by project management and software team personnel. These criteria identify development requirements for the completion of each milestone. Completion of each milestone is predicted upon the existence of a critical item in the module file, e.g., the existence of the high level language (code) satisfies the coding completion criteria.

A development scoreboard is formed by the combination of a function hierarchy and software development milestones. A matrix of values can be obtained if a value is assigned to each milestone and to each module in the hierarchy. A milestone value represents a specific development weighting factor whereas a module value can be thought of as a design complexity factor for the design of the module. The resulting matrix elements are defined by computing the product of each combination of milestone value and module value. Milestones which are not completed are assigned a value of zero. The significance regarding the implications of this approach should not be overlooked. Applying a set of weighted values to milestones is in effect a means for budgeting the time required to fulfill each milestone as a fraction of the total time for an average module. At a modular level, this budgeting effort is much more precise than at a functional level. Typical estimates are available from the Pie chart illustrated in Figure 3 and in terms of industry standards for lines of code per programmer day. On the other hand, module weights are derived by allocating a total value to each function based upon perceived difficulty, and in turn, rationing this total among all modules of the associated function. The total value attributed to the function represents the amount of effort budgeted for the function. The ratio of the sum of all the matrix values to the total possible sum for the matrix is interpreted as the reportable completion percentage of the function at the time of audit.

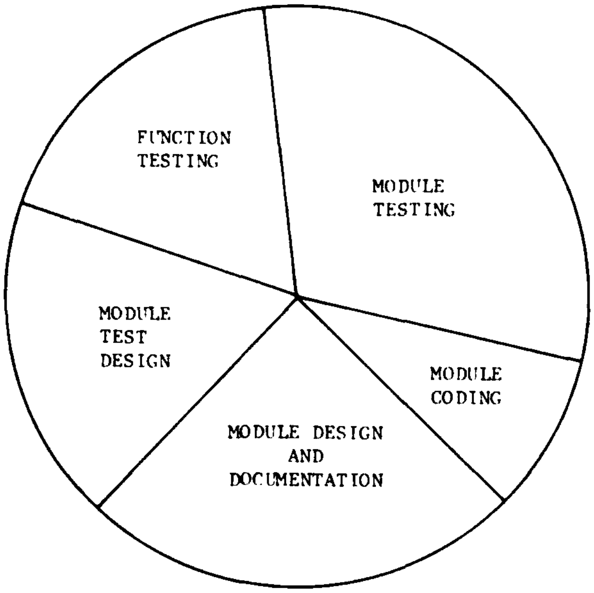

Figure 3. Function Development Costing

A centralized, computer-resident software development library makes possible automatic auditing of the software inventory. All modules are readily accessible and maintainable. Although modules are developed by individual designers, a module belongs to the project and resides in the control library. This feature is essential to project control, since all modules must be available for auditing purposes.

All modules in the central library are entered according to the format developed for Device 20B5. Templates are provided to designers and data entry personnel to simplify the process and insure standardization. The object of the format is to capture the high level language along with design summaries and internal documentation for the module, as depicted in Figure 4. These module files contain sufficient information for automatic generation of contractual reports such as the PDS. Module files represent self-contained repositories of information concerning the embedded execution language (FORTRAN) routine. This information also includes a module test procedure (a driver description) as well as configuration management data for the code and test procedure.

```
**************** 20B5 MODULE FILE ****************
**************** MODULE CONTROL DATA *************

*  MODULE NAME:  SA6SAADJ
*  MODULE TITLE:  SONOBUOY SONAR AMPLITUDE
                  ADJUSTMENT
*  MODULE SECURITY CLASSIFICATION:  U
*  MODULE PART NUMBER:  58181-7-0S1-36405-U
*  PROGRAMMER:  GABROWN

**************** PDS DATA ***********************

*  MODULE PROCESSING: SA6SAADJ WILL COMPUTE THE *
                      VESSEL SONAR AND INTER-
*                     FERING SONOBUOY AMPLITUDE
*                     DEGRADATION FACTORS OF THE
*                     RESULTING SIGNAL ENVELOPE
*                     WITH RESPECT TO EACH OF
*                     FOUR POSSIBLE SONOBUOYS ON
*                     CHANNEL.  THE DEGRADATION
*                     FACTORS ...

*************** PROGRAM DESIGN LANGUAGE *********

*PDL- 1  DO FOR EACH VESSEL TARGET SLOT
*PDL- 2     IF THE VESSEL SONAR PING INDICATOR IS
            SET TO
*PDL- 3      TRUE THEN
*PDL- 4        DO FOR EACH SQR-17 CHANNEL

**************** MODULE REVISION HISTORY *********
*  0000 06/18/83 GAB INTEGRATED
**************** TEST PROCEDURE REVISION HISTORY *
*  0000 06/18/83 GAB INTEGRATED
**************** MODULE TEST PROCEDURE ***********

C      PROGRAM DRIVER
C      REAL * 4  ERVAL11  /-2.0/, TOLER11 /0.001/
C      CALL BEGINMTP (MODULE)
C      OINSHIPB = 1
C      AASPINGL = .TRUE.
C      CALL SA6SAADJ

**************** CODE ****************************
       SUBROUTINE SA6SAADJ
       INCLUDE SONOB
       INCLUDE SONOBP
*
**************************************************
*PDL- 1             DO FOR EACH VESSEL TARGET SLOT
**************************************************
*
       DO I = 1, OINSHIPB
*
**************************************************
*PDL- 2    IF THE VESSEL SONAR PING INDICATOR IS
           SET TO
*PDL- 3     TRUE THEN
**************************************************
*
        IF ( AASPINGL (I) ) THEN
```

