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Calspan

Technical Report

Calspan Corporation
Buffalo, New York 14221

Calspan

B-1 SYSTEMS APPROACH TO TRAINING
TECHNICAL MEMORANDUM SAT-3

SIMULATION TECHNOLOGY ASSESSMENT REPORT
(STAR)

JULY 1975

Distribution limited to U.S. Government Agencies only; test and evaluation; July 1975. Other requests for this document must be referred to B-1 System Program Office, ASD/YHCD, Wright-Patterson Air Force Base, Ohio, 45433.

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PREFACE

This document is one of several technical memoranda which have been delivered to the B-1 Systems Project Office (B-1 SPO) in performance of the Systems Approach to Training (SAT) Task under Contract Number F33657-75-C-0021. Each of the separate SAT documents is listed below. Additional copies may be requested from: B-1 Systems Project Office, Data Configuration Division, Wright-Patterson Air Force Base, Ohio.

Technical Memoranda	Number	Author(s)	Date
B-1 Systems Approach to Training, Final Report.	SAT- 1 Vol. 1	R. Sugarman S. Johnson W. Ring	July 1975
B-1 Systems Approach to Training, Final Report. Appendix A: Cost Details.	SAT- 1 Vol. 2	H. Reif W. Ring	July 1975
B-1 Systems Approach to Training, Final Report. Appendix B: Bibliography and Data Collection Trips.	SAT- 1 Vol. 3	A. Blair	July 1975
Behavioral Objectives for the Pilot, Copilot, and Offensive Systems Operator.	SAT- 2 Vol. 1 & 2	J. Mitchell W. Hinton S. Johnson	July 1975
Simulation Technology Assessment Report (STAR).	SAT- 3	S. Johnson J. Knight R. Sugarman	July 1975
Sorting Model for B-1 Aircrew Training Data. User's and Programmer's Guide.	SAT- 4	J. Menig T. Ranney	July 1975
Training Resources Analytic Model (TRAM). User's Manual.	SAT- 5	W. Ring G. Gaidasz J. Menig W. Stortz	July 1975
Training Resources Analytic Model (TRAM). Programmer's Manual.	SAT- 6	W. Ring G. Gaidasz J. Menig	July 1975
Task Analysis Listings.	SAT- 7	J. Mitchell T. Ranney	July 1975
Control/Display Catalog and Action Verb Thesaurus.	SAT- 8	T. Ranney A. Blair	July 1975

CALSPAN CORPORATION

JULY 1975
SAT-3

SIMULATION TECHNOLOGY ASSESSMENT REPORT (STAR)

Steven L. Johnson
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SUMMARY

This technical memorandum summarizes the present state-of-the-art in both the engineering and behavioral aspects of simulation technology. It is this information which the Calspan technical personnel are using in the formulation of recommended requirements for B-1 training devices. Although the primary emphasis is on simulation used in training applications, the technology derived from other applications is often pertinent and its relevance to training is integrated into the discussions and assessments contained herein. This memorandum is not to be considered as a "textbook" on simulation and its usage, but rather, as a description of the important factors that impact upon the training device requirements for the B-1 training systems.

The implications of the state-of-the-art in simulation are discussed as they pertain to fulfilling the training objectives of the B-1. The simulation technology presently available does not appear to be constraining factor with respect to the Defensive Systems Operator (DSO) training devices. The major problems involving the DSO station simulation are not hardware concerns, but rather are in determining the multitude of logical contingencies involved in realistic scenarios. With respect to the Offensive Systems Operator's (OSO) station, the only state-of-the-art problem area is real-time, interactive simulation of forward-looking infrared (FLIR) simulation. An alternative approach to fulfilling the training objective is discussed. The simulation requirements for the front station (pilot and copilot) that pose a problem for the present state-of-the-art (pending ongoing studies) are visual scene presentation for refueling and, as with the OSO, the FLIR presentation. Alternative solutions to these problem areas are discussed.

Other aspects of simulation that have implications for the B-1 training program are also discussed. These include the utility of part-task training, automatic performance measurements, and simulator maintenance considerations.

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Section 1

INTRODUCTION

1.1 OBJECTIVE

This report includes a survey of flight-related simulators and the behavioral aspects of the use of simulators as training devices for the B-1 training program. The report presented here is organized into four major sections. Section 1 is this Introduction which includes a description of the scope and organization of the report. Section 2, Technical Information for Simulation Devices, illustrates simulation technology as it is implemented to date. This section is a summary of technical data available that represents the state-of-the-art systems presently in use. Simulation devices used for research and development, as well as training, are discussed. User comments as to the capabilities and limitations of the various devices are included where appropriate. This section includes the limitations imposed by the state-of-the-art and alternative approaches that are presently being pursued.

Section 3, Behavioral Aspects of Simulation, is a discussion of the trade-offs involved in the mechanization and use of simulators as training devices. Section 3 includes a review of the relevant behavioral research that has addressed the question of training effectiveness of various simulation capabilities (e.g., motion and visual simulation).

Section 4, Implications for B-1 Training, discusses the implications of the current state of simulation technology as they pertain to the requirements for B-1 aircrew training. This discussion is based on both hardware capabilities and limitations and behavioral aspects of device requirements as discussed in Section 3. The possibilities of cost savings as a result of thoughtful hardware trade-offs that meet behavioral requirements are elaborated. This section includes the conclusions of the survey.

Through the organization of this report, the engineering and behavioral trade-offs in simulation are discussed, the current approaches being taken are illustrated, and the areas of the simulation state-of-the-art that are not totally adequate for B-1 training are delineated.

1.2 BACKGROUND

The Systems Approach to Training (SAT), as a general methodology, requires cognizance of all elements of the system that can have impact on the decision processes involved in developing a training program. One of the greatest sources of impact is the simulation state-of-the-art that is to be taken as a baseline for the study. This state-of-the-art includes equally the engineering and behavioral technology of simulation. This report includes a survey of behavioral principles and existing and in-development simulators (the larger, most expensive types). This is for the purpose of ensuring that the B-1 SAT analysts are aware of those simulation concepts that are technically plausible for use in the training system, and the attributes and problems associated with the concepts that should guide their possible utilization in B-1 aircrew training. It is not a textbook on simulator design, nor an economic analysis of simulator selection (the SAT program, with its separate economic data base, provides that function). It is also not intended to be a total technical description of existing training simulators, since the training system design is to be "driven" by the training objectives, and not the existing hardware specifications. Enough detail is provided, then, to produce a sufficiently informed training analysis team.

The goal of the SAT effort is to derive the most cost effective training system from an analysis of the training objectives in combination with the information provided in this, and other data bases. The SAT study will also point out the areas in which the training objectives can not be met with the use of simulation (and in some cases even with the aircraft). For example, there are areas where the state-of-the-art is not presently adequate and alternative approaches must be explored (e.g., forward-looking infrared simulation). On the other hand, there are other areas of simulation technology where the state-of-the-art meets, and in some cases exceeds, the requirements for training.

SECTION 2

CHARACTERISTICS OF SIMULATION DEVICES

2.1 GENERAL

Presented in this section are some of the various cue-generating components that may be required in simulators to achieve the realism necessary to aid the trainee in his decision making processes essential during actual flight conditions. Also, selected simulators and trainers are described to show the relationship between system specifications and training requirements in existing programs and to present capabilities of potential systems. Support consideration which might impact on the type of simulator to be used are also discussed.

2.2 CUE-GENERATION COMPONENTS

Characteristics of the principal cue-generating components of simulators and trainers surveyed under this study are presented. Descriptions and discussion of the cue-generating components for motion, vision and radar landmass systems are covered in some detail.

The descriptors used for the devices are the same as those used in the functional specification of devices which are being derived from the B-1 aircrew training objectives. This facilitates the comparison of devices which are desired with devices that are within the state-of-the art. In addition, discussions of the trade-off among certain variables and between existing systems are included.

2.2.1 Motion Systems

In some cases it is believed that in order to train pilots effectively in a simulator, some of the motions cues which are present in an aircraft must be provided. A practical ground-based simulator, however, has limited motion capability and, therefore, cannot reproduce all the motions experienced in an aircraft. The task of the training system design is to determine which cues are required for training and how to provide them. The following paragraphs outline the physical limitations and interactions that are encountered in typical motion system designs.

2.2.1.1 Linear Travel

One of the fundamental limitations of motion bases is the range of linear travel available. It is this distance, in combination with the washout acceleration level which limits the maximum useful velocity and acceleration. Washout is the technique of returning the motion base to its neutral position in order to mimic a sustained velocity change without providing false cues;

see Section 2.2.1.4. In addition, the range of linear movement impacts on the useful angular rotation.

It is typical that most of the available linear movement is required to bring the simulator to rest. Unfortunately in order to double the useful velocity, one may need to have four times the available motion range. Using larger washout accelerations is generally not useful because they become noticeable to the pilot and he responds as if they were aircraft motions. Although simulated gusts can help mask the washout motions, they also mask the aircraft cues. Scaling down the aircraft accelerations may help by allowing increased times to follow the aircraft motion, but it may also be necessary to reduce the level of the washout accelerations so that they are smaller than the intended cues.

2.2.1.2 Angular Travel

Although large angular motions can be provided in simulators by means of gimbals or other designs, training simulators are generally limited to less than 40° in angular motion. Although larger angles would be useful in allowing the simulator to follow the rotations of the simulated aircraft, other considerations make large angles less useful. For large aircraft, roll angles are generally accompanied by a lateral acceleration which maintain the direction of the resulting acceleration through the body Z-axis. In most ground simulators lateral accelerations can only last a few tenths of a second, so a steady roll angle will produce an unrealistic lateral acceleration. For this reason the roll angle is implemented with a washout that returns it to zero.

Pitch rotations are not coordinated with linear accelerations in the same manner as are roll rotations, and it is generally found that keeping a one-to-one relationship between aircraft and simulator motions is satisfactory for large aircraft simulators. This is obviously not useful for maneuvers such as the loop performed in some simulators, where a more complex and probably nonlinear mapping of aircraft motions to simulator motions is necessary to preserve sensitivity to small motions, but allow large simulated aircraft motions without hitting the travel limits of the simulator. Large aircraft pitch motions are sometimes scaled down to accommodate the range of aircraft pitch motions to a somewhat smaller simulator pitch range.

Yaw rates in most maneuvers are small enough that they can be adequately simulated.

2.2.1.3 Limits of Velocity and Acceleration

There are hardware limits on the maximum velocity that can be obtained in a motion base simulator. With the typical hydraulically driven base, these are set by the size of the servovalves and by the flow rate of the fluid from the supply. Setting these limits at moderate values, where they might affect the performance occasionally, both reduces cost of the system and provides a measure of safety in case of control systems failure.

The maximum acceleration is set by the hydraulic pressure available, as well as the piston area and mass to be accelerated. The maximum pressure is generally 1000 - 5000 psi in commercially available systems. The piston area generally is at the option of the designer, however, increasing it increases the fluid flow required and the cost of the system. Also, providing excess capability reduces the safety of the device in case of failure. Large accelerations can damage some of the simulation equipment, especially the CRT's in visual display equipment if it is provided. Generally, present motion bases can provide around 1G acceleration with the design payload, and could produce more with smaller payloads. If sustained accelerations or larger magnitudes are required, an alternative is a special purpose device, such as a centrifuge which can provide large accelerations in one (selectable) axis.

2.2.1.4 Washout Design

The method used to return the motion platform slowly to rest after following an aircraft motion is called the washout network. The design of the best washout network for a given simulation is a difficult task. The design depends on a detailed study of the maneuvers to be performed on the simulated aircraft. Generally the maximum travel in any one axis depends on the travel in other axes, although the maximum accelerations of the aircraft usually do not occur in all axes simultaneously. These considerations, together with the previously mentioned aspects of the acceptable washout levels (depending on the magnitude of the primary cues and the presence of gusts), make the actual design very complex. As a result, a simplified approach is taken where each axis is treated separately and priorities are established for those cases where motion in two or more axes cannot occur simultaneously. Acceleration in each axis may be washed out by a high pass network, or by nonlinear logic, which restores the simulator to its original position. The steady state position of the motion base is made independent of the aircraft position, with the exception of pitch, and occasionally roll, where the steady state position may depend on either the steady state angle or its rate.

2.2.1.5 High-Frequency Response

The high frequency response limit is bounded by the resonant frequency of the motion platform. This is a function of the mass to be accelerated and the compliance of the supporting structure, which is generally limited by the bulk compressibility of the hydraulic fluid. In most designs the length of the fluid column must increase as the total motion available increases, so that the resonant frequency decreases. The formula relating these quantities is $\omega = \sqrt{50\ a/L}$ for the simple case where a mass is supported by a fluid column of length L, where ω is the resonant frequency in rad/s and a is the maximum acceleration available (assuming full hydraulic pressure). The constant 50 is the ratio of the bulk modulus of hydraulic fluid to the maximum supply pressure, assumed to be 5000 psi. For a maximum vertical acceleration of 64 ft/s^2 (1 G incremental) and a length of one foot, the resonant frequency is 57 rad/s or about 9 Hz. This is adequate to follow the rigid body motions of aircraft and probably adequate to present low order bending modes or buffet. A particular device could have a higher resonant frequency by designing for a higher maximum acceleration, or by achieving with less than maximum supply pressure. Note that the length L is the effective length of the hydraulic cylinder, with both ends contributing to the stiffness so that a symmetric cylinder with ±2 ft of motion capability would have an effective length of 1 ft.

The closed loop frequency response of the motion servos will probably be considerably smaller than the 9 Hz calculated here, but this is not necessarily a problem because the derivative of the aircraft variables can be used to compensate for servo lags (e.g., pitch rate can be used to minimize the pitch lag of the platform).

2.2.1.6 Low-Frequency Response

The magnitude of the low frequency response is set by the limits of motion available and will be further reduced by the effects of the washout network. For example, if ±2 ft of motion is available and if the whole range is used to produce a sine wave acceleration of 1 rad/s (0.16 Hz), the peak acceleration will only be 2 ft/s^2 or 1/16G. This is so small that some way of enhancing the sensation of sustained acceleration is desirable. One way which has been used is the G seat, a simulated aircraft seat with many movable panels under the cushions. These panels are driven by bellows, inflated by compressed air in a way that changes the pressure distribution on the buttocks, thighs and back of the pilot. In addition, the seat belt tension is controlled. The result of these combined motions is to produce some of the sensations associated with sustained acceleration in an aircraft.

Another system which has been used to provide sensations associated with a sustained high G environment, is the pressure suit or G suit. Inflating the normal flight suit provides some of the cues associated with positive normal acceleration in high performance aircraft. The rate of pressure increase as a function of acceleration is normally reduced from the rate in flight because of the lack of acceleration to counteract the effects of the suit. The acceleration level at which the suit begins to inflate can also be reduced to zero. This may be of particular benefit in zero-G maneuvers for fighter aircraft simulators.

2.2.1.7 Relative Advantages of Some Designs

The advantage of the three degree-of-freedom motion systems (pitch, roll, and heave), used with some early simulators, over later motion systems is cost. These systems cost less themselves and require less power and room to operate. Some of these systems, however, were designed for a smaller payload than the anticipated weight of a hypothetical B-1 pilot-copilot simulator with an on-board instructor and visual system. These systems may not provide enough cues to train or maintain proficiency for many maneuvers, such as crosswind landing and engine out on take-off and landing. A way to augment these designs may be to use the G seat to provide some of the missing cues.

The four, five, and six degree-of-freedom systems which are developed by augmenting the three degree-of-freedom systems, became relatively complex devices. These can provide additional cues, but they have essentially been superseded by the six-post or synergistic designs. The main disadvantage of these designs is that motion in any axis reduces the motion available in any other axis. This relationship is difficult to state simply, but for the Atkins and Merrill system, for example, it is just possible to get ±8 in simultaneous in each translation axis with 6° in each rotation axis. An important advantage of these designs is that multiple use of similar parts makes the maintenance of these systems relatively easy.

An advantage of systems capable of very large motions, such as the LAMAR or FSAA (see Section 2.2.1.8), is that the range of motion available appears to be enough to ensure that performance for tasks such as landing approaches is as good as in the actual aircraft, although it is reported that the motion/visual environment requires the adoption of unrealistic control techniques to achieve such performance.

2.2.1.8 Typical Motion Systems Specifications

Table 1 contains important parameters that describe the performance limits of several motion systems. The listing is not all inclusive, but does represent a range of motion systems with related applications. It is important to note that some variations from the listed specifications should be expected when considering various total systems (i.e., simulators) that employ a particular motion system.

SYSTEM / RESPONSE	SINGER (3 DOF)*	SINGER FB111 (5 DOF)	SINGER 48 INCH LEGS (6 DOF)	SINGER 60 INCH LEGS (6 DOF)	AMES FSAA	AMES (6 DOF)	NORTHROP LAMAR (5 DOF)	ATKINS & MERRIL (4 DOF)	ATKINS MERRIL (6 DOF)	REDIFO (6 DOF)
PITCH										
ROTATION (deg)	+14, -6	+14, -6	+26, -24	+30, -20	±18	±35	±25	+15, -10	+30, -20	±28
VELOCITY (deg/s)	12	12	15	15	29	97	60	10	22	17
ACCELERATION (deg/s^2)	270	270	50	50	92	260	400	7100	90	80
FREQUENCY (Hz)**	0.5	0.5	1***	1***	1.5	0.55	3	0.7	1	0.7
ROLL										
ROTATION (deg)	±10	±10	±22	±22	±36	±35	±25	±10	±24	±19
VELOCITY (deg/s)	12	12	15	15	29	75	60	10	22	12
ACCELERATION (deg/s^2)	270	270	50	50	92	570	460	7100	90	80
FREQUENCY (Hz)**	0.5	0.5	1***	1***	3.1	0.63	3	0.7	1	0.7
YAW	NONE									
ROTATION (deg)		±5	±29	±32	±24	±35	±25	±10	±35	±9
VELOCITY (deg/s)		–	15	15	29	170	60	10	22	11
ACCELERATION (deg/s^2)		–	50	50	92	170	200	7100	90	80
FREQUENCY (Hz)**		–	1***	1***	1.7	0.7	3	0.7	1	0.7
VERTICAL										
TRANSLATION (ft)	±1	±1	+2.6, -1.9	+3.2, -2.5	±4	±9	±10	±0.5	+2.9, -3.5	±4
VELOCITY (ft/s)	–	–	2	2	6.9	7.5	13	0.33	2.1	2.5
ACCELERATION (G)	1	1	0.8	0.8	0.31	0.27	3	1	0.9	0.75
FREQUENCY (Hz)**	0.5	0.5	1***	1***	2.2	0.2	3	0.7	1	0.7
LATERAL	NONE							NONE		
TRANSLATION (ft)		±0.5	±3.5	±4	±40	±9	±10		±4.2	±6
VELOCITY (ft/s)		–	2	2	16	8	10		2.1	2.5
ACCELERATION (G)		–	0.6	0.6	0.31	0.29	2		0.7	0.7
FREQUENCY (Hz)**		–	1***	1***	1	0.54	3		1	1
LONGITUDINAL	NONE	NONE					NONE	NONE		
TRANSLATION (ft)			±4	+4.1, -4	±3	±9			+4.1, -4.5	±2.9
VELOCITY (ft/s)			2	2	5	9			2.1	2.5
ACCELERATION (G)			0.5	0.6	0.25	0.23			0.7	0.5
FREQUENCY (Hz)**			1***	1***	1.8	0.24			1	0.7
PAYLOAD										
WEIGHT (lb)	10,000	10,000	18,000	18,000	6,000	4,000	–	8,000	14,000	25,000
Ixx (SLUG/ft^2)	–	–	33,000	33,000	–	–	–	–	–	–
Iyy (SLUG/ft^2)	–	–	37,000	37,000	–	–	–	–	–	–
Izz (SLUG/ft^2)	–	–	19,000	19,000	–	–	–	–	–	–

*DOF = DEGREE OF FREEDOM

**FREQUENCY AT 30° PHASE LAG

***ESTIMATED VALUE

† PAYLOAD CAN BE INCREASED TO 18,000 lbs

†† COMBINED WITH LATERAL RADIUS OF 40 ft

Table 1
TYPICAL MOTION SYSTEM SPECIFICATIONS

REDIFON (6 DOF)	REFLECTONE 60 INCH (6 DOF)	McDONNELL DOUGLAS (3 DOF)	McDONNELL DOUGLAS (4 DOF)	McDONNELL DOUGLAS (6 DOF)	CAE ELECTRONICS (4 DOF)	CAE ELECTRONICS (6 DOF)	CAE ELECTRONICS DDF)
±28 17 80 0.7	+30, -25 20.3 200 –	+15, -6 15 – –	+14, -9 20 25 –	±15 15 – –	+20, -12 10 50 –	±32 20 100 –	+32, -28 20 60 –
±19 12 80 0.7	±27 22.9 200 –	±10 20 – –	±15 – 5 –	±20 20 – –	±10 18 30 –	±28 20 100 –	±25 20 60 –
±9 11 80 0.7	±33 23.8 200 –	NONE	NONE	±10 10 – –	NO INDEPENDENT††	±34 20 100 –	±32 22 60 –
±4 2.5 0.75 0.7	+3.2, -3.1 2.4 1.3 –	±1 1.7 0.5 –	±1 – +0.8, -1 –	±3 1 – –	+1.5, -0.5 0.9 0.3 –	±2.7 2 0.8 –	±2.8 2.8 0.75 –
±6 2.5 0.7 1	±3.6 2.9 1 –	NONE	±0.5 – – –	±5 3 – –	±5 3 0.1 –	±3.3 2.3 0.6 –	±4 3 0.5 –
±2.9 2.5 0.5 0.7	+4.3, -3.5 2.7 1.1 –	NONE	NONE	±2 3 – –	NONE	±4 2.3 0.6 –	±4.1 2 0.5 –
25,000 – – –	5,000† – – –	– – – –	– – – –	– – – –	– – – –	12,000 – – –	20,000 – – –

2.2.2 Visual Systems

In the past, many military aircraft simulators have not had the capability of producing out-the-window visual scenes. This has not been a serious problem because enough aircraft time has been available to train pilots and maintain efficiency in those tasks which would have required visual scenes. Such tasks include take-off and landing, aerial refueling, air-to-air and air-to-ground weapons delivery. The recent increases in fuel costs, the greater flying costs of new aircraft, and other restrictions on flying time, as well as the practice of rehearsing these skills in a mission context (i.e., only one landing per mission) have increased the importance of visual capability in simulators.

2.2.2.1 General Problem Areas

One of the prime limitations of a visual presentation is that of the amount of data that can be stored in the data base. In model-based systems, this is a physical size limitation of the model and terrain board, combined with the smallest object that can be shown. In computer-based systems, this is generally expressed as the number of lines or points or objects that can be stored on-line. In either case it is relatively easy to concentrate much detail in a small area or spread it over a large area, but difficult and expensive to produce the amount of information in a highly detailed, large area.

Another area where a trade-off is required is in the interaction of high resolution and wide field-of-view. Most display CRTs have an approximate resolution limit of from 500 to 2000 lines across the active area because of the size of the illuminated spot. Some very large (and expensive) CRTs can do better. Assuming a 60° diagonal field-of-view gives a resolution of around 4 minutes of arc. A way used to get more field-of-view without sacrificing resolution is to mosaic several pictures together, but this adds to the system complexity, requires careful matching of picture edges, and leaves visible seams where pictures are joined.

Visual systems cannot duplicate the real world parameters of contrast and brightness. This is generally not important for presenting necessary cues for flight, but it does eliminate the ability to practice certain difficult situations such as refueling into the sun and may potentially affect the use of such systems for practicing bomb damage assessment.

The computational delay or servo lag in some visual systems, combined with the delay in equation of motion computations, can make the simulator fly differently enough from the real aircraft to cause stability problems. These delays can become especially long in some computer generated image systems where extra cycles are used for such special effects as edge smoothing or weather effects. There are analytic techniques to compensate for these delays, but their implementations make the simulation equations very complex.

Another limitation of visual systems is the restricted freedom of movement of the viewer. Most systems with a collimated image have allowed a head movement of about nine inches without image distortion. On the other hand, systems without collimating optics give false cues as the pilot moves his head, although these become small as the distance to the screen is increased.

2.2.2.2 Comparison of Data Storage Methods

There are many media used to store the data for image generation. Among these are:

1) the object itself;

2) a solid model of the object mounted on a board or a belt;

3) an image on film;

4) data stored in computer usable form for conventional computer generated images (lines) or for night visual scenes (points); and,

The relative advantages of these methods are discussed in the following paragraphs.

1) An engineering simulator for studying refueling has received some attention in which the visual scene would be an actual tanker body or a full scale mockup. This would be suspended at one end of a building which housed a simulator with a large motion capability so that the motions of the aircraft would be reproduced one-to-one. Another simulator which uses the view of real objects is the TIFS (see Section 2.3.4.4). These systems avoid many of the problems of conventional visual systems and can give realistic depth cues, but may be limited by other factors such as cost, space requirements, and so forth.

2) Solid model systems are capable of presenting apparently realistic displays. An advantage of these systems is that the technology is well established.

One drawback of solid model systems can be the limited depth-of-field that can be achieved with small scale models. This problem has been alleviated for flat objects, such as the area near a runway, by using a Scheimflug probe which allows the plane of focus to be controlled. This approach will not help significantly for a three-dimensional object such as a tanker and boom used for refueling (however, the criteria for required depth-of-field may well be within the current engineering capabilities).

Another difficulty with model-type systems is the limited extent of the model. A smaller scale would alleviate this problem, but for models used for take-off and landing, the scale used is limited by the closest approach of the probe to the model which is about 1.5 mm. A scale of 2000 to one puts the pilot's eye point about 10 ft off the ground. If we assume the largest practical model is about 15 x 45 ft, we have a real world size of 5 nmi by 15 nmi. If an approach used a turn radius of 1 nmi, there is only 1.5 nmi on each side of the track. The apparent distance has been increased by the use of mirrors adjacent to the model in many systems. Weather-effect generators have been used so that the aircraft flight path is not limited to the area of the model. When the aircraft approaches the edge of the model, haze or clouds can be presented to obscure the picture. At this time the model system can be switched to some other aircraft simulator so that more efficient use can be made of the device.

A related disadvantage of the model approach is the limited flexibility in scenes. The models themselves are quite expensive and bulky so that any one facility can be expected to have a very limited number of models. The use of the models also requires a large facility with a significant amount of power used for lighting the model, and hence also for air conditioning.

Belt type models have advantages and disadvantages similar to solid models, with the additional advantage that continuous travel in one direction is possible. The maximum width of these belt devices is somewhat smaller than that of the solid models and are subject to considerable wear and tear from extensive use.

3) Using film as a storage device for visual data, provides a compact system. The display is quite realistic, has good resolution, and generally more detail than other means of producing the image. The principle disadvantage of this method is its lack of flexibility. The flight path of the vehicle is restricted to small deviations from the path the aircraft took when the data was recorded. Spurious cues may also be apparent as a result of other vehicles being present in the area during data recording. Also, vertical objects may be distorted as the system changes the perspective of the displayed surface to accommodate departures from the nominal path (see VAMP, Section 2.2.2.4.10). These systems originally used servo driven optics to distort the images and introducing weather effects proved difficult. Newer systems use a TV system which uses scan distortion to produce the perspective distortion. A video weather effects module is now used, a feature that was difficult to produce in the older optical versions.

4) Computer-generated images (CGI) have the advantage of great flexibility. It is potentially quite easy to switch from one scene to another, or to modify a given scene. The aircraft has complete flexibility to fly any path, and even to crash with impunity for the simulator.

One obvious set of difficulties with CGI systems has been due to the sampled nature of the video signal. Each picture element on a boundary between two objects is assigned a color and brightness as if it belonged to one object or the other. This had led to the 'staircase' effect and other anomalies such as objects about the size of one element blinking on and off. These problems have been largely overcome with newer systems which use various ways to smooth the edges, including substituting less detailed models of objects near the limit of resolution, and other special processors. A possible objection to computer generated images is that they tend to look very stylized because of the few details they contain, having been constructed from straight lines, and because of the large areas of uniform color or shading.

An advantage of digitally generated images is that the data can be defined in a coordinate system that makes it easy to coordinate with other sensor information (e.g., FLIR, LLLTV). In addition, the digital nature of the equipment makes the images repeatable from run to run without the errors due to analog servomechanisms.

Night visual systems of a similar nature are supplied by several companies. These systems present a scene defined by light points, with a few shaded surfaces typically a horizon glow and a runway surface. These systems are comparatively inexpensive. These systems avoid most of the quantization effects of the standard CGI systems because the spot positioning resolution is considerably smaller than the spot size on the CRT. These systems have also been used to show the image of an aircraft carrier, but have not yet been used to show a tanker for airborne refueling.

Contact analog displays show a repetitive pattern of low detail best suited to indicating attitude. These can be used to extend the usefulness of other types of displays when the extent of the model is exceeded, or to provide rotation cues on a wide angle display while a detailed picture is projected in a small area.

2.2.2.3 Viewing Systems

Almost all visual systems today use some form of cathode ray tube to present the image. Some of the film type systems projected the image directly, but those being produced now use an electronic link with a CRT. The greatest brightness and resolution is possible with a monochrome CRT.

Beam penetration tubes use two phosphors with a barrier between them. Low energy electrons activate the first layer, while electrons accelerated with a higher voltage penetrate to the second color layer. These tubes can produce a 2 primary color picture and are brighter than shadow mask tubes.

Shadow mask CRTs are used for full color pictures, but the mask limits both the brightness and resolution of the picture.

There are a number of ways of viewing the image being used in present simulators. Although the viewing system can degrade the image in a number of ways, its chief contribution lies in the capability to collimate the image resulting in more realistic apparent depth and no false parallax cues.

The Farrand "pancake window" is a collimating system which consists of an in-line spherical beam-splitter mirror with a birefringent plate and polarizers. These elements are arranged in such a way that they act like a large magnifying glass with low transmission. These systems can be matched at the edges to cover a very wide field of view with very small gaps in the image. These systems have essentially no aberration problems, but there can be problems with ghost images which are not completely suppressed. A major disadvantage of these systems is the low transmission of one to three percent, which makes them difficult to use with color CRTs.

Other viewing systems achieve collimation by using a spherical mirror with a separate beam splitter set at 45° to reflect the image of the CRT. These systems have the advantage of relatively high transmissions (around 25%). These systems can be easily matched in one axis to increase the field of view, but because the CRT is in the way, it is more difficult to join the systems in the other direction. Hence, they do not fit in a way that would allow a surrounding visual scene both vertically and horizontally. A variation is to use a section from a spherical mirror and position the CRT so that no beam splitter is required.

Some visual systems have used large plastic lenses to produce a collimated image. Single lens systems are compact and fairly lightweight, but unfortunately, these simple designs produce large chromatic distortions, especially near the edges of the field. Specially designed, multi-lens anamorphic systems have been designed to reduce the aberations, but at increased cost and weight.

One method used to produce a wide angle display is by projecting an image on a large screen that is viewed directly. Systems using this method have used either segmented flat screens with separate projectors for each segment, or spherical screens. The spherical screens lend themselves to systems using two image generators, one for a low detail background and one for a smaller high resolution segment of interest.

The difficulty with these systems is their size. If the screen is too close, head movements cause apparent image movement. If the screen is far away its size must be such that it is difficult to mount on a motion base.