Figure 4. Module File Template

Finally, based upon all of the above features, an automated auditing and status reporting procedure is employed to control software development. This procedure is driven by the manager's selection of one or more function hierarchies. For each function selected, the associated hierarchy is used to provide the module names and corresponding weights. The actual modules in the central library are automatically inspected and the criteria is applied to the retrieved information such that a set of reports can be prepared. Both module and function summations are computed, along with their respective percentages of completion. Discrepancies in module file formats are discernable from the resulting reports, providing quality control for both audits and module files. History files are updated to automatically record the current audit statistics. In addition to producing status reports, information reports are conveniently produced for review by software designers. These summaries provide highly useful organizational information.

AAIS Outputs: Status Reports

The AAIS program generates seven (7) distinctive report formats for review by both managers and design personnel. The report formats contain the following information:

(1) Functional Design History and Resource Utilization by module

(2) Functional Development Status by module

(3) Functional Milestone Status by module

(4) Functional Hierarchy by module

(5) Functional Configuration Status by module

(6) Milestone Summary by function

(7) Cost Performance Summary by work order (charge) number

Report formats (3), (6) and (7) are provided as the basic set of status outputs to the manager. These summaries describe software development status in terms of milestones and cost. Report formats (1), (2), (4) and (5) provide additional organizational information to the designer. These reports highlight module design status in terms of documentation requirements and configuration management data.