2.2.2.4 Typical Visual Systems

Table 2 presents the primary data for the surveyed devices. The table is preceded by the following brief characterizations and components for each system:

1) McDonnell Douglas VITAL

There are two of these devices available. The VITAL II scene is generated entirely by point lights. The maximum number of points displayed at one time is 2000, which is enough for an airport and surrouding city, and additional scenes can be stored for immediate use. The horizon is represented by a string of lights which is at a simulated distance of 50 miles from the aircraft. The display unit uses a beam penetration tube which can display shades of red, yellow, green, and orange. Some of the lights can be directional. The position of the spots on this kind of display has smaller jumps than a spot size (0.6 minutes of arc for most systems) which eliminates quantizing effects such as occur with other types of computer generated images.

The VITAL III has the same capabilities as the VITAL II and adds the ability to present some shaded surfaces. This is used to provide a runway surface and markings illuminated by landing lights, and a horizon glow which adds to the realism of the display.

2) Redifon Model Type at Ames Circa 1973

This gantry and model is used in combination with various simulations at NASA Ames. This device became operational in 1973 and is similar to the model and gantry used in the Redifon DUO VIEW and MONO VIEW systems. The servo response in the various axes of the gantry are well matched so that false cues are not generated by transient servo errors. The large acceleration and velocity limits are useful for synchronization of the gantry as the aircraft flies into the range of the visual display, and for fast resetting of the display.

3) Redifon Model Type at Ames Circa 1965 (Gantry Dynamics Only)

This model is scaled at 1:600. Comparison of the gantry dynamics specifications of this device with the later one (circa 1973) shows the advance in the state of that art.

4) Redifon Belt Type

This device was for sale in 1967. The terrain is stored in a flexible belt stretched between two rollers. The motion is achieved along the belt by moving the belt instead of moving the camera. The advantage of this type of model is that less room is required, and continuous travel in one direction is possible, although the scene does repeat.

5) Redifon Novo View

This system is nearly the same as the McDonnell Douglas VITAL III system.

6) Redifon Mono View

In one version of this system, a projector produces an image on a screen in front of each pilot. This image is viewed through collimating optics. Another version is reported to use a CRT, with a beamsplitter and spherical mirror to collimate the image.

7) Redifon Duo View

In this system a projector produces an image on a rear projection screen. This image is viewed simultaneously by both pilots in a large concave mirror which collimates the image.

8) Singer Night Visual System (NVS)

This system is similar to the McDonnell Douglas VITAL III system. Differences are that up to 8 channels can be driven by the basic system, and that it is possible to generate a continuous data base which has more than 2000 light points, from which the local area is shown.

9) Simulator for Air-to-Air Combat (SAAC)

One problem with the many segment approach to visual displays such as employed in the SAAC is the difficulty in obtaining and maintaining alignment between segments. With proper test patterns and alignment procedures, this can be reduced to a tolerable level. Another difficulty is the presence of visible breaks between segments, but in recent designs these are very small. In this design, the breaks between the eight pancake windows is .05 inches. Since the imagery is focused at infinity, the seams, which are approximately three feet from the viewer, become less noticeable.

10) Singer VAMP

In the original VAMP systems, a motion picture of a landing was viewed through an optical system that distorted the picture to provide proper perspective for objects in a horizontal plane. These film based systems have a number of distinct advantages and disadvantages. Advantages are good resolution and a bright display with an abundance of realistic detail. Disadvantages are the lack of flexibility. If the simulated aircraft does not follow the same flight path that the original aircraft did when the film was made, the scene becomes noticeably distorted. In addition, the servomechanism that was used to control the perspective in earlier versions of the VAMP systems were troublesome. Recent designs have replaced the optical perspective correction devices with a television system which uses electronic means for perspective control.

11) Advanced Simulator for Undergraduate Pilot Training (ASUPT)

The presentation unit of this visual system is similar in concept to that of the SAAC. One important difference is that the ASUPT simulates the T-37B aircraft, a side by side seating aircraft, which requires a much larger display to fit around the cockpit. These units used the largest CRTs ever developed. The extra computation required for edge smoothing and curved surface shading require extra time and decrease the effective frequency response of the system.

12) General Electric 2F90

The display unit of this visual device is three floor-mounted rear projection screens with Schlieren light valves projecting the images. This approach was possible because of the relatively small range achieved by the motion base. The image is programmed to follow the motion platform and so a form of synthetic collimation is achieved, but the image does not follow head motion.

The large angular coverage was achieved with only a few channels. Relatively low resolution is achieved with this device. The data base contains 2200 edges, which can be expanded to 5000. The 2200 edges include an airfield, an air-to-ground area, a shore area near Corpus Christi, and an aircraft carrier. At any one time 512 edges may be displayed. Fog, programmed as a function of altitude, was found to aid the perception of distance, and reduce the staircase effect of the horizon. Roll control of the combined aircraft and visual display is difficult near touchdown as it is in many other simulators. This is attributed to the total delay of the aircraft and visual systems computations.

13) General Electric Laboratory System

This system can be used with either a projection or a spherical mirror and beamsplitter display system. The scenes available include a terrain model with an airport, an aircraft carrier, and a tanker with a boom for airborne refueling. In the refueling simulation, two displays are used, one showing the tanker from the bomber pilot's point of view, and the other showing the bomber from the boom operator's position.

SPECIFICATION \ SYSTEM	VITAL II VITAL III	REDIFON MODEL TYPE C1973 (AT AMES)	REDIFON MODEL TYPE C1965 (AT AMES)	REDIFON BELT TYPE C1967	SINGER NVS	SAAC SINGE FARRA
FORMAT	SPOTS	MODEL	MODEL	MODEL	SPOTS	MODEL + STYLIZED
HUE	†LIMITED COLOR	–	COLOR	FULL COLOR	LIMITED COLOR	MONOCHR
BRIGHTNESS (fL)	15	–	6*	18 (7.3' x 5.5' PICTURE)	–	6
RANGE	1000 mi	–	6 mi	3.8 x 4.5 mi	19.0 mi	UNLIMITE
RESOLUTION (arc min)	5	–	6	6	2	1
FIELD OF VIEW						
HORIZONTAL (deg)	44	–	46	48	46	200
VERTICAL (deg)	30	–	28	36	29	+120, -30
TIME OF DAY	NIGHT**	–	DAY-NIGHT	DAY, DUSK, NIGHT	NIGHT	DAY
ATMOSPHERE						
CEILING	0-10 kft - CLEAR	–	–	0-1750 ft	–	–
RUNWAY VISUAL RANGE	0-40 kft - CLEAR	–	–	300 ft - 27 kft	–	–
CLOUDS	0-40 kft - CLEAR	–	–	–	–	DISTANT
VIEWING POSITION	9 IN RADIUS	–	0.5 ft RADIUS	1 ft RADIUS*	9 in RADIUS	1 ft RADIU
UPDATE RATE	30/s	–	30/s	–	30/s	30/s
GEOMETRIC DISTORTION	3% MAX	–	–	2.5% MAX	–	–
RESPONSE						
PITCH						
ROTATION (deg)	UNLIMITED	±25	+20, -30	±24.5	UNLIMITED	UNLIMITI
VELOCITY (deg/s)	UNLIMITED	140	170	29	UNLIMITED	UNLIMITI
ACCELERATION (deg/s²)	UNLIMITED	1360	1250	57	UNLIMITED	UNLIMITI
FREQUENCY (Hz)	1.2	2.9	2.8	–	1.2	1.2
ROLL						
ROTATION (deg)	UNLIMITED	±190	±100	UNLIMITED	UNLIMITED	UNLIMITI
VELOCITY (deg/s)	UNLIMITED	310	290	86	UNLIMITED	UNLIMITI
ACCELERATION (deg/s²)	UNLIMITED	5100	5200	200	UNLIMITED	UNLIMITI
FREQUENCY (Hz)	1.2	2.8	2.8	–	1.2*	1.2*
YAW						
ROTATION (deg)	UNLIMITED	UNLIMITED	+70, -250	UNLIMITED†	UNLIMITED	UNLIMIT
VELOCITY (deg/s)	UNLIMITED	190	190	42	UNLIMITED	UNLIMIT
ACCELERATION (deg/s²)	UNLIMITED	1700	1700	128	UNLIMITED	UNLIMIT
FREQUENCY (Hz)	1.2	2.9	2.8	–	1.2*	1.2*
VERTICAL						
TRANSLATION (ft)	UNLIMITED	0.006, 4 (12 ft, 9 kft)	0.014, 1.25 (28 ft, 2500 ft)	0.006, 0.875 (12, 1750 ft)	UNLIMITED	UNLIMIT
VELOCITY (ft/s)	UNLIMITED	1.4 (168,000 ft)	0.093 (11,000 ft/min)	0.034 (4,000 ft/min)	UNLIMITED	UNLIMIT
ACCELERATION (ft/s²)	UNLIMITED	1.8 (110 G)	0.24 (15G)	0.064 (4G)	UNLIMITED	UNLIMIT
FREQUENCY (Hz)	1.2	.32	0.75	–	1.2*	1.2*
LATERAL						
TRANSLATION	1000 mi	±7.5 ft (±15 kft)	±4.5 ft (±9 kft)	±4 ft (±8 kft)††	190 mi	UNLIMIT
VELOCITY (ft/s)	UNLIMITED	0.9 (M1.6)	0.5 (M.91)	0.21 (M.38)	UNLIMITED	UNLIMIT
ACCELERATION (ft/s²)	UNLIMITED	1 (62G)	0.45 (28G)	0.032 (2G)	UNLIMITED	UNLIMIT
FREQUENCY (Hz)	1.2	2.9	0.42	–	1.2*	1.2*
LONGITUDINAL						
TRANSLATION	1000 mi	±32 ft (±64 kft)	±17.5 ft (±35 kft)	38 ft (76 kft)	190 mi	UNLIMI
VELOCITY (ft/s)	UNLIMITED	0.66 (M1.2)	0.53 (M.96)	0.15 (M.27)	UNLIMITED	UNLIMI
ACCELERATION (ft/s²)	UNLIMITED	1 (62G)	0.80 (50G)	0.016 (1G)	UNLIMITED	UNLIMI
FREQUENCY (Hz) AT (30° PHASE LAG)	1.2	2.8	0.52	–	1.2*	1.2*
SCALE	–	1:2000	1:2000	1:2000	–	–

* ESTIMATED VALUE

**SEE SEC. 2.2.2.4 (I) FOR DISTINCTIONS BETWEEN VITAL II AND III

† AT ±60° CLOUDS SWITCHED IN

†† MODEL 10 ft WIDE

Table 2
TYPICAL VISUAL DISPLAY SYSTEMS SPECIFICATIONS

VS	SAAC SINGER-FARRAND	ASUPT GE-FARRAND	GE 2F90	GE LAB SYSTEM	SINGER VAMP	SINGER MARK V MODEL TYPE
	MODEL + STYLIZED	STYLIZED	STYLIZED	STYLIZED	FILM	MODEL
LOR	MONOCHROME	MONOCHROME	FULL COLOR	FULL COLOR	FULL COLOR	FULL COLOR
	6	6	2.5	2.5	20	5
	UNLIMITED	–	60 mi	–	UNLIMITED	5.2 x 14.5 nmi
	1	7	11	7	3	3
					48	48
	200	240	180	30	36	36
	+120, -30	+120, -40	60	23	DAY, DUSK, NIGHT	DAY, DUST, NIGHT
	DAY	DAY-NIGHT	DAY	DAY	ELECTRONIC	–
					O-CLEAR	O-CLEAR
	–	CONTROLLED	–	–	O-CLEAR	O-CLEAR
	–	VARIABLE FOG	VARIABLE FOG	VARIABLE FOG	O-CLEAR	O-CLEAR
	DISTANT	TEMPORARY	–	–	9 in RADIUS	9 in RADIUS
S	1 ft RADIUS*	0.5 ft RADIUS	2 ft RADIUS	9 in RADIUS	–	–
	30/s	30/s	30/s	30/s	DEPENDS ON AIRCRAFT POSITION	–
	–	–	–	–		
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	±18°	UNLIMITED
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	1.2	0.8	1.2	0.8	–	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	– –
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	1.2°	0.8°	1.2°	0.8°	–	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	±28°	UNLIMITED EXCEPT AT EDGE
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	1.2°	0.8°	1.2°	0.8°	–	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	±1° FROM GS*	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	1.2°	0.8°	1.2°	0.8°	–	–
	UNLIMITED	–	60 mi	–	±10° FROM LOC*	±6 ft (16 kft)
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	1.2°	0.8°	1.2°	0.8°	–	–
	UNLIMITED	–	60 mi	–	APPROACH	±72 ft (44 kft)
	UNLIMITED	UNLIMITED	UNLIMITED	–	–	–
	UNLIMITED	UNLIMITED	UNLIMITED	UNLIMITED	–	–
	1.2°	0.8°	1.2°	0.8°	–	–
	–	–	–	–		1:2000

2.2.3 Radar Landmass Simulation

2.2.3.1 Requirements

The requirements of a landmass simulation must be defined very carefully because it is easily possible to define a system that is very difficult to implement. That is, while it is possible to generate a good radar simulation for a restricted set of conditions, it would be possible to use any simulation and get unrealistic results. The requirements for a radar landmass simulation fall conveniently into three general categories. The first is the requirement for a high level wide area simulation for general navigation practice. Note that this does not require a high level of detail. The second requirement is for low level terrain following and navigation practice. These areas do require a relatively high level of detail. For this task, however, relatively narrow corridors will suffice because of the predefined nature of the flight path. The third requirement is for target area simulation. This task requires high detail and allowance for some flexibility in flight path.

2.2.3.2 Problem Areas

One of the principle difficulties in landmass simulation is to generate the data base. Although large areas have been previously included in radar landmass systems, both analog and digital improvement in both radar systems and simulation systems implies a need for an improved data base. Although ways of producing terrain elevation data automatically do exist, both from maps and from photographs, adding cultural data and radar reflectance data require a large number of manhours, especially for areas of higher resolutions.

For digital systems, the large amounts of data stored and the requirement for fast access to some of the data has led to the requirement for elaborate data retrieval systems. At present, the only economic way to store such magnitudes of data and have rapid access is by using disk memories. These data then must be transferred to a faster type memory to enable the radar equation processor to operate at the high speed necessary for realistic simulation.

The time delay caused by the last data transformation and computation steps can be significant even at the high computation rate used. This is because "pipeline" processors are used where several elements do part of the processing and pass the result to the next element. If the data used to determine the position of a point on the display is 50 ms old, for example, and the aircraft is traveling at 1,000 ft/s, the error in the displayed image will be 50 ft.

2.2.3.3 Comparison of Radar Landmass Systems

Digital radar landmass systems have been developed as a result of several deficiencies in the film plate simulation used for aircraft like the FB-111. One major difficulty with these film plate systems has been the lack of detail in cultural features. Cities and towns are defined by the outlines of high reflectance areas, and lacks detail on a scale commensurate with the accuracy of the navigation and radar systems. Because of the nature of the servosystems and the scale of the plates used, it is not possible to locate points with the precision that the aircraft systems are capable of, or to repeat a previously flown flight path. In addition, small defects in the emulsion can cause erroneous commands to be generated in the terrain following system. Electronic noise and CRT imperfections can also cause erroneous commands.

The long time to produce a new plate (six months to a year), and the large cost involved make it unreasonable to have multiple plates of an area to show the effect of seasonal changes or to show the effect of new construction or destruction by previous missions. The time to switch plates and realign the servomechanism takes several hours so that these effects could not take place within one mission.

The Naval Training Equipment Center is pursuing an upgrade of the transparency system that could be used with higher resolution radars or infrared sensors. This upgrade depends on several advances in technology. The first of these is the introduction of films with grains smaller than the diffraction limit of visible light. These films were developed originally for holograph work, but their use for landmass data storage would greatly increase the information that could be stored per unit area. A second development is the commercial availability of mechanical scanners with accuracies better than one micron. Third, the limitations of CRT spot size readout device resolution can be eliminated by using a scanning laser or charge-coupled device.