The Functional Design History and Resource Utilization report lists, on a module basis, development and testing revision histories. Figure 5 depicts a sample report format.

```
3.3.2.5.2  ASW ENVIRONMENT (SONOBUOY & SQS-56)      -- FUNCTION DEVELOPMENT HISTORY --  6/13/83  06:18

COMPUTER   SEL TASK  MODULE    PROG.   DISC      ENTRY     MODULE   MODULE TEST      TEST WORST WORST
                                                 DATE      REV.     REV.   REV.      REV. CASE  CASE
                                                           DATE     LEVEL  DATE      LEVEL TIME  MEM.

OWNSHIP    NEW TASK  NCZBSRCH  FINLEY  STS20B5E  4/12/82   12/14/82 0000   12/14/82  0000 30    280
OWNSHIP    NEW TASK  NCZINTP2  FINLEY  STS20B5E  4/13/82   06/03/82 0001   06/03/83  0001 8     496
OWNSHIP    NEW TASK  NE4EXEC   FINLEY  STS20B5E  3/4/82    03/10/83 0000   03/10/83  0000 816   1160
OWNSHIP    NEW TASK  NE5AMBNS  FINLEY  STS20B5E  2/22/82   05/11/83 0001     ERR     0001 300   208
OWNSHIP    NEW TASK  NE5DOPRT  FINLEY  STS20B5E  2/22/82   01/11/83 0002   01/11/83  0002 5     200
OWNSHIP    NEW TASK  NE5KBSHD  FINLEY  STS20B5E  2/19/82   03/10/83 0000   03/10/83  0000 250   712
OWNSHIP    NEW TASK  NE5OPL56  FINLEY  STS20B5E  04/13/82  03/02/83 0000   03/02/83  0000 250   1088
OWNSHIP    NEW TASK  NE5OPRLS  FINLEY  STS20B5E  4/14/82   03/10/83 0000   03/10/83  0000 100   608
OWNSHIP    NEW TASK  NE5RVERB  FINLEY  STS20B5E  09/27/82  05/19/83 0001   05/19/83  0001 100   576
OWNSHIP    NEW TASK  NE5SNBWO  FINLEY  STS20B5E  2/19/82   03/01/83 0000   03/01/83  0000 30    144
OWNSHIP    NEW TASK  NE5TCNIM  FINLEY  STS20B5E  03/05/82  04/11/83 0003   04/11/83  0003 300   840
OWNSHIP    NEW TASK  NE5WKMSK  FINLEY  STS20B5E  07/26/82  02/22/83 0000   02/22/83  0000 100   1040
OWNSHIP    NEW TASK  NE6HARME  FINLEY  STS20B5E  16JUN82   04/12/83 0002   04/12/83  0002 10    432
OWNSHIP    NEW TASK  NE6INTRP  FINLEY  STS20B5E  04/15/82  06/02/83 0001   06/02/83  0001 2     368
OWNSHIP    NEW TASK  NE6OPLRT  FINLEY  STS20B5E  04/14/82  03/21/83 0000   03/21/83  0000 30    336
OWNSHIP    NEW TASK  NE6RECRD  FINLEY  STS20B5E  05/24/82  05/12/83 0002   05/12/83  0002 100   312
OWNSHIP    NEW TASK  NE6STATS  FINLEY  STS20B5E  07/23/82  02/21/83 0000   02/21/83  0000 100   192
OWNSHIP    NEW TASK  NE6STREN  FINLEY  STS20B5E  07/27/82  02/21/83 0000   02/21/83  0000 100   328
OWNSHIP    NEW TASK  NE6VALID  FINLEY  STS20B5E  05/21/82  04/11/83 0001   04/11/83  0001 200   256
OWNSHIP    NEW TASK  NE6WHERE  FINLEY  STS20B5E  07/23/82  02/22/83 0000   02/22/83  0000 300   560
OWNSHIP    NEW TASK  NE6WMREF  FINLEY  STS20B5E  07/28/82  02/22/82 0000   02/22/83  0000 100   656
OWNSHIP    NEW TASK  TC4EINIT  FINLEY  STS20B5E  09/27/82                                100   632
OWNSHIP    NEW TASK  XDYTAMID  FINLEY  STS20B5E  6/3/82    03/22/83 0002   03/22/83  0002 100   528
OWNSHIP    NEW TASK  XDYTCNID  FINLEY  STS20B5E  09/27/83                                100   260
OWNSHIP    NEW TASK  XDZTCN1D  FINLEY  STS20B5E  01/20/83  06/08/83 0000   06/08/83  0000 100   1736
OWNSHIP    NEW TASK  XDZTCN2D  FINLEY  STS20B5E  01/20/83  06/07/83 0000   06/07/83  0000 100   840
OWNSHIP    NEW TASK  XDZTCN3D  FINLEY  STS20B5E  03/14/83  06/01/83 0000   06/02/83  0000 100   136
OWNSHIP    NEW TASK  XDZTCN4D  FINLEY  STS20B5E  01/15/83  05/31/83 0000   05/31/83  0000 100   928
OWNSHIP    NEW TASK  TN2TCNIX  FINLEY  STS20B5E  09/27/82                                100   1000
OWNSHIP    NEW TASK  TNZTCN1D  FINLEY  STS20B5E
OWNSHIP    NEW TASK  TNZTCN2D  FINLEY  STS20B5E
OWNSHIP    NEW TASK  TNZTCN3D  FINLEY  STS20B5E
OWNSHIP    NEW TASK  TNZTCN4D  FINLEY  STS20B5E
OWNSHIP    NEW TASK  TC6GLB55  FINLEY  STS20B5E  05/19/83                                100   100
OWNSHIP    NEW TASK  TC6GLB53  FINLEY  STS20B5E  05/19/83                                100   100
OWNSHIP    NEW TASK  AMBNS2    FINLEY  STS20B5E  05/18/83                                100   100
```