Some of the limitations associated with slow production of transparencies can be eliminated by using automatic equipment to expose the film. The original data base for this could be the Defense Mapping Agency Aerospace Center digital tapes. The total cost of such a system would be much less than a system like Project 1183, but it would also be much less flexible in the kind of effects which could be introduced. Problems which would not be solved would be those due to imperfections in the film and maintenance of the mechanical parts of the mechanism. In addition it is clear that without greatly increased funding over the current levels the system will not be ready for production.

The relative advantages between the various digital display systems (viz. GE, Honeywell, Singer) are not as obvious. The ridge and valley line approximating technique used by General Electric in their radar simulator, lends itself more naturally to the concentration of data in areas of interest, or in areas where there is more information (rougher areas). It is not clear, however, that placing more detail around points of interest, such as a navigation checkpoint, would not draw a student's attention to that area. One other advantage of this method is that it is possible to match the slope of steep local areas which has a large effect on radar reflectivity. This can be done without having very dense data points throughout the data base. The uniform appearing presentation that might occur because of the few data points presented in avoided by including a code that represents the small scale appearance of the terrain. That is, the variations that normally occur because the return is the result of the summation of many reflectors within the pulse pocket are modeled statistically.

2.2.3.4 Radar Landmass Systems

A description of current radar landmass simulations follows. Performance data is presented in Table 3 for comparison.

1) Singer Film Plate

This system is used in the FB-111 mission simulators and in the T-10 avionics simulators. The data is stored on a large three-color film plate. Reflectance data and coarse and fine elevation data are stored as densities of the three colors. The position of the aircraft is tracked over this plate by servos which position a flying spot scanner (FSS) and sensor assembly. The radar scan is simulated by the sweep on the FSS so that return power and masking can be computed by analog circuits.

2) Singer Digital

Singer's first generation of digital landmass simulations has performance capabilities (e.g., area, resolution, etc.) similar to the film plate system. The digital data base for these systems was obtained by digitizing the transparencies used to generate the three-color film plates.

3) Project 1183

Project 1183 is an advanced digital landmass simulation which is under development. It consists of two principle efforts, one is to develop a data base, the second is to use this data base to produce radar images.

The data base is being produced in several levels of detail. The major part of the elevation data will be digitized at 3 s of arc (about 300 ft) intervals. About 400 square miles will be digitized at 1 s, and 1 square mile at 0.5 s. Because the most detailed area is in Las Vegas and cultural features are added at six levels, this small area requires a large number of hours to prepare.

The data base contains a physical description of terrain and culture contained therein. This physical description is based upon geometrical material composition of all significant features. This constitutes the "off-line" data base and a transformation program is required to convert this information to an on-line program for use in simulation. After conversion radar reflectivity codes are assigned based upon material composition. Geometry information is available to perform the required calculations for shadow and power return information.

Table 3

RADAR LANDMASS SYSTEMS SPECIFICATIONS

	SINGER FILM PLATE	SINGER DIGITAL	SINGER PROJECT 1183	HONEYWELL UNTS	GENERAL ELECTRIC 1D23
RANGE (mi)	15-200	15-200	3-200**	280**	30-120
EXTENT (mi)	1500 x 1500	1500 x 1500	200,000 (sq mi)**	CONTINENTAL UNITED STATES	1000 x 1000
SPEED (Mach)	–	–	--	2	1
RESOLUTION* (ft)	250	200	50	250	200
ACCURACY* (ft)	5280	200	50	250	200

*POSITION WITHIN DISPLAY

**DATA SUPPLIED BY USAF ASD/ENCTS

When the data is used, information flows through a hierarchy of memories from large, slow memories to small, fast memories so that high speed processing of the local area can take place. The regional memory contains the total on-line data base. The area under surveillance by the radar is moved unchanged to the distinct memory. The data contained within the sector memory is interpolated and processed thru the radar equation processor. The output from this processor is stored in a beamspread memory which adds a "weighting function" based upon azimuth antenna pattern.

4) Honeywell Undergraduate Navigation Training System (UNTS)

This system should soon be in operation at Mather Air Force Base. For further information see Section 2.3.2.2.

5) General Electric 1D23

The G.E. radar systems use an unusual method of storing on-line landmass data. Instead of storing elevation and reflectance data in uniform increments in some coordinate system, data are stored by line segments with stored coordinates. The line segment might define a change in reflectance, or it might define a change in terrain slope. This method naturally leads itself to storing data with different levels of detail in different areas, and requires few data points in uniform areas. Since this method does tend to produce unnaturally uniform appearing areas a method to randomize the signal returns is also included.

2.3 SELECTED SIMULATORS AND TRAINERS

Selected devices (simulators and trainers) are described to indicate how system specifications have been related to training requirements in existing programs and to indicate total capabilities of potentially applicable devices. Comments from users are incorporated wherever useful. The summary contained here does not contain complete engineering data which is obtainable from the literature, or cost data which is formulated elsewhere within the B-1 SAT program. For convenience, the devices are classed into five categories; mission and flight simulators, avionics simulators, part-task trainers, procedures trainers, and engineering simulators.

2.3.1 Mission and Flight Simulators

These devices are used to simulate full or partial mission rehearsals enabling one or more crew members to perform their respective duties in a coordinated manner. This type of simulator allows the user to become familiar with normal operations for the simulated aircraft as well as how to handle possible problems which may be encountered.

2.3.1.1 FB-111A

The FB-111A simulator is intended to fill three functions for the two-man crew: upgrade training for personnel who have not flown the FB-111; recurrent training to reduce flight time required to maintain flying skills; and forward area simulation. Major facilities provided are a motion system, flight control and navigation, bombing, terrain following and attack radars, and the radar homing and warning system.

The motion system supplied with the simulator is a 3 degree-of-freedom device modified to provide small amounts of yaw and lateral acceleration (see Section 2.2.1). The range of motion available appears adequate although comments are made that longitudinal motion would be useful to provide feedback on the effects of flaps and landing gear.

The FB-111A simulator does not have a visual system. This is believed to be a serious deficiency because there are some difficult landing problems that can not be practiced on the simulator.

A number of comments are offered concerning the usefulness of the radar landmass simulation (see Section 2.2.3). Many of these center on the fact that the equipment on the FB-111 has greater capabilities than the simulator. For example, it is not possible to score trainees on bomb runs because errors in the landmass simulation are greater than those expected from the equipment or trainees. Similar problems occur when trying to score navigation.

Other comments concern the lack of flexibility of the landmass simulation. To change the covered area takes several hours and to generate a new plate may take 6 months to a year. This prevents the kind of simulation where the second run over a target shows the damage produced by the first, and ensures that any simulation will not show the newest landmarks. In addition, these hand made maps may have errors of several miles in the placement of certain features. Other disadvantages of this system occur because of the difficulty of maintaining the servo mechanisms and analog signal processors. Also, variability in these devices prevents students from flying the exact mission twice.

Because aerodynamic forces are not computed after touch down, and there are no variable crosswinds simulated, some difficult landing situations cannot be practiced. This is aside from the fact that the lack of a visual attachment precludes landing training.

Both pilot and navigator instructors are used to operate this simulator. The instructors' station is outside the aircraft, although the instructor can ride in the other seat if only one crewmember is being taught, or lean into the aircraft if the motion system is off. The lack of direct vision by the instructor sometimes leads to uncertainty over what actually happened and loss of confidence in the simulator. The preprogrammed missions are not sophisticated enough to be useful, so that much instructor time is used controlling the mission. Mission-writing procedures should be available to the instructors. Negative comments registered are that the positions of the pilot and navigator are reversed from their normal positions in the aircraft. There are over 200 malfunctions that may be inserted in the simulation, although many of these are never used. Their presence, however, makes the simulator unduly complex since many of the simulated malfunctions require non-standard instruments. As a result, when such an instrument fails, standard aircraft spare parts cannot be used. This increases down time and makes purchase and repair of simulator instruments more costly.

The simulator has a good record of availability for training. Procurement delays, combined with heavy use and scheduled maintenance, have lead to the simulators being more than a year out of date with respect to the aircraft.

2.3.1.2 S-3A

The S-3A simulator is a mission simulator that the Singer Simulation Products Division has provided for the Navy. The S-3A is a carrier-based anti-submarine warfare aircraft. There are four crewmembers, pilot, co-pilot, tactical coordinator, and sensor operator. The simulator can be used in four modes. The flight station can be operated alone or the tactics stations can be operated alone, with the instructor providing pilot and co-pilot inputs. The whole facility can be operated in an integrated mode with all interactions taking place normally, or the flight and tactics sections can operate simultaneously but independent of each other.

The problems of simulating the on-board computer with its software for this aircraft, led to the decision to use the actual aircraft computer, even though this computer costs about $1.3M.

The simulator is provided with a Singer six degree-of-freedom motion base (see Table 1), and is being fitted with a VITAL visual display system (see Table 2).

2.3.1.3 Simulator for Air-to-Air Combat (SAAC)

This simulator consists of 2 F-4 aircraft cockpits on Singer 6 degree-of-freedom motion bases, with wrap-around visual displays. The visual display is an electronically generated earth, horizon, and sky with a superimposed image of another aircraft from a model which has working speed brakes and afterburner. In addition, various weapon systems can be simulated.

The immediate primary purpose of this developmental simulator is to determine the utility of air-combat training in simulators. Extended uses are aircraft development, tactics development, an investigation of simulation techniques. Because of its developmental nature and the purposes for which it will be used, flexibility and adaptability are stressed in the design, rather than specific training features, reliability, and self-test features.

A Singer 6 degree-of-freedom motion base with 60 in legs is provided (see Table 1). Other motion cues are provided by G seat and G suit.

The combination of motion presentation methods provides useful cues for correct performance of almost any maneuver. However, some incorrect cues can provide problems. A prime example is the simulation of pitch in a loop where continuous rotation and continuous positive acceleration cannot be obtained. The simulation of buffet is necessary to provide angle of attack and airspeed cues and must be aided by seat motion because the visual system is too fragile for cues provided by the whole motion system. The presentation is by 8 in-line infinity (collimating) image systems (see Sections 2.2.2.3 and 2.2.2.4 (9)). The scene contains squares as the ground, a representational horizon line, and a sky. Lack of haze effects results in an impression of too high a rotational rate because of the abnormally high amount of moving elements in the visual scene (even though the movements may be veridical). There is haze on the horizon in the present system.

Aerodynamic data for large angle of attack and sideslip are required in this simulation. In addition, data that define buffet as a function of flight conditions are necessary. The buffet cues are used by pilots as indicators of angle of attack and airspeed which cannot be obtained otherwise without looking at instruments.

This simulator was built for the Aeronautical Systems Division of the Air Force Systems Command by the Singer Simulation Products Division.

2.3.1.4 Boeing 747

The 747 simulator at United Airlines is representative of up-to-date simulators purchased by the airlines. The 747 simulator has a Singer six degree-of-freedom motion base (see Section 2.2.1). This motion base is felt to be very adequate for United's training needs.

The visual system supplied is a film type (VAMP, see Section 2.2.2.4 (10)). This system is felt to be less useful than camera model-type of visual displays.

These systems are driven by a minicomputer and, in general, do not use advanced training features, but depend on instructors for control and pilot monitoring and check ride evaluation.

The software originally supplied with these devices is not always adequate to realistically represent the aircraft. Thus, a number of engineering programmers are employed to change the flight characteristics and make other software changes.

A difficult and expensive aspect of the software development is representing the on-board computer on aircraft like the DC-10.

The reliability of these simulators is felt to be good with 20 hour per day use schedules being possible.

2.3.1.5 Advanced Simulator for Undergraduate Pilot Training (ASUPT)

The ASUPT is a simulator designed for research in undergraduate pilot training. It has two T-37B simulator cockpits mounted on six degree-of-freedom motion bases, a wide angle visual display, three types of instructor stations, and a computation facility that allows easy changes in the software.

On set cues are provided by a Singer six degree-of-freedom motion base with 60 in legs (see Table 1). The angular acceleration capability has been increased somewhat to $114°/s^2$ and the vertical acceleration to $\pm 1G$. Sustained motion cues can also be provided by a G seat.

The visual system is a combination of a Farrand-designed display unit and a General Electric computer-generated image system (see Section 2.2.2.4 (11)). The display unit consists of seven pentagonal faces of a dodecahedron. Each face is an in-line infinity display, consisting of a large, high brightness, monochrome CRT with spherical reflectors and polarizers arranged so that an image collimated at infinity is visible from the pilot's position. Monochrome was chosen because the inline optics pass only approximately 1.25 percent of the input light and the high brightness required is possible only from monochrome tubes.

A total of 2,000 edges can be shown for the 14 display channels (7 for each simulator). The data base supplied is composed of approximately 100,000 edges. The area covered can be 1,250 by 1,250 nmi and includes Williams Air Force Base, T-37 contact practice areas, and Headpin Airport, with a perimeter of 50 nmi. In addition, a lead aircraft is available for formation flight training. Edge smoothing and surface shading are available to improve the image quality and lights can be displayed for dusk or night simulation.

The equations of motion for most training simulators are well defined only for small perturbations about normal or trim conditions. The aerodynamic coefficients for the ASUPT are defined for all possible angles of attack and sideslip so that maneuvers such as stall and spins can be accurately modeled. In addition, various degradations in accuracy or limiting assumptions can be built into the computations so that their effects can be studied. The aerodynamic effects of the lead aircraft are also computed for formation flight.

There are three types of instructor stations available for use with the cockpits, so that the effectiveness of various station designs can be investigated. One is a conventional station with the standard repeater instruments. A second combines a standard station with an advanced station containing CRT and keyboard controls. The advanced station has 2 graphic CRTs, and 2 alphanumeric CRTs. A number of different pages of information can be displayed on the alphanumeric CRTs and cross-country, CGA, spatial, and other displays are possible on the graphic displays. There are also keyboard and some mode control switches at this station. Inside each cockpit there is another instructor station with an alphanumeric CRT, a keyboard, and some mode control switches.

Other training features allow real or slow time demonstrations with recorded messages, difficulty adjustment, automatic malfunction insertion, data recording for later analysis, direct student feedback both aurally and through the CRT in the cockpit, and automatic task sequencing.

This simulator will be used by the Air Force Human Research Laboratory at Williams Air Force Base. Singer provided the basic simulator and was responsible for system integration. Farrand built the visual display and General Electric built the computer image generator.

2.3.1.6 Undergraduate Pilot Training - Instrument Flight Simulator (UPT-IFS)

The IFS is being built to train undergraduate pilots for perhaps "most of the rest of the century." Each simulator complex will consist of four T-37 or four T-38 cockpits.

Each cockpit has a visual display unit. Each pair of cockpits share a camera and model board. These units are supplied by Redifon. In addition, each cockpit has a Singer six degree-of-freedom motion base (see Table 1).

The instructors ride with the student on the motion platform so he can directly monitor the student's progress. Students will practice specific maneuvers until proficient instead of flying complete missions. In addition to the instructors there will be two operators at a console which is not on the motion platform. One operator will be responsible for two cockpits under normal conditions.

The Singer Simulation Products Division will deliver 34 of these complexes before 1981.

2.3.2 Avionics Simulators

These devices simulate electronic warfare or navigation systems environments and exclude flight operations of mission rehearsals, their characteristics and capabilities are described briefly below.

2.3.2.1 Simulator for Electronic Warfare Training (AN/ALQ-T5) - (SEWT)

This device is intended to teach trainees the skills associated with electronic warfare. It is not intended to model a specific aircraft, but has simulated a wide variety of presently used equipment, and is structured in a way that makes it relatively easy to add new equipment.

There are two special purpose computers in this device, and one general purpose computer. One of the special purpose computers uses emitter effects, such as PRF, pulse width, frequency, frequency agility, and scan rate to compute instantaneous frequency, amplitude, polarizations, etc., of the emitter signal. This information is placed on a data bus. The second special purpose computer simulates the receivers. Each receiver operates on each of the signals on the data bus and computes the output signal. This signal is converted to an analog voltage and used to drive CRT displays and audio channels. The general purpose computer is used for computing signal strength, vehicle responses, and other slow effects. In addition, it is used for data recording and problem control, in effect programming the special purpose computers.

The equipment types simulated are EW receivers and transmitters, analysis equipment, radar homing and warning receivers, communication equipment, a navigation panel, and an anti-radiation missile. Up to 126 emitters can be active at one time and can be updated once per second by the simulation computer. A library of emitter characteristics is maintained on disk for use. Up to five aircraft (friendly or hostile) with their EW signals can be flown at once. The gaming area is 2000 by 2000 nmi and altitudes from 0 to 100,000 ft with speeds flown up to 2,000 knots. The simulation assumes a smooth earth for its computations, but a time history can be programmed as if an emitter were being masked.

There is one instructor's station for eight student stations on this simulator, but it is generally assumed that two instructors will be used. There is a CRT readout of the mission progress and a post mission printout of overall grade and detailed performance of each student. The operator monitors and can insert changes in the mission, acts as pilot, and provides HF and UHF communications for the student.

Each student station has a data terminal which provides computer-aided-instruction for three types of sessions. These are equipment familiarizations, procedure training, and tactics. There is automatic evaluation of student actions, and errors may be displayed to the student, recorded for later printout, or for severe errors the mission may be halted and an instructor called.

An initial set of 9 instructors and programmers worked two years to generate 33 labs and missions for the initial courses using this device.

Only one of these trainers was built by the AAI Corporation in Baltimore for the Air Training Command at Mather Air Force Base.

2.3.2.2. Undergraduate Navigator Training System (T-45)

The UNTS is a training device, currently under development, for undergraduate navigators. It does not represent a specific aircraft, but is intended to teach the following navigation techniques: radar, celestial, grid and over water. It will have 52 student stations in 13 complexes with one instructor for each complex.

The systems simulated are doppler radar, inertial navigation, LORAN, search radar in mapping or weather modes, communication/navigation aids such as TACAN, VOR, UHF, astro tracker, and navigation computer. By far, the most difficult aspect of this simulation is the radar landmass (see Section 2.2.3). The basic on-line data base is stored on 32 moving head disks with a total of 233×10^6 bits of storage. Each student station has a 1.2×10^6 bit fixed head drum with a copy of the data within radar range at two resolutions. This data is then transferred to semiconductor memory while undergoing a transformation to range and azimuth coordinates, by a hardwired processor. A special purpose computer then computes the radar signal strength from this data.

There is one instructor's station for each four student complex. The instructor can view each students station directly and monitor progress, or a CRT readout provides information such as flight path, fix accuracy, and instrument use. An operator is also available to act as air traffic controller or pilot interacting with the students. The instructors can fail certain instruments or otherwise control the mission through their terminals and can communicate with any of their four students or any other complex.

Each student flies his mission separately, but only one mission is programmed for each complex. The equipment layout is the same as in the T-34A flying simulators. At present, 30 different missions and labs are programmed to use this equipment.

Although only one of these devices is planned at the Air Training Command, Mather Air Force Base. Honeywell hopes to use the same technology for other radar simulators and, perhaps, for forward-looking infrared or television sensors.

2.3.2.3 Communication and Navigation Trainer (ID23)

The ID23 is a minicomputer-based navigation trainer for teaching dead reckoning, inertial, doppler, and radar navigation techniques to undergraduates. There are 40 students in two groups of 20. Each group can fly separate missions, or all the same mission. Each group is monitored by one instructor and two training device operators.

The equipment simulated allows training of basic communications, use of ground-based navigation aids such as TACAN, VOR, DME, RMI, and ADF. Basic dead reckoning, as well as inertial, doppler, air data computer and magnetic compass techniques. can be practiced. There are two drum units which store the data base of 3.25 x 10^6 16 bit words for the landmass simulation (see Section 2.2.3). The data at the radar processor is updated approximately every 0.5 s. The gaming area covers the eastern US from 24° to 44° latitude and 76° to 96° longitude. Altitudes up to 50,000 ft. can be used with speeds to 750 KIAS. Radar ranges available are 30, 60 and 120 nmi. There are 8 NOVA 800 minicomputers used for simulation and problem control.

The instructors' stations consist of a standard display which can show graphics such as ground tracks or alphanumeric information. There is also a radar repeater which can show any student's display and a keyboard for problem control. There are eight operating models which allow for problem setup, control and monitoring, trainee testing, and mission playback. The operators can provide simulated ground communication with the trainees.

The student stations are representative of Naval aircraft such as the F-4 and E-2. The students provide control of their aircraft and other communications through a command/response panel and the training computers update each students position and instruments independent of the others. Alarm or warning messages can be displayed to the student through this panel.

This system was supplied to the Naval Air Station at Pensacola by General Electric's Ground Systems Department.

2.3.3 Part-Task and Procedures Trainers

The part-task training devices are intended to simulate only a particular segment of the aircraft in order to train a few specific tasks. The procedures trainers, however, represent a substantial part of the aircraft environment, but with low dynamic fidelity, and are used for teaching sequences of actions.

2.3.3.1 Formation Flight Trainer (FFT)

The FFT is a device intended to provide a cost effective means of training formation flight techniques. The major components are a simulated T-38 cockpit, an image presentation unit, a computer/video unit, and an image generation unit. The FFT is intended to teach 5 basic maneuvers:

1) Level flight in "fingertip position"
2) Cross-under
3) Pitch-out
4) Turning rejoin
5) Straight ahead rejoin

This trainer has no motion system. Because of the slow and precise maneuvers involved, visual cues predominate.

The visual presentation consists of two distinct projections on a 7.4 ft radius screen. The horizon generator is an internally illuminated transparency on gimbals. These gimbals move in a way to provide a correct scene as the aircraft pitches, rolls and changes heading. The scene consists of a blue sky, light colored undercast, and distant clouds. The servo limits are ±20° pitch, ±80° roll, continuous in heading. Maximum velocity is 60°/s in each axis, minimum velocity is 0.25°/s and resolution is 0.01°. There is a fourth servo on this system to correct for the fact that the projector is not on the axis of the screen.

The image of the lead aircraft is projected from a model by a closed circuit TV system. The position of the lead aircraft in elevation and azimuth is controlled by a projector servo assembly. The limits of this device are ±160° in azimuth and -25°, +42° in elevation. Maximum rate is 60°/s, minimum rate is 0.1°/s and resolution is 0.01° for each axis.

The pitch, roll, and heading of the lead aircraft, relative to the wingman, are controlled by another set of servos. These have the following performances: roll of ±170°, 80°/s maximum rate, 0.4°/s minimum rate, 0.01° resolution; pitch of ±65° and heading of ±135° with both having maximum rates of 60°/s, minimum rates of 0.25°/s, and resolutions of 0.01°.

Distance is simulated by a range servo which moves the TV camera out to 304 simulated feet; at which point a raster shrinkage technique is used to simulate increased distance. The range servo has a maximum simulated velocity of 33 ft/s, minimum simulated velocity of 0.03 ft/s, and a full scale resolution of 0.4 inches.

The instructor pilot has a control and indicator panel mounted on a portable case. Using this device the instructor can select three initial conditions, demonstrate the cross-under or rejoin maneuvers, and control the leading aircraft through a limited set of maneuvers.

The equations of motion are defined to simulate the T-38 at 30,000 ft and an airspeed of 300 KIAS. The only active instrument is the airspeed indicator.

The FFT was designed for minimum production cost by Goodyear Aerospace for the Air Force Human Resources Laboratory at Williams Air Force Base.

2.3.3.2 Experimental Radar Prediction Device (ERPD)

The radar prediction console provides a non-real time radar display of a forward area for mission planning and familiarization. It is not meant to represent a specific device, but can generate a radar display with the same effects such as beamwidth and antenna pattern as any particular radar, and produce shadow and incident angle effects as they would appear from any location.

This device consists of a minicomputer, a radar image processor, a data base, and an interactive terminal. The terminal, which has a joy stick, uses a beam splitter to superimpose the radar image over a map or photograph of the area. It is possible to shift or scale the display so that it lines up with the map. This makes it easy to correct the data base, or to add new entries, or to create a new data base. New data bases are generally created in three phases. First, areas of uniform reflectance are outlined using the joy stick to control a cursor. Second, elevation data is entered, usually along ridge and valley lines. Third, point and line targets which have high reflectance are defined. Normally while defining the data base, the display will have the special effects turned off so that the display will be a plan view of the terrain, but after the data base is defined the display can be "flown" over the terrain using the joy stick.

The resolution for the data points is 10 ft in a 110 nmi by 110 nmi data base. The on-line data base can have up to 16,000 words. The display is computed with 1,000 elements per sweep and each sweep takes 1 ms. This is adequate for this task, but not fast enough to simulate some radars in real time.

The device described is built by the General Electric Ground Systems Department and is being evaluated by the Rome Air Development Center and by the Naval Intelligence Support Center.

2.3.3.3 Radar Intercept Observer Trainer

This device is a minicomputer-based graphic terminal which has been programmed to simulate the radar intercept problem. The hardware consists of a general purpose minicomputer, a special display processing minicomputer, 15K of core, a graphics display, a keyboard, and some auxiliary equipment such as a paper tape punch. The total device is about the size of a desk, and is all general purpose equipment (not specific to this training task).

The radar intercept observer is in charge of tactics in an air-to-air engagement. It is his job to operate the radar, to gather information from the radar display, to perform some mental computations which establish relationships between the fighter and the enemy aircraft, to decide what the appropriate maneuver is, and to communicate his commands to the pilot.

The graphics terminal is programmed to teach these skills, except for the operation of the radar itself, by presenting to the student a series of progressively more difficult tasks. The initial tasks are just the computation of intercept geometry values from a list of initial conditions in a tote board format. The student is given immediate feedback if he enters a wrong answer. In addition, a graphic display of the actual ground tracks is presented to him. The student can also ask for the correct answer to be displayed.

In the next mode, a B-scan display is presented of a dynamic situation, but the student still computes the values from the initial conditions. After the student enters the correct command, the fighter turns to that heading and the student can see the problem progress. The true geometry is also displayed on demand by the student.

After the student is proficient at computing the intercept course, he learns to use the B-scan to fly the fighter to intercept, which usually involves three turns. At the correct moment, the student presses a FIRE key which causes the true geometry to be displayed and a hit probability to be computed. If the probability is below 0.8, the student flys the same problem again with a continuous display of the true geometry and computed angles. In these problems, the speed level of the aircraft can be increased as the student becomes more proficient.

This trainer was developed by members of the Behavioral Technology Laboratories, University of Southern California, for the Naval Training Equipment Center.

2.3.3.4 Engine Start Simulator

This trainer is a turbine powered helicopter engine start simulator. It consists of a cockpit with the engine instruments active, a sound generator, a relay rack of analog computing equipment, and an operator's console. The procedures for normal and many kinds of failed engine starts can be practiced and the equipment monitored for out of tolerance conditions such as overtorque.

This device is supplied by the Trainer Corporation of America.

2.3.3.5 Refueling Simulators

There are no training simulators at present with an airborne refueling capability. However, there are several engineering simulators with this capability. The General Electric Laboratory visual display has demonstrated airborne refueling (Section 2.2.2.4 (13)). The NASA Ames Flight Simulator for Advanced Aircraft has been used for refueling studies for the B-1. This was accomplished by mounting a model tanker on the terrain board of the camera model visual display. This was in effect a station keeping exercise because there was no active boom used. A similar approach has been used by American Airlines. Calspan also did a refueling study for the B-1. A fixed base simulator was used and a model tanker was suspended in front of the camera and moved by means of six strings. This concept is similar to that of the synergistic motion bases.

At present, the Aeronautical Systems Division of AFSC is evaluating industry proposals on an engineering development program to provide one-each part task trainers for the B-52 aerial refueling task and KC-135 boom operation. These are intended to meet SAC Required Operational Capabilities 7-73 and 2.74, respectively.

2.3.3.6 Other Procedures Trainers

The use of procedures trainers is a way to reduce the demand on high cost items such as full mission simulators. The description of the devices known as procedures trainers varies widely. Some, such as the FB-111 at Plattsburgh Air Force Base, consist of only a mockup of the cockpit, with switches that can be moved. A similar device, the KC-135 at Castle Air Force Base is presently being modified to include an audio-visual presentation.

More elaborate devices are used by United Airlines in their training. These devices are controlled by fixed logic which allow displays to respond approximately, although the dynamics may be unrealistic. American Airlines uses more flexible procedure trainers which are controlled by a minicomputer. In these devices most instruments respond in an appropriate manner to inputs, but the flight instruments are inactive.

Both normal procedures and recognition of abnormal conditions can be taught with these more flexible devices.

2.3.4 Engineering Simulators

Simulators which are used for aircraft development or for development of simulation techniques, and not used for training, fall into the category of engineering simulators. They are relevant because they are likely to represent the current -- or indicate the future -- state-of-the-art.

2.3.4.1 B-1 Engineering Simulation

This device is an engineering simulator used by Rockwell International principabiy as a design tool for the B-1 aircraft. Additional uses are for familiarizing the test pilots with the aircraft for initial B-1 flights, and for procedures training.

The simulator has a simulated B-1 cockpit mounted on a Singer six degree-of-freedom motion base (see Table 1). The motion system's drive has been modified to get extended high frequency response. This was done to get accurate representation of the bending mode motions of the B-1, which could cause pilot control problems in certain conditions. A rough air input to the motion platform is used, as well as the rigid body motion of the B-1. Only the rigid body motion is washed out.

The equations of motion are solved with an analog computer, but a digital function generator is used to compute the variations in aerodynamic coefficients with flight condition.

The input to the visual display is a camera-model type, with the models being of the belt type similar to the Redifon designs in Section 2.2.2.4.(4). Two belts are provided, one of an air field for takeoff and landing studies, and one used for terrain following studies. A long path for terrain following is generated by following a spiral path around the belt.

2.3.4.2 Forward-Looking Infrared (FLIR)/Low-Light-Level-Television (LLLTV)

The introduction of forward-looking infrared and low-light-level TV sensors on aircraft in the last few years, has posed new requirements for training and simulation. The ability to generate images for these sensors is still being developed. Important uses of these sensors are to confirm the identity of targets and of navigation checkpoints during low level flight. Because of the recent elimination of the LLLTV from the B-1 design, this section will concentrate specifically on the FLIR.

There are a number of problems yet to be solved before a FLIR or LLLTV simulation is ready for inclusion in training devices. This includes the definition of which sensor effects are important for training and efficient ways to simulate them. Sensor effects include optical effects such as resolution limits, contrast reduction, and noise; and in the FLIR sensor, streaking due to gain variation. Also to be determined for FLIR simulators, are ways of generating surface brightness as a function of material and time history (temperature, time of day and season) or whether these detailed differences are important or not. Answers to questions relating to how many gray levels are necessary to cover the range of tones and not create artificial boundaries on smoothly changing surfaces, are required, as are studies on how much detail is required in the presentation as it would be very difficult to produce real world detail over large areas, and is probably not required. Another area for study is what weather effects are important and how to include them. Other problems have to do with the generation of a data base once the required characteristics are known. Because the resolution of the FLIR and LLLTV sensors is much better than that of a radar, the data base for these simulations could take much longer to generate. It is not yet known, however, how much detail is necessary to define a building for example.