Figure 5. Function Design History and Resource Utilization Report

The Functional Development Status report denotes, on a module basis, the current state of design for a function. The design states are categorized by the major milestones assigned to a module. In this way, the designer can quickly assess the overall development state of a function hierarchy and identify incomplete or incorrect data entries. Figure 6 shows a Functional Development Status report.

```
3.3.2.5.2  ASW ENVIRONMENT (SONOBUOY & SQS-56)      -- FUNCTION COMPLETION STATUS --   06/13/83  06:18

COMPUTER  SEL TASK  MODULE    PROG.     DISC      CONF  FILE     COMPLETION STATES
                                                  CONT  STATUS
                                                                 HEADER  PDL  CODE  MTP  MOD   TEST  I
                                                                                         REV    REV

OWNSHIP   NEW TASK  NCZBSRCH  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  NCZINTP2  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0001  0001  S
OWNSHIP   NEW TASK  NE4EXEC   FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  NE5AMBNS  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0001  0001  S
OWNSHIP   NEW TASK  NE5DOPRT  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0002  0002  G
OWNSHIP   NEW TASK  NE5KBSHD  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  NE5OPL56  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  E
OWNSHIP   NEW TASK  NE5OPRLS  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M   0000  0000  S
OWNSHIP   NEW TASK  NE5RVERB  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M   0001  0001  S
OWNSHIP   NEW TASK  NE5SNBWO  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  NE5TCNIM  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0003  0003  S
OWNSHIP   NEW TASK  NE5WKMSK  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  NE6HARME  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0002  0002  R
OWNSHIP   NEW TASK  NE6INTRP  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0001  0001  S
OWNSHIP   NEW TASK  NE6OPLRT  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  C
OWNSHIP   NEW TASK  NE6RECRD  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0002  0002  S
OWNSHIP   NEW TASK  NE6STATS  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  NE6STREN  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  NE6VALID  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0001  0001  S
OWNSHIP   NEW TASK  NE6WHERE  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  NE6WMREF  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0000  0000  G
OWNSHIP   NEW TASK  TC4EINIT  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M               S
OWNSHIP   NEW TASK  XDYTAMID  FINLEY    STS20B5E  YES   ENTERED  H    1   P    C     M   0002  0002  S
OWNSHIP   NEW TASK  XDYTCNID  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M
OWNSHIP   NEW TASK  XDZTCN1D  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M   0000  0000  S
OWNSHIP   NEW TASK  XDZTCN2D  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M   0000  0000  S
OWNSHIP   NEW TASK  XDZTCN3D  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M   0000  0000  S
OWNSHIP   NEW TASK  XDZTCN4D  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M   0000  0000  S
OWNSHIP   NEW TASK  TN2TCNIX  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M
OWNSHIP   NEW TASK  TNZTCN1D  FINLEY    STS20B5E  NO    ABSENT
OWNSHIP   NEW TASK  TNZTCN2D  FINLEY    STS20B5E  NO    ABSENT
OWNSHIP   NEW TASK  TNZTCN3D  FINLEY    STS20B5E  NO    ABSENT
OWNSHIP   NEW TASK  TNZTCN4D  FINLEY    STS20B5E  NO    ABSENT
OWNSHIP   NEW TASK  TC6GLB55  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M
OWNSHIP   NEW TASK  TC6GLB53  FINLEY    STS20B5E  NO    ENTERED  H    1   P    C     M
OWNSHIP   NEW TASK  AMBNS2    FINLEY    STS20B5E  NO    ENTERED  H    2        C     M

                                                                 ======  ===  ====  ===  ====  ====
                                                                 ======  ===  ====  ===  ====  ====

                                                MODULE TOTALS:     32    31    32    32    26     26
```

Figure 6. Function Development Status Report

The Functional Milestone Status report depicts, on a module basis, the milestone matrix for a function hierarchy. This matrix represents the reportable status of the function at the time of audit. The matrix values are displayed for each milestone and each module. Figure 7 illustrates a Functional Milestone Status report.

```
                                       20B5 SOFTWARE STATUS REPORT                06/13/83      06:18
                                             MODULE STATUS
                                                  FOR
                                   3.3.2.5.2  ASW ENVIRONMENT (SONOBUOY & SQS-56)

MODULE     WT   PROG.   - - - - - - - - - - MILESTONES - - - - - - - - - - - - - - - - -   CURRENT STATUS
                          1*         2*      3,4,5*       6*          7,8*            9*
                        DESIGN !   PDL   ! DESIGN  ! TEST PROC !    CODE       ! FUNCTION
                               !  ENTRY  !   W/T   !   ENTRY   ! WALK THRU/  !   TEST      - - - - - - - - - - -
                               !         ! CODING  !           !  MOD TEST   !             MOD    MOD    PERCENT
                               !         ! ENTRY   !           !             !             STAT   SCORE  COMPLETE
                         (12)      ( 1)     ( 6)      ( 6)         ( 9)           (12)     CODE
                        - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   - - - - - - - - - - -

NCZBSRCH   1    FINLEY   12         1         6         6            9             0-        8      34    100.0
NCZINTP2   1    FINLEY   12         1         6         6            9             0-        8      34    100.0
NE4EXEC    2    FINLEY   24         2        12        12           18             0         8      68     73.9
NE5AMBNS   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE5DOPRT   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE5KBSHD   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE5OPL56   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE5OPRLS   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE5RVERB   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE5SNBWO   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE5TCNIM   3    FINLEY   36         3        18        18           27             0-        8     102    100.0
NE5WKMSK   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6HARME   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6INTRP   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6OPLRT   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6RECRD   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6STATS   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6STREN   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6VALID   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6WHERE   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
NE6WMREF   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
TC4EINIT   2    FINLEY   24         2        12        12+           0             0-        6      50     73.5
XDYTAMID   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
XDYTCNID   3    FINLEY   36         3        18        18            0             0-        6      75     73.5
XDZTCN1D   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
XDZTCN2D   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
XDZTCN3D   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
XDZTCN4D   2    FINLEY   24         2        12        12           18             0-        8      68    100.0
TN2TCNIX   2    FINLEY   24         2        12        12+           0             0-        6      50     73.5
TNZTCN1D   2    FINLEY    0         0         0         0            0             0-        0       0       .0
TNZTCN2D   2    FINLEY    0         0         0         0            0             0-        0       0       .0
TNZTCN3D   2    FINLEY    0         0         0         0            0             0-        0       0       .0
TNZTCN4D   2    FINLEY    0         0         0         0            0             0-        0       0       .0
TC6GLB55   2    FINLEY   24         2        12        12            0             0-        6      50     73.5
TC6GLB53   2    FINLEY   24         2        12        12            0             0-        6      50     73.5
AMBNS2     2    FINLEY   24         0        12        12+           0             0-        6      48     70.6

          ==            ==        ====      ====      ====        ======         ====             ===    ====

TOTALS:   72            768        62       384       384          459             0              2057    83.2

                                                                      * CORRESPONDS WITH MODULE STATUS CODE.
```