There are several possible methods to generate FLIR images in a simulation environment. Computer generation of the images is quite feasible. The volume of data that would be required if a large area was digitized for simulation would lead to a data retrieval system as complex as that used for radar landmass systems. The data retrieval system would be complicated by the fact that there is no well defined maximum range as there is in radar systems. The time delay in the scene generation system, especially if a digital system is used, could lead to errors and difficulty in synchronizing the display with other sensors. The computing power required is no more than that required for visual CGI and probably less because of the resolution and field of view limits of the sensors. The total delay in presenting the image may be slightly greater because of the extra processing to include sensor effects. Singer has proposed using the same off-line data base for the generation of FLIR images that will be used to generate radar images for Project 1183. This would probably be sufficient for relatively high level images, but may not contain enough detail for low level flight.

Boeing employs a film strip based system for presenting IR images. The advantage of this system is a realistic level of detail in the display. Disadvantages are lack of flexibility and, because the film is exposed at a higher altitude than it is played back at, the masking effects are not realistic.

It has been suggested that the film plate technology used for radar landmass simulations be adopted for FLIR simulation. Most of the disadvantages of this method as applied to radar simulations, apply to IR simulation, but it does allow more flight path flexibility than the film strip method. The techniques for converting altitude information to perspective and masking information in real time have not been successfully demonstrated.

Redifon has produced model-type FLIR displays by using the same basic equipment as their model-type visual displays. This approach should allow reaslistic looking displays of a limited area. The disadvantages are limited flexibility in scale changes or new areas. Techniques to produce weather effects could be used similar to one used by the visual simulations, but special processors would be needed for sensor effects.

A set of digital computer programs has been written by General Electric to produce simulated FLIR images. The purpose of the simulation is to determine the characteristics required of a satisfactory FLIR sensor simulation.

The simulation is organized much like G.E.'s visual simulation. Objects are stored as polyhedra with faces assigned brightness values. Geometric computations include projection to a viewing plane, tests for an object partly or entirely in the viewing frame, and tests for object overlap. Atmosphere effects at present include exponential contrast reduction.

Images have been produced which appear to satisfactorily introduce sensor effects such as noise, edge blurring (an effect on resolution of the optical transfer function), and streaking (an effect peculiar to IR sensors because the picture is scanned with nonuniform sensors).

The data base consists of three target areas containing a few cultural features and simple vegetation. The cultural features are, in general, low profile buildings and include a tank farm.

Seasonal effects are not simulated. A range of brightness values associated with daytime or nighttime conditions can be inserted into the program. Also the effect of changes in sun angle or moon angle can be inserted through changes in computer software.

This work was funded by the Human Resources Laboratories, Wright-Patterson Air Force Base. Technology Services Corporation (TSC) also did this in a parallel effort with General Electric.

2.3.4.3 Flight Simulator for Advanced Aircraft (FSAA)

The flight simulator for advanced aircraft has been used for handling qualities studies for large aircraft and for investigations into the range of motion required for simulators. The most outstanding feature of this simulator is the range of lateral movement available (see Section 2.2.1). Instead of being driven by hydraulic servos as most training simulation motion bases are, this one is driven by electric servos. This approach allows large motions without decreasing the resonant frequency of the structure.

The lateral motion is provided by two tractors, one at each side of the frame. Toothed timing chains engage a neoprene track to provide the necessary traction. The vertical platform is carried by the lateral frame, and is driven by ball screws. The steady weight of this frame is supported by gas filled cylinders, so that the vertical servos must provide only acceleration forces. The longitudinal drive is also powered by a ball screw, and it in turn supports the gimbal system for angular rotations. The gimbals for pitch, roll, and yaw use chain drives. One disadvantage of this system is the large amount of audio noise transmitted to the cab from the lateral drive.

The visual system is a virtual image TV display which can be provided with an image from any of several model boards (see Section 2.2.2). Hybrid computers are available for aircraft dynamics computations as well as a large digital facility available for data reduction.

2.3.4.4 Total In-Flight Simulator (TIFS)

The two major advantages of in-flight simulators are the near duplication of motion cues and visual cues as they would appear in the actual aircraft.

The TIFS is a modified C-131H. Modifications include addition of an evaluation cockpit, conversions to turboprop engines, and the addition of direct lift flaps and side force surfaces. In addition, there is a data collection system and an onboard computer which simulates the aircraft of interest and computes control surface commands for the TIFS.

The evaluation cockpit allows the duplication of the flight environment of the aircraft being simulated. The windshield may be changed to give the field of view of the simulated aircraft. The control positions are commanded by an electro-hydraulic feel system so that they duplicate the feel of the simulated aircraft, or may be replaced with other types of controls, such as side arm controllers.

The additional control surfaces give the aircraft independent control of all six degrees-of-freedom. At speeds up to 270 knots the TIFS has the basic ability to reproduce the motions of the simulated cockpit exactly. The actual performance limits of the aircraft are a complex function of flight conditions, but the following are representative at 200 knots. The basic aircraft is stressed for load factors from +2.5 G to -1 G, with about 1 G incremental available from the direct lift flaps. The lateral accelerations available are ± 0.3 G, and longitudinal +0.15, -0.07 G.

The maximum pitch, yaw, and rolling accelerations are 60, 20 and 120 deg/s^2, respectively. The control surface bandwidths range from 2 to 10 Hz.

The TIFS has been used for tasks such as aircraft and control system designs, ride quality research, fly-by-wire hardware flight testing, SST certification, rule definition, study of use of sideforce for crosswind landings and familiarization of test pilots with new aircraft before first flight as was recently done for the B-1 test pilots prior to their first flight.

The TIFS was built for the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base by Calspan.

2.3.4.5 Large Amplitude Multimode Aerospace Research Simulator (LAMAR)

The LAMAR is a facility intended to aircraft simulation problems including air-to-air and air-to-ground work. The motion system is an unusual design capable of large motions in two axes (see Section 2.2.1). The motion platform is on the end of an arm which is driven in elevation and azimuth to move the platform in the vertical and lateral directions. In addition, the control system is designed to cancel some bending modes in the arm in order to extend the frequency response of the system.

The visual system is similar in concept to that of the Formation Flight Trainer. There is a screen of 10 ft radius which covers a field-of-view of 266° horiziontally by 108° vertically. There are two scenes projected on the screen. The first of these is a low detail representation of the ground, sky, and a horizon. The other is a television projection system that can be used in two modes. The first mode is a 15 degree field-of-view projection of a model aircraft. The second mode uses an image from a terrain board and is projected over a 60 degree field-of-view.

There are four gimbals for the horizon projector, one each for pitch, roll, and yaw, and a fourth to provide antilock capability. Together they provide a continuous pitch, roll and yaw capability. The maximum velocities of the pitch, roll, yaw, and antilock gimbals are 230, 550, 570, and 520°/s, respectively. The maximum accelerations are 1000, 2000, 2800 and 900°/s^2 in the same order.

The pitch, roll, and yaw servos of the model aircraft also have continuous capability. Their maximum velocities and accelerations are all 460°/s and 460°/s^2 respectively. The maximum static error of all the above servos is 0.22 percent. The servos that drive the TV projector can follow continuous azimuth changes and ±90° in pitch. The maximum rate is 570°/s for each while the acceleration limits are 1100°/s^2 in azimuth and 2200°/s^2 in elevation. These last servos are designed with a static error of only 0.08 percent for accuracy and repeatability in air-to-air and air-to-ground weapons delivery. The brightness of the display is 2.5 fL and the resolution is 1.3 minutes of arc in the 15° field-of-view mode and 5 minutes on the 60° field-of-view mode.

This system has been supplied to the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base by Northrop.

2.4 SUPPORT CONSIDERATIONS

Information relating to several aspects of simulation support is presented in these sections. Included are a discussion of the computing facility (with a special emphasis on the use of the "on-board" computer hardware and equations of motion) and a short discussion relative to maintenance.

2.4.1 Computing Facility

The computing facility is used for many tasks in addition to solving the aircraft equations of motion and tactical computations. One of the most time consuming of these is the input and output operations necessary to provide communication with the cockpit, instructors stations, and other simulation equipment. Other I/O is required because some simulation data such as aerodynamic data tables are stored on devices such as disks because of the limited memory in the computer. Some data are normally recorded during a mission to aid in mission evaluation. This can be either in the form of playing back some of the mission, which requires a large number of variables to be stored, or in providing error measures and plots which require only a few important variables to be stored.

Other on-line tasks performed by the computer are problem control such as simulated failure insertion and monitoring for errors in the problem computations. Various types of computer aided instruction can also be provided.

Off-line tasks that the computer can be used for are playback of mission segments and scoring, simulator maintenance procedures, course development, mission definition, program changes and program library maintenance.

In order to prevent the simulators from slowly drifting apart in configuration, especially in a decentralized training system, it is recommended that program changes be made at only one programming center, probably Combat Crew Training School. Otherwise small changes made differently at each of the bases would make debugging extremely difficult and complicate implementing changes to be made in each simulator.

One of the important ways computers that have been used in simulators vary, is in word length. Computers have been built with wordlengths from 4 bits for the simplest microcomputer to 36 or more bits for large scale computers. Typical for simulation computers is 16 bits with 24 and 32 bits also being used. The importance of word length is in the flexibility allowed in the instruction set. A larger wordlength allows more instructions to be defined and a larger data address to be specified which allows more efficient use of data. The normal data used in computations is also one word long, and 15 bits (leaving one bit for sign) gives resolution of one part in 32,768 of full scale. This is obviously not enough resolution for some variables such as position on the earth's surface. It is also not enough for computing variables such as pitch angle accurately. The maximum value of pitch angle is 90°. If a pitch rate of 1°/s is a reasonable lower limit, and it is desired to compute it with an accuracy of 1 percent and the sampling rate is 20/s, then the accuracy of the increment is 0.0005 degree or one part in 180,000 of full scale.

The advantage of short wordlength is cost. All elements of the computer are cheaper because fewer bits are processed at once, and it is generally possible to do critical computations in double precision, i.e., using twice the normal number of bits. Unfortunately, these double precision computations normally take much longer to execute than single precision computations. The cost of digital hardware is decreasing very quickly. Because writing programs for larger machines is more efficient, and in general, software costs are higher than hardware costs for systems where only a few units are built, it is recommended that a relatively powerful computer be used. Another advantage of the more powerful computers is the availability of floating point arithmetic units. The use of floating point numbers reduces the need for scaling the dynamic variables in the equations of motion, and automatically allows small motions to be computed accurately without overloading when large motions take place.

Other important features of a computer are the ability to perform input and output operations while normal computation is proceding which allows more efficient use of the arithmetic unit, and the ability to transfer control to subroutines efficiently. This last feature allows the programs to be written in small sections which is required for efficient debugging and modification of programs, without slowing the execution of the programs.

Even with all the advantages listed above, the use of a single fast computer to run the entire simulation facility including, perhaps several simulators is probably not a good idea. Computers of the required speed to meet all simultaneous needs are very expensive and it would not necessarily be more reliable. If the computer went down the whole simulation complex would be unusable. In addition, the use of one computer requires that the whole simulation complex be developed by one contractor, which is not necessarily most efficient. If the simulation is later made more complex by the addition of failure modes, for example, a single computer system could become overloaded where a system designed for several processors could be augmented more easily.

2.4.1.1 On-Board Computers

The simulation of on-board computers has become a serious problem in the last generation of simulators. This is true both for military simulators such as the FB-111 and commercial simulators like the DC10.

Writing a program to simulate the effects of the on-board computer with its software is a task, at least as difficult as writing the original programs for the on-board computer. It may be more difficult because some features of the original computer may not be implemented on the simulation computer and may require extra software to simulate. It may also be required to simulate some of the failures of the on-board computer. Many of the earlier on-board computers were not very powerful so that it did not require a large part of the simulation computers time to reproduce its effects, but recent on-board computers are so powerful that it may require a separate CPU to simulate them.

Because the simulation programs for the on-board computer are fairly complex, notifying them when changes are made to the on-board software may take several months. These changes are normally not started until the on-board changes are checked out. The result is that changes to the simulators are made many months after the aircraft is modified, instead of before as would ideally be the case. This is especially important with new weapon systems where such changes are quite frequent.

There are three principle techniques used in the simulation of on-board computers. The first is the traditional way of writing programs for the simulation computers that duplicate the effects of the on-board system. The second is to use cross compilers so that the programs used in the on-board computer are translated automatically to run on the simulation computer. The third is to use the on-board computer itself in the ground system.

The first method has the principle advantage of low capital cost. Both a cross compiler and the on-board hardware are significant investments. In addition, the simulation software can be written from the functional description of the on-board system so that development can proceed in parallel. Unfortunately this is an inefficient way to proceed because there are usually many changes made in the system during the development. It becomes necessary at some point to decide that no further changes will be made in the simulation so that a final simulation can be designed, finished and accepted. This will usually mean that even the initial simulator will be out of date.

The design of a cross compiler has the advantage that most of the on-board software can be translated automatically to run on the simulation computer. This generally requires that a higher level language be used for the on-board computer because many assembly language programs would not be translatable. In addition, there are generally a number of special techniques that are not covered in the specification of a language, but which are used by programmers. These would have to be carefully excluded in order for the translator to work reliably. There are normally sections of the program that cannot be written in higher level languages. These typically include service subroutines that perform input and output operations and monitor for error conditions. They may include some mathematical subroutines which would be very slow if written in higher level languages. These sections of the program must be provided separately for the simulation computer, but they generally are not changed once defined.

The use of the on-board computer in a ground simulator has several advantages. A large percentage of the program used in the aircraft can be used directly in the simulator. This would include those sections defining procedures which are most likely to change. Modifications would be required, however, to accommodate those conditions which occur only in a ground simulator.

These include the ability to put the simulator in the hold mode, then restart the problem. The navigation Kalman filters would be seriously effected if some way were not devised to separate problem time from real time. Changes will also be required to simulate some failures of the system. If the on-board system has redundant computers, each of which can perform all the required computations, it may be desirable to eliminate one of them in the ground simulation to save hardware costs. This would require additional software changes and complicate failure simulation. The use of the on-board computers will require special interfaces to be built to simulate the actions of equipment that will interface with the computer. This would include many logic signals where timing of the response is critical and too fast for the response of a general purpose computer. These interfaces would have to be programmed by the general purpose computer to indicate the simulated status of the equipment. This requires a more detailed understanding of some equipment than might otherwise be required.

2.4.1.2 Equations of Motion

The equations of motion of many simulators have had various deficiencies. In general, the obvious problems have been because the simulator is used in a way that it was not originally intended. Examples are practicing crosswind landings in a simulator in which aerodynamic forces are not computed after touchdown (FB-111) and adding a visual display to a simulator intended for instrument flight only (the 2F90). More subtle effects can affect the quality of the simulation without being as obvious.

The implementation of the feel system can drastically change the apparent nature of the aircraft response. Increasing the control "stiffness" of the stick, for example, can change a fast, responsive aircraft to a sluggish and difficult-to-control aircraft. Removing the dead band from the aileron control can produce an aircraft which is difficult to stabilize and requires constant attention. In other cases, however, "stiffening" may lead to improved aircraft response and handling.

Because the angle of attack and sideslip angle are generally small in a large aircraft such as the B-1, linearized equations of motion probably would be adequate to represent the dynamics of the aircraft. Unfortunately, both the trim conditions and dynamics are a function of many variables and the control system response is a function of the trim conditions so that it may be more economical to use a more complete model of the aircraft and control system. Variables that effect the trim conditions and the coefficients of a linearized set of equations, include Mach number, wing sweep, altitude, center of gravity, and weight. In addition, if the performance limits of the aircraft are to be accurately modeled, the engine performance, fuel flow and drag data must be included with their dependence on environmental variables such as temperature.

Flexibility effects are important to an aircraft like the B-1 both because they affect the high frequency gust response and because of the active bending mode suppression. There is also an interaction between bending mode response and pilot control actions.

In order to be able to practice difficult landing conditions, such as varying crosswinds or icy runways, it will be necessary to be able to specify the wind and ground effects as a function of position and to compute aerodynamic forces through at least most of the rollout.

The sampling rate and precision of the computations can have a significant effect on the dynamics of the simulation. The effective delay of the sampling operation is one sampling interval and generally the computations add at least one more sample interval to the delay. If the sampling rate is 20 times per second, the delay added is 0.1 s which is already nearly the same magnitude as the delay of the pilot in difficult tracking tasks. Added to this delay is that of the display mechanisms such as the visual scene generator, the radar display or the motion system. In addition, the response of higher frequency modes in the control system, surface actuators, or bending modes can be seriously distorted by the phase shift associated with the sampled computations.

A computational disadvantage of using higher sampling rates is the consequent worsening of precision problems. That is, if the aircraft states are updated by adding the increment for the update interval to the old value, the increment becomes smaller as the update rate increases. This requires an increase in accuracy of the addition if the same relative accuracy of the update is to be maintained.

2.4.2 Maintenance

The cost of maintenance for a simulator is a significant part of the life cycle costs and for some parts of the simulator can approach the purchase cost. This is especially true for those parts of the simulator that are new or developmental in nature. One likely prospect for high maintenance costs is the visual presentation equipment. Much of this equipment is of relatively new design and a history of use to predict lifetimes does not exist. The wide angle probes with focal plane control, for example, are mechanically complex devices and may require considerable maintenance to continue operating correctly.

Multi-tube cameras used in some color TV systems are more apt to be trouble prone just because of the added complexity. Large, high brightness and high resolution CRT's are still prototype devices and, as such, subject to limited lifetimes and will be expensive to replace. The drive circuitry for tubes of this nature is also of special design and not well tested. This is especially true if unusual raster waveforms are used, such as dual resolution or raster sharing between CRT's. Raster sharing, that is using one raster to cover several CRT's, also requires higher peak brightness to get the same average brightness from the display.

Other parts of the simulator that may be prone to failure are aircraft equipment that has a limited lifetime. Airborne CRT's, for example, may have an expected lifetime of several hundred hours, which has little impact on a weapon system whose primary mission lasts less than 10 hours. In a training environment, however, the same equipment may get 100 hours of use every week and replacement time and costs may be significant. Unfortunately, use of different equipment to fill the same functions require the setting up of a separate supply and repair line for the new equipment which is itself a significant cost.

It is possible to assemble complex arrays of digital equipment to perform difficult computing tasks. Examples of these arrays are the general purpose and special purpose computers used in simulations. These complex arrays can fail in a large number of ways. Fortunately most of these failures have obvious results and can be quickly corrected. In addition, most modern computers are supplied by the manufacturers with a set of diagnostic programs which can be run to help localize a problem. The design of such programs or test patterns for special purpose equipment such as radar and visual display generators may be expensive, but is necessary for reasonable maintenance procedures.

Software maintenance is an area that might be easy to ignore. It would seem that a program, once written and checked out, would continue to work indefinitely. In practice whenever new conditions are encountered, that is a new set of inputs, there is a chance of discovering a logical bug in the program. Once discovered it is general practice to modify the program to fix the problem. Unfortunately, if this is not done very carefully this can cause or uncover another problem in the program. Very careful program design and documentation are required to minimize these problems. Especially when a large number of program modifications will be made during the life of the simulator. Special programming techniques have been developed to aid in producing a program which is more easily debugged and maintained. A formal approach to writing and documenting the programs should be used to minimize the maintenance problems.

Section 3

BEHAVIORAL ASPECTS OF SIMULATION

3.1 INTRODUCTION

This section presents the behavioral variables which must be considered in the determination of simulator requirements for training applications. These variables, along with the engineering constraints discussed in Section 2, must be taken into account in order to arrive at cost/training-effective device requirements. The objective of the training system designer is to produce qualified trainees at the lowest possible cost (in terms of both dollars and time). Also discussed is the research on stimulus requirements related to training devices and interpretations of the results of this research as it pertains to selection of devices for B-1 training.

Simulation, as defined in a dictionary is "to assume or have the appearance or form of, without the reality; counterfeit; imitate". Figure 1 illustrates, in graphical form, a simulation system (a) and the air-vehicle system (b). The physical parameters of Block I are discussed in Section 2. This section discusses the appropriateness of the physical parameters and translation of these parameters into responses by the trainee. If Blocks II, III, and IV could be combined and described by a multidimensional transfer function,

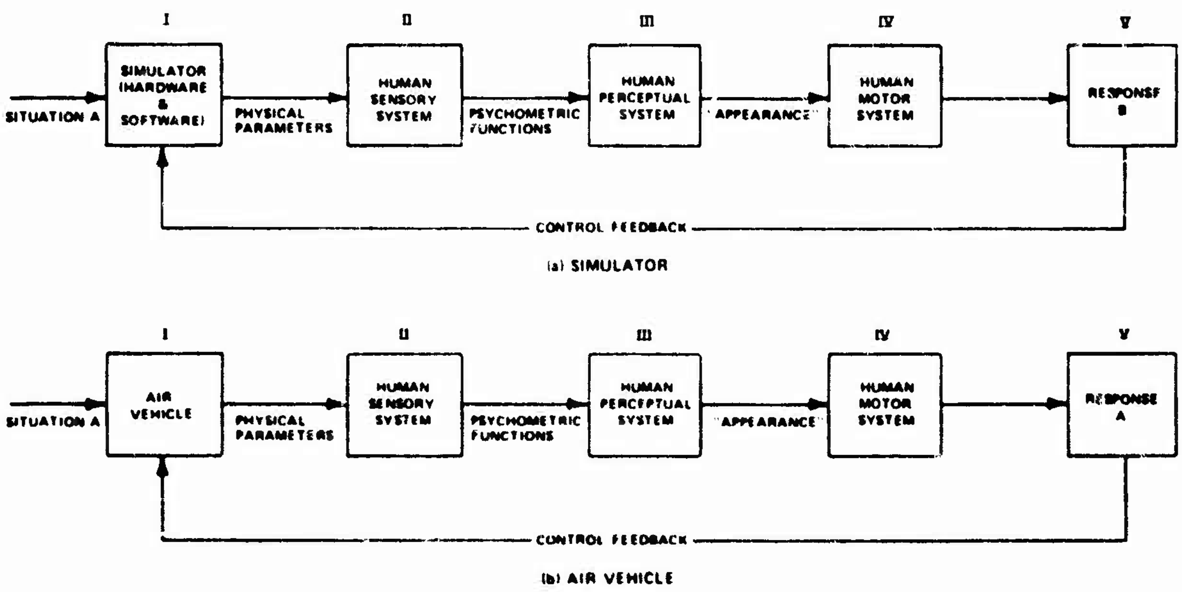

Figure 1 FUNCTIONAL COMPARISON OF AIR-VEHICLE AND SIMULATOR SYSTEMS

the job of the training device designer would be simple. The task would reduce to "physical simulation". The fact is that these blocks cannot be considered as one or many simple transducers. This fact is really to the benefit of the training device designer in that is is possible to capitalize on human sensory and perceptual capabilities and limitations as discussed in Section 3.2.

The context of the B-1 SAT with respect to simulation is its use in training. The term training implies "a change in behavior due to experience". The experience might involve organized instruction or trial-and-error practice (discovery learning). For example, if an entering trainee encounters a situation and gives the acceptable response (reliably), there is no need for further training on that situation. However, if the response is not reliably demonstrated, then further training may or may not be effective (depending upon frequency, criticality, and difficulty).

An important issue with respect to training as a whole, and simulation in particular, is the description of the "acceptable" response. The measurement techniques used to define these responses in simulation research are discussed in Section 3.4. A significant point to be made in this section is that an acceptable response is really a range of responses that are sufficient to handle the situation. This range, to a great degree, depends upon the type of situation encountered. Categories of situations are discussed in Section 3.3. The applicability of research results on simulation to training devices must be evaluated with respect to both the situations and the responses.

The ultimate goal of using training devices is to develop behaviors in the trainee to ensure that responses learned in the training (Response B), fall within the range of the acceptable response in the air vehicle (Response A). This would represent the situation where there is direct transfer from the simulator to the air vehicle. This alone does not ensure the cost-effectiveness of simulation. In essence, training in a synthetic trainer is only cost-effective if learning a response in the simulator and, subsequently transitioning to the air vehicle, is less costly than learning the acceptable response totally in the air vehicle. Costs, as previously used, refers to dollar cost, but also refers to equipment and personal injury costs (such as in hazardous maneuvers). These latter types of cost are an important factor in evaluating the cost-effectiveness of ground training for many emergency procedures. The remainder of this section evaluates the available information that will allow informed recommendations for cost-effective B-1 training.

3.2 PHYSICAL VERSUS PSYCHOLOGICAL SIMULATION

In the previous section, the term "physical simulation" was used to represent the case where the physical parameters encountered in the aircraft are duplicated to the greatest extent possible. With respect to the definition of simulation, this approach interprets "appearance or form" to be in terms of the physical parameters (e.g., position, velocity, and acceleration for the six degrees of freedom of motion). As is illustrated in Figure 1, "appearance or form" to the human involves two processing steps beyond the physical parameters.

The first of these processing steps, the human sensory system, has been discussed in the context of flight simulation research in many other reports. There has been a significant amount of research conducted on Block II, the human sensory system, which has resulted in quite extensive information as to the humans capability to detect and discriminate variations in physical parameters. Much of this literature has utilized the term "absolute threshold" to refer to the lowest level of stimulation that is detectable and "difference threshold" to refer to the smallest change of stimulation (s + Δs) that is detectable. These "thresholds" have been referenced many times in conjunction with determining required physical parameters for simulators. The problem is that it is recognized today within experimental psychology that there is no "step function" threshold. Rather, detection capability plotted against physical parameter strength results in an ogival "psychometric function". The term threshold, therefore, is only useful when defined as a specific point on the psychometric function (e.g., 75 percent) above which detection is "probable". A second and far more serious problem that exists is that human detection "thresholds" (absolute or difference) can be drastically altered by controllable influences (e.g., stress, fatigue, task loading). For example, the subject in an experiment designed to establish psychometric functions is in a controlled environment, optimizing the detection capability of the subject. Even in this situation, however, the "threshold" varies as a function of the person's criterion for stating that he detected the signal or not (Green and Swets, 1966). The effect of the criterion on pilot opinion with respect to simulation requirements is discussed in Section 3.4.4.

It is possible for the training device designer to take advantage of the human perceptual processes (Block III) in establishing cost-effective training devices. Figure 2 illustrates the often discussed curves relating transfer-of-training, device fidelity (in the physical sense), and simulator costs. The literature of simulation research has, to a great extent, ignored the perceptual process and the extensive amount of information available.

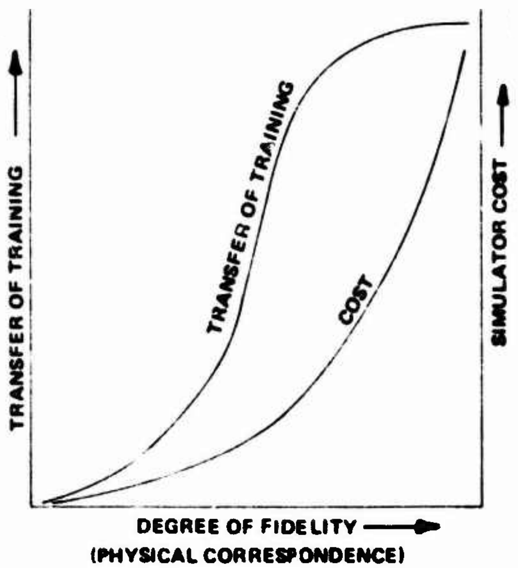

Figure 2 COST, FIDELITY, TRANSFER OF TRAINING CURVES

It is evident from the multitude of perceptual illusions, that human perceptual processes (Figure 1) must be considered along with the physical parameters and psychometric (threshold) functions. When the perceptual system is included in the analysis of training device requirements, the term "psychological simulation" is appropriate. The previous discussion focused on the translation of stimulus information into "appearance or form"; however, this accounts for only a portion of the considerations involved in "psychological simulation". As we stated earlier, influences that are under the control of the training program designer are also of importance (e.g., task loading, stress, and environmental factors). Muckler, Nygaard, O'Kelly, and Williams (1959) use the term "psychological simulation" as the ... "problem of transfer of training from the device to the aircraft that involves the psychological similarity between trainer and aircraft tasks" (p. iii). The emphasis of the Muckler, et. al., definition is on the term "tasks." Prophet and Caro (1974) have used the term task simulation in a similar context. The next three sections of the report, Section 3.3 through 3.5 discuss psychological simulation broken up into the three areas: (1) the situation, (2) measures of training device effectiveness, and (3) "appearance" attributes of simulation, respectively.

3.3 REPRESENTING THE SITUATION

The goal of a training program is to ensure that the graduating trainee can successfully handle the possible situations he might encounter to the extent that the mission will not be jeopardized. These situations can be grouped into three basic categories: 1) cueing, 2) controlling, and 3) task loading or distraction.

3.3.1 Cueing

The term "cue" is used here to represent the stimulus complex that informs the operator to initiate an action or to complete an action. Discrimination of cues is important when different responses are required for "different" cues. One of the most complete treatments of the relationship of discrimination of stimuli and selection of appropriate responses is that of Osgood's "transfer and retroaction surface" (Osgood, 1949, 1953). Osgood's transfer surface is graphically depicted in Figure 3. The two conclusions that can be formulated on the basis of this surface are:

1) When cues are varied and responses are functionally identical, positive transfer is obtained. The magnitude of the transfer increases as the similarity between cues increases.

2) When cues are functionally identical and responses are varied, negative transfer is obtained. The magnitude of the transfer decreases as the similarity between responses increases.

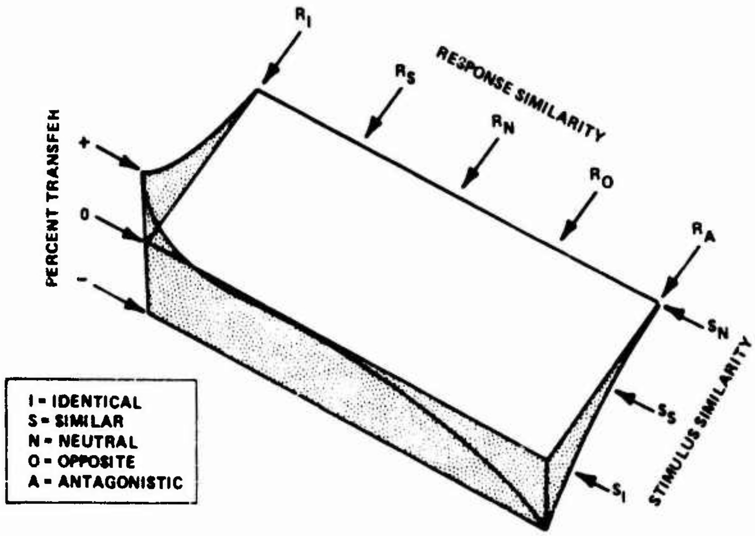

Figure 3 TRANSFER SURFACE

With respect to training devices, these conclusions have a large implication with respect to fidelity of the cues. When the response is the same to two or more cues, the transfer of training will be comparable with both high or low fidelity simulation. Therefore, the cost of high fidelity is not justified. However, if different responses are required for two different cues. then negative transfer will occur if the cues are "functionally identical" (i.e., not discriminable). In this case, for positive transfer the fidelity of the simulation must be adequate to ensure that the trainee can discriminate among the cues. The task of the training device designer, therefore, is to establish the minimum fidelity of the cues that will ensure the discrimination.[1]

Let us take two hypothetical "situations" that the trainee is to be able to accomplish. Each of these two situations, in "real life", has a large complex of cues that inform the trainee to act (or cease action). Also, the two situations have two different appropriate responses. As is indicated by Osgood's transfer surface, for positive transfer, the trainee must be able to discriminate between the cues to ensure the correct response. The task becomes, therefore, to provide the fewest cues (assuming more cues involve increased cost) that will allow the discrimination. If two "situations" are reliably discriminable on the basis of a small subset of the total complex of "real life" cues, this subset is adequate to ensure that the trainee will respond appropriately. Many other cues might add to the realism, but they do not enhance the training effectiveness of the device to train for these situations.