Figure 7. Functional Milestone Status Report

The Functional Hierarchy report reiterates the module breakout defined for the PDS and associates module completion codes with each module name. The module completion code represents an index of the current reportable status of the module. Figure 8 exemplifies the Functional Hierarchy report.

```
3.2.2.5.2     ASW ENVIRONMENT (SONOBUOY & AN/SOS-56 SONAR) FUNCTION SWWBS
                                    (PDS SECTION:  3.3.2.5.2)

          SEL TASK:  NEW                COMPUTER:  OWNSHIP

          NO2NEXEC                      NEW TASK EXECUTIVE                                  *
             NE4EXEC                    ASW ENVIRONMENT (SONOBUOY & SOS-56) EXEC            5
                NE5WKMSK                WAKE MASKING CONTROL                                2
                   NE6WMREF             WAKE MASKING DATA FORMAT                            5
                   NE6WHERE             WAKE SEGMENT POSITIONS                              2
                   NE6STATS             SENSOR STATUS AND WAKE POSITION                     5
                   NE6STREN             WAKE SEGMENT STRENGTH                               4
                NE5DOPRT                DOPPLER RATIO                                       5
                NE5OPL56                SOS-56 OCEAN PROPAGATION LOSS CONTROL               4
                   NE6INTRP             PROPAGATION CONTROL                                 6
                      NCZINTP2          TWO-WAY INTERPOLATION                               4
                NE5SNBWO                SONOBUOY WASHOVER                                   5
                NE5OPRLS                OCEAN PROPAGATION LOSS CONTROL                      6
                   NE6OPLRT             OCEAN PROPAGATION LOSS RETRIEVAL                    4
                      NCZINTP2          TWO-WAY INTERPOLATION                               4
                NE5AMBNS                AMBIENT NOISE                                       4
                NE5KBSHD                KELP BED SHADOWING                                  0
                NE5TCNIM                TCNI MANAGEMENT CONTROL                             4
                   NE6HARME             HARMONIC FAMILY DATA                                6
                      XDZDSCIO          DISC I/O QUEUING                                    5
                   NE6RECRD             RECORD NUMBER                                       4
                      XDZDSCIO          DISC I/O QUEUING                                    5
                   NE6VALID             VALIDITY CHECK                                      4
                      XDZDSCIO          DISC I/O QUEUING                                    5
                      NCZBSRCH          BINARY SEARCH                                       6
                NE5RVERB                REVERBERATION                                       2
```

Figure 8. Functional Hierarchy Report

The Functional Configuration Status report illustrates the current integration state of each module of the function. The module is listed under the appropriate control library designation. Figure 9 provides a sample report.

```
              20B5 SOFTWARE STATUS REPORT                06/13/83  06:18
                          FOR
      3.3.2.5.2  ASW ENVIRONMENT (SONOBUOY & SQS-56)

                   CONFIGURATION STATUS

    MODULES                 MODULES                MODULES                MODULES
     UNDER                  CONFIGURED              UNDER                 ABSENT
  DEVELOPMENT                                      REVISION
  -----------              ----------             ----------             -------

                           NCZBSRCH
                           NCZINTP2               NCZINTP2
                           NE4EXEC                NE4EXEC
                           NE5AMBNS               NE5AMBNS
                           NE5DOPRT
                           NE5KBSHD
                           NE5OPL56               NE5OPL56
  NE5OPRLS
  NE5RVERB
                           NE5SNBWO
                           NE5TCNIM               NE5TCNIM
                           NE5WKMSK
                           NE6HARME               NE6HARME
                           NE6INTRP               NE6INTRP
                           NE6OPLRT               NE6OPLRT
                           NE6RECRD               NE6RECRD
                           NE6STATS
                           NE6STREN
                           NE6VALID               NE6VALID
                           NE6WHERE
                           NE6WMREF
  TC4EINIT
                           XDYTAMID               XDYTAMID
  XDYTCNID
  XDZTCN1D
  XDZTCN2D
  XDZTCN3D
  XDZTCN4D
  TN2TCNIX
                                                                         TNZTCN1D
                                                                         TNZTCN2D
                                                                         TNZTCN3D
                                                                         TNZTCN4D
  TC6GLB55
  TC6GLB53
  AMBNS2
```

Figure 9. Function Configuration Status Report

The Milestone Summary report lists, by function, the actual and scheduled budget values and associated variances from subsequently scheduled audit dates. This report provides the manager with a snapshot of the current software design status in terms of the milestones established. Figure 10 presents a sample Milestone Summary report for Device 20B5.

20B5 SOFTWARE STATUS REPORT 01/11/83 07:33

FUNCTION STATUS

SECTION	DESCRIPTION	CHARGE NO.	TOTAL POINTS	POINTS TO DATE	PER CENT COMPLETE	01/01/83 BUDGET PER CENT	02/01/83 BUDGET PER CENT	DEFICIT/ SURPLUS POINTS	POINTS TO NEXT MILE-STONE
3.3.2.1.1	VEHICLE DYNAMICS	125611	11784	1652	92.6	100.0	100.0	-132	132
3.3.2.1.2	OWNSHIP ENVIRONMENT	125611	692	563	81.4	94.0	100.0	-87	129
3.3.2.1.3	MK-15 CIWS	125621	432	156	36.1	100.0	100.0	-276	276
3.3.2.1.4	MK-12 AIMS IFF/SIF	125611	160	88	55.0	100.0	100.0	-72	72
3.3.2.1.6	NAVIGATION SYSTEM	125611	92	92	100.0	92.0	100.0	8	0
3.3.2.1.7	HAND-HELD UNIT	125611	92	92	100.0	100.0	100.0	0	0
3.3.2.1.8	LINK-14	125611	500	338	67.6	100.0	100.0	-162	162
3.3.2.1.11	MK-75 GUN	125621	228	100	43.9	100.0	100.0	-128	128
3.3.2.1.13	LAMPS NON-ACOUSTIC SENSORS	125641	352	172	48.9	60.0	72.0	-38	81
3.3.2.1.14	OWNSHIP WEAPONS DAMAGE ASSESSMENT	125611	636	414	65.1	33.0	66.0	205	5
3.3.2.1.15	HARPOON MISSILE	125641	1498	1075	71.8	62.0	73.0	147	18
3.3.2.1.16	STANDARD MISSILE	125641	1124	782	69.6	51.0	66.0	209	0
3.3.2.1.17	MK-46 TORPEDO	125641	1192	976	81.9	60.0	72.0	261	0
3.3.2.1.18	COMMON MODULES	125641	408	360	88.2	70.0	79.0	75	0
3.3.2.2.1	PASSIVE ACOUSTICS (PASS. EFFECTS)	125641	9328	6876	73.7	81.0	90.0	-679	1519
3.3.2.3.1	ASW ENVIRONMENT (SQS-56)	125611	296	272	91.9	100.0	100.0	-24	24
3.3.2.3.2	ACTIVE ACOUSTICS (SQS-56)	125641	636	534	84.0	78.0	93.0	38	57
3.3.2.3.3	PASSIVE ACOUSTICS (AN/SQS-56 TASK)	125641	1814	1424	78.5	81.0	90.0	-45	208
3.3.2.3.4	PASSIVE BUFFER	125641	46	0	.0	92.0	100.0	-42	46
3.3.2.3.5	ASW SONAR I/O	125611	204	0	.0	92.0	100.0	-187	204
3.3.2.4.2	ACTIVE ACOUSTICS (SONOBUOY)	125641	908	650	71.6	74.0	93.0	-21	194
3.3.2.4.3	LAMPS SONOBUOY ACOUSTICS	125641	1872	1315	70.2	100.0	100.0	-557	557
3.3.2.4.4	LAMPS SONOBUOY ACOUSTICS I/O	125611	204	0	.0	92.0	100.0	-187	204
3.3.2.5.1	SONOBUOY AND SQS-56 RELATIVES	125611	1158	1110	95.9	95.0	100.0	10	48
3.3.2.5.2	ASW ENVIRONMENT (SONO & SQS-56)	125611	1724	1185	68.7	100.0	100.0	-539	539
3.3.2.6.1	OWNSHIP DISC I/O	125611	468	399	85.3	94.0	100.0	-40	69
3.3.2.7.1	OWNSHIP MONITOR	125611	204	204	100.0	93.0	100.0	15	0
3.3.2.7.2	REAL-TIME EXECUTIVES	125611	476	476	100.0	93.0	100.0	34	0
3.3.2.8.1	DDL I/O	125611	432	144	33.3	93.0	100.0	-253	288
3.3.2.8.2	AN/SQS-56 PING PROCESSING	125641	1978	1252	63.3	80.0	92.0	-330	567
3.3.2.8.3	INTERBUS LINK HANDLER	125611	1104	1104	100.0	89.0	100.0	122	0
3.3.3.2.3	DISC FILE TRANSFER	125611	160	106	66.2	93.0	100.0	-42	54
TOTALS:			32202	23911	74.3	82.7	91.0	-2718	5384

Figure 10. Milestone Summary Report

The Cost Performance Summary report provides a tally of the milestone matrix values in terms of the assigned work order numbers and displays the variances associated with each tally. The variances identify the difference in expected and actual design completion for a work order. In effect, a work order represents the allocated budget for a particular design effort, while the variance represents the additional effort required or surplus effort expended in meeting the budgeted milestone. Figure 11 illustrates a sample Cost Performance report.

```
                             20B5 SOFTWARE STATUS REPORT             01/11/83  07:33

                                   POINT NUMBER STATUS

                                      01/01/83   01/01/83   02/01/83
CHARGE    TOTAL    POINTS   PER CENT   BUDGET    EXPECTED    BUDGET     POINTS     STATUS
 NO.      POINTS   TO DATE  COMPLETE   PER CENT   POINTS     PER CENT   REQUIRED

125511      0         0        .0         .0         0          .0         0       INACTIVE
125521      0         0        .0         .0         0          .0         0       INACTIVE
125522      0         0        .0         .0         0          .0         0       INACTIVE
125611    10386     8239      79.3       92.1      9570        97.9      1331      TROUBLE
125621     660       256      38.8      100.0       660       100.0       404      TROUBLE
125622      0         0        .0         .0         0          .0         0       INACTIVE
125632      0         0        .0         .0         0          .0         0       INACTIVE
125634      0         0        .0         .0         0          .0         0       INACTIVE
125641    21156     15415     72.9       77.5      16399       87.3       983      TROUBLE
125711      0         0        .0         .0         0          .0         0       INACTIVE

SURPLUS POINTS:                                                           0

          =======  =======  =======  =======  =======  ========  ========  ==========

TOTALS:    32202    23911     74.3      82.7     26629      91.0      2718     TROUBLE
```

Figure 11. Cost Performance Summary Report

In addition to the standard reports generated by the AAIs program, the manager can direct the program to accumulate milestone statistics over auditing periods to graphically construct progress plots. This accumulation is accomplished by the use of the history files described in the previous section. These progress plots have been effectively presented to the contract sponsor by the 20B5 management during periodic Program Progress Reviews (PPRs). One such plot is presented in Figure 12.

AAIS Inputs: Control Data

Software managers must define seven (7) input data sets to drive the AAIS program. These data sets are as follows:

(1) Baseline starting dates

(2) Software work order numbers

(3) Plotting options

(4) Function hierarchies

(5) Function milestone weights

(6) Function milestone dates

(7) Module weights.

Data input sets (1), (2) and (4) apply to the entire software effort and are specified for each function hierarchy defined. The remaining input data sets are unique to each function hierarchy.

As shown previously in Figure 2, each function hierarchy must be established when the design is initiated. The hierarchy is subsequently maintained in a file on the computer storage media. Note that module values are specified according to the level of complexity. It should be recognized that the status reports will incorporate any design changes as performed on the appropriate data files. However, the manager must understand that this flexibility allows for a rolling baseline for audits. The particular function or functions audited are specified when performing an audit.

AAIS Processing

AAIS processing is given by the functional flow diagram presented in Figure 13. For Device 20B5, a full audit involving approximately 800 modules requires about 45 minutes of computer execution and report generation time. The entire process does not interfere with software development activities.

Organizing the control inputs presented in the previous section into files on the computer storage media requires approximately one (1) man-month of effort. These files are subsequently updated by individual designers as software designs are expanded or modified. An additional man-month of effort is required to produce the AAIS program in the desired high level language.

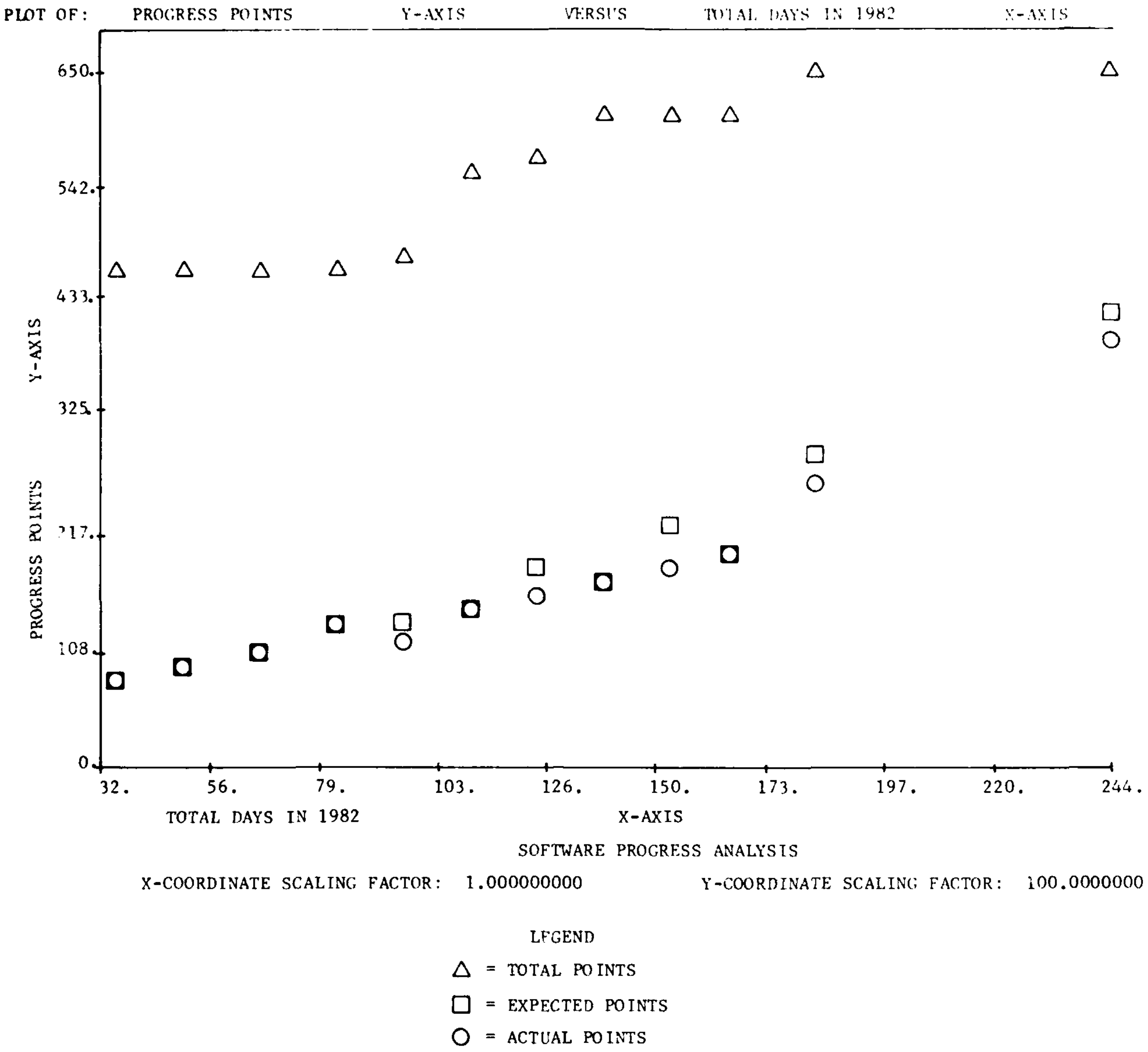

Figure 12. Historical Plot of Software Progress

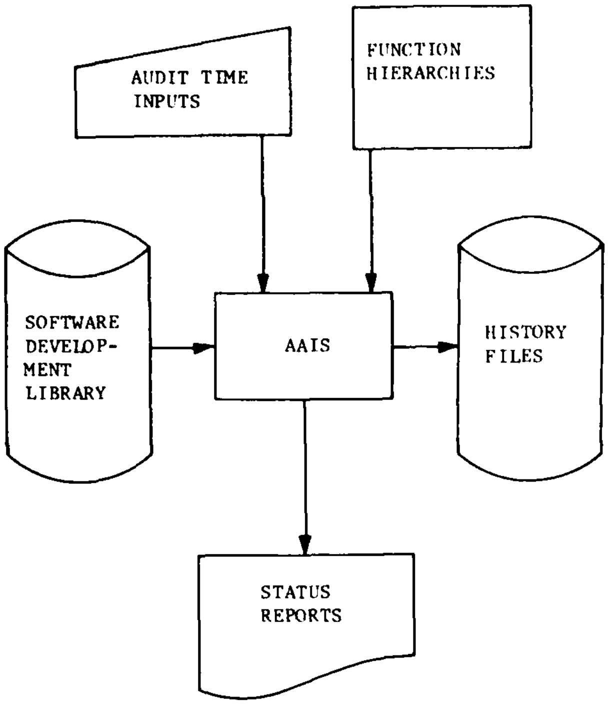

Figure 13. The AAIS Program Functional Flow

Summary

The AAIS procedure performs audits of the 20B5 software development library upon demand. The audit information provides managers with an improved capability to control software development activities and to improve projections for completion. The system is adaptable to other projects if similar organization and procedures are applied.

ABOUT THE AUTHOR

MR. GARY A. BROWN is a Senior Engineering Analyst in the Training and Simulation Department of the Electronic Engineering Division of AAI Corporation. He is currently responsible for the design, development, and implementation of microprocessor based software and diagnostic programs for the Device 20B5 Pierside Combat System Team Trainer. He is the principal designer and implementer of the AAIS and other 20B5 unique software tools. He holds a Bachelor's of Science degree from Rensselaer Polytechnic Institute in Computer and Systems Engineering. Gary has formerly developed system software for Device 15F12, a Radar Landmass Team Trainer.

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