If the two situations cannot be discriminated solely on the basis of the subset of cues, the question becomes, should more parameters be added? If

1. A procedure that most nearly ensures the efficient expenditure of analyst effort is that developed by Cream (1974) and coworkers in the development of the Functional Integrated Systems Trainer (FIST). In that procedure, the analyst is guided by subject matter expert estimates of task difficulty, critically, and frequency for each task. For the tasks thus identified as important, the subject matter experts can then be questioned in more detail as to the aspects of each task that make it so.

the criticality of one or both of the situations is low (little or no effect on the mission) and/or the frequency of occurrence of one or both of the situations is low, then the cost involved to train for perfect detection might be unnecessary. For example, the trainee could be taught to respond to a cue as though it always represented one of the situations, recognizing that he will respond incorrectly some small portion of the time.

Alternatively, additional cues can be added to the training device (usually at additional cost). That is, if the criticality and/or frequency of the situations are high, additional parameters might be required to allow reliable discrimination of the situations. Section 3.5 of this report discusses the research data on the effect of various cue parameters on performance.

The cueing requirements for training devices are dependent upon discrimination training. Properly shaped discrimination curves can be obtained by judicious selection of training situations. Additional conditions do not increase the training effectiveness of a device, but can greatly increase its cost. The process of developing discrimination and generalization curves for the many different tasks (situations) requiring training is specifically the reason that training device requirement specification is an integral part of training system development.

Cueing is of great importance to training device requirements due to the fact that essentially all procedures (normal and emergency) involve sequences of cues. The definition of a procedure given by Miller (1973) is "A procedure is a kind of task in which discrete, principally all-or-none, responses are made to given cues, or to specific values of cues in a continuous series of stimuli. Procedures are verbally mediated (that is, voluntarily instigated and directed) early in the process of learning them." Because of this verbal mediation which involves Block III (Figure 1), the perceptual system, it is obvious, on theoretical grounds, that most procedures training should not require high fidelity simulation. This conclusion is supported by the research data on procedure part-task trainer fidelity (Grimsely, 1969; Cox, Wood, Boren, and Thorne, 1965).

3.3.2 Controlling

Even in continuous aircraft control tasks, the same considerations are important. The type of task that requires continuous controlling and the influence of "psychological" vs "physical" simulation will be discussed in the next section.

The term controlling as used in the present context, involves essentially continuous perceptual-motor tracking. This can be with respect to the pilot tasks of maneuvering the air vehicle, as well as, the navigator (Offensive Systems Operator) tasks of maintaining orientation and position during low level, terrain following, flight. The controlling task, as described by Matheny, Williams, Dougherty, and Hesler (1953), is basically a continuous cueing task. They state that "transfer of training in this situation depends more upon a correspondence between the sequence or pattern of control forces required in trainer and aircraft than it does upon a correspondence between the absolute amounts of control forces required." The "situation" in their study consisted of climbs and glides in the P-1 simulator and the AT-6 aircraft. The primary distinction between cueing and controlling in this context is the temporal aspects and the requirement for continuous anticipation (prediction) on the part of the operator. It is interesting to note that Pfeiffer, Clark, and Danaher, (1963), found that the correlation between the ability to control an aircraft and the ability to detect emergencies (cueing) was very close to zero. This can be explained by the fact that the former type of responses are "graded"; whereas, the latter type are "ballistic" in nature. These are two separate abilities according to the work conducted by Fleishman (1967).

The use of simulators for control system studies has received, by far, the most extensive amount of research interest. This is primarily a result of the utilization of simulators in the development and design of aircraft systems. Studies in this area vary from relatively basic two-axis tracking task with and without a motion base (e.g., Bergeron, 1970) to aircraft-simulator comparisons of landing performance. The information derivable from the research and its applicability to training device design are discussed in Section 3.5. The present section addresses the variables that must be considered when one is making judgements as to training device requirements.

A goal of a training program is to provide the trainee with the necessary and <u>sufficient</u> experiences and information that will increase his proficiency to the point where he is a reliable component of the operational system (weapons system). As with any component of the system, 100 (or even close) percent reliability is not always attainable and is often not cost-effective. Training a crew-member in a weapons system such as the B-1 can be viewed in a manner very similar to increasing the reliability of other primary and back-up components. Increases in component reliability can be costly. Human reliability is no exception. It should be recalled that the goal of a training program (and, therefore, the purpose of the training device) is <u>not</u> necessarily to exactly replicate the behavior encountered in the "real life" situation. Rather, the goal is to develop behaviors in the training environment that allow the crew-member to successfully handle various situations, without jeopardizing the mission. If the behavior is not exactly the same as would occur if the training had occurred totally within the operational environment (aircraft), but the response falls within the range of appropriate (although, possibly not optimum) behaviors, then the training is effective. Playing a large part in this process is the "cognitive" transfer of a perceptual-motor task. The difficulty and criticality aspects of the control situation also has an impact on, with respect to difficulty, training (therefore, inclusion in the training device) is only warranted if the trainee could not perform the behavior sufficiently prior to training. The purpose of the human in most systems is his versatility and his capability to handle previously unencountered events. The criticality of correctly performing the behavior is also important. If the occurrence of a situation does not degrade the mission, the training implications are reduced.

The characteristics of the operational system have a large influence on training device requirements. These characteristics must be considered in the analysis of the tasks in which the trainee must become proficient. In determining which control tasks to include in a training program, and what degree of fidelity should be utilized, three things must be considered. The first consideration is the probability of finding oneself in a particular situation. It is obvious that trainees graduating from a Combat Crew Training School (CCTS) do not have the same experiences as a graduate from a Test-Pilot School. The differences between these two types of curricula can, to a great extent, be traced to the "probability of occurrence" issue. With respect to CCTS, the issue is implicit in the training of multiple, simultaneous malfunctions. Many combinations of malfunctions (e.g., three engines out and SCAS Failure) can be very costly to simulate with high fidelity flight equations, however, they have very low probability of occurrance.

Even with respect to normal operations, Ellis, Lowes, Matheny, and Norman (1968) found that higher fidelity equations of motion (rigid body equations only versus rigid body equations plus <u>least squares approximation</u> of aeroelastic equations) did not result in higher transfer of training. In fact, the latter condition resulted in poor transfer and high variability for the task employed. The flight tasks used were a 360 degree standard rate turn with a 2000 ft/min climb and a constant altitude turn. The research results derived from studies on simulation relating to controlling and the training of control tasks are included in Section 3.5, Research In Simulation. As in the case of Cueing, the problem involved in training device design with respect to controlling is simulation of the task (psychological simulation) which may or may not involve high fidelity (physical simulation).

3.3.3 Task Loading

Some aspects of the environment of a simulation are sometimes used for the purpose of making a particular task more difficult due to physical disruption or distraction. An example of this type of consideration is the study by Soliday (1965) of the low-altitude high speed flight. Task loading can be in the form of time-sharing requirements or stress.

The real question to be evaluated in this condition, as it was in cueing and controlling, is whether the behavior will change (increased probability of mission success) as a result of the training. It is often the case that the operator must "do the same thing" under task loading, but it is more difficult. To the extend that behavior is not changed, training, and, therefore, device capability is not justifiable. If a different behavior (technique) is required under task loading, then that particular behavior should be trained and the device should allow adequate capability for that training.

Another use of task loading capabilities in a training device, is in the proficiency measurement process. The assumption (which will not be endorsed or disputed here) is that if one can perform adequately under high task loading, then he will be able to perform under normal conditions more easily.

Training that is intended to increase the operators proficiency under task loading has been investigated. Soliday (1965) studied the influence of varying the task loading in a low-altitude, high-speed flight task. Gabriel, Burrows, and Abbott (1965) found that time-sharing performance in collision avoidance can be improved by simulator training. Pfeiffer, Clark, and Danaher (1963) found that training in visual time-sharing is necessary, even for highly skilled pilots.

3.3.4 Summary

The B-1 SAT program is concerned with all three of the task categories. Cueing is predominant in an air vehicle that is as "systems oriented" as the B-1. Controlling is of importance primarily, during takeoff, landing, refueling and manual terrain following. The obvious example of high task loading is during low-level (terrain following) flight. The effect of simulation technology on training effectiveness can only be evaluated in terms of the performance measurement used.

3.4 MEASURES OF TRAINING DEVICE EFFECTIVENESS

Inherent in any evaluation of training devices is the methodological issue of "what does one measure to determine effectiveness?" The methods utilized can be grouped into five general categories: (1) whole curriculum approach, (2) human performance measures, (3) system performance measures, (4) physiological measures, and (5) pilot (expert) ratings. These methods and their interpretation with respect to B-1 training devices are discussed in this section.

3.4.1 Whole Curriculum Approach

Many of the evaluations of training device effectiveness have been in the context of retrofitting an existing training program. The new program involves new training devices. The time savings in terms of the required aircraft flight time of the new program relative to the old is (at least in part) attributed to the new device. To the extent that the saving in flight time (cost, fuel, airframe life, etc.) is greater than the procurement and operating cost of the new device, the device is effective. One of the problems with this type of interpretation is that when the new program is initiated, much more than the devices have been improved. For example, although some commercial airlines attribute their "lack of need for aircraft time today," to their new simulators, this is confounded with their concurrent major alterations in the training curriculum. There are various means of calculating the transfer of training. These methods are adequately discussed in the literature (e.g., Roscoe, 1971; Underwood, 1966; Micheli, 1972) and will not be covered in the present report.

As was previously mentioned, the comparison has traditionally been concerned with transfer to the aircraft. With the cost of complex training devices (sometimes referred to as "full mission simulators") increasing, it is appropriate to evaluate the transfer of training from one device to a more complex device.

The evaluation of training device effectiveness only in terms of aircraft time saved, can result in a conservative evaluation. One of the things that is sometimes not accounted for in this type of evaluation, is that often more behaviors can be trained in the simulator than in the aircraft. Electronic warfare training is an obvious example of this situation.

The measure of transfer of training in total curriculum evaluations is the time to meet a criterion performance (usually in the form of a check-ride). This criterion performance involves proficiency in many different tasks. The information provided by this method of evaluation helps the training device designer very little in making "prescriptive" decisions for different operational criteria. That is, given that various tasks that need to be trained, no information is provided as to the device requirements in terms of components (e.g., motion, visual) required to train that task. There is also a tendency to be "overjoyed" with the savings involved with the new device (and curriculum). The question remains that, given different device capabilities, would the total savings have been greater?

3.4.2 Human Performance Measures

The use of human performance measures most often occurs in the context of air vehicle control system design and development in terms of pilot transfer function characteristics (Newell, 1967). These measures have also been used in research on basic human tracking behavior in simulators (Salmon and Gallagher, 1970; Bergeron and Adams, 1964). The most often used measures in this category are the amplitude and phase of the operator's output relative to a continuous control task input. Research data utilizing these measures are included in Section 3.5.

The problem exists, however, of the interpretation of the data with respect to training device effectiveness. As previously discussed, a "statistically significant difference" in the phase lead or lag encountered in the simulator as compared to the actual aircraft may or may not indicate that the transferred behavior is appropriate to perform the task. The relevance of the result depends upon the magnitude of the effect. As is emphasized many times throughout this report, the task being performed, the characteristics of the air vehicle, and the criterion of performance must all be considered in the determination of training device requirements.

3.4.3 System Performance Measures

The measurement of system performance as a function of training device characteristics is the most often used effectiveness measurement method. The human is considered as a component of the system contributing to its performance. Typical measures of tracking proficiency in flight simulation include time-on-target, root-mean-squared (RMS) error, and average absolute error. For example, RMS glide slope error is a typical system measure of approach to landing proficiency. Another type of system performance measure that is used in the context of simulation is "terminal performance." These are discrete measures, such as the probability of a hit in weapons delivery. The analogous measures for terminal landing performance are touchdown point and vertical velocity.

These measures are more easily interpreted in terms of prescriptive judgments as to training device requirements for a "given" task. The problem of generalization to other tasks is apparent, as it is with most experimental work. One of the large gaps in the literature on aircrew training is a taxonomy of tasks. Hopefully, there will eventually exist a taxonomy of tasks and their simulation fidelity requirements within the context of training that can be used by the device designer.

Within the simulation community, it is generally recognized that device requirements are very task dependent. There are many pitfalls in attempting to generalize across tasks. The type of statements that are very questionable include, "The acceptance of the need for motion systems today is widespread, if not universal" (Cohen, 1971, p. 1). Cohen also quotes, "Gibino (7), expressing the Air Force's position, recommended that "Sophisticated flight simulators should not be purchased by the United States Air Force without motion systems of comparable sophistication" (Cohen, 1971, p. 1). There is no definition of what Gibino terms "comparable sophistication" in the original report (Gibino, 1968, p. 2). Statements to the effect that "motion is, or is not necessary", outside the context of task requirements are meaningless and provide little information to the device designer considering minimum device requirements. An example of drawing conclusions on the basis of task characteristics is given by Huddleston (1966). For example, he concludes:

> "3. Yaw and sway accelerations would be most frequently useful in the simulation of V/STOL and engine failure cases."
>
> "4. The more gentle flight modes (take-off, landing, straight and level flight) can be more thoroughly treated in static simulators than the more vigorous, maneuvering modes (target chasing, terrain following, investigating boundaries of pilot acceptability)." (p. 3).

There are some guidelines to be drawn from the research literature with respect to the influence of simulation fidelity and system performance for various tasks. (See Section 3.5 and Section 4).

3.4.4 Pilot Ratings

For the purposes of investigating the controllability of simulated flying characteristics, pilot acceptance ratings are a measurement technique that have proven effective and have been used extensively. The best known rating scale is the Cooper-Harper system (Cooper, and Harper, R.P. Jr., 1969). This method of evaluation has been used less in the context of training. Matheny, Lowes, and Bynum (1974) investigated the motion-base issue using pilot opinion, human performance, and system performance. They found that pilot ratings were inconsistent and not related to either human or system performance. Similarly, Bray, Drinkwater, and Fry (1971) found inconsistencies between pilot ratings and performance. Subjective opinion, even with its problems, remains a useful tool particularly when supplemented with "objective" performance data.

The methods of measuring device effectiveness are obviously dependent upon the operational skills and knowledges to be trained. The measurement method utilizing the "total curriculum approach" is difficult to interpret. The research results do, however, illustrate the cost savings involved with the use of simulators (Povenmire and Roscoe, 1972; Caro, 1973). The use of human performance measures such as operator control amplitude and phase, are also very difficult to interpret in terms of transfer of training and mission success. There are areas where this information is important (e.g., PIO avoidance training). Development projects in which test pilots are questioned as to their opinion of the devices for training purposes, must be interpreted carefully. The form and context of the question is all-important. It is often the case that the test pilot knows the conditions he is performing and has preconceived opinions that are left uncontrolled in the tests. As previously discussed, there also exist conflicts between performance and opinion. Both of these must be considered and weighted with respect to the purpose of the device. System performance provides the most information related to transfer of training questions. The data available in the research, utilizing all of these methods and their interpretation are discussed in the next section.

3.5 "APPEARANCE" ATTRIBUTES OF SIMULATION

This section of the report will deal with the variables that are of importance in evaluating the results of research on training device requirements. The variables discussed are appropriate across the entire range of training devices, from line drawing mock-ups to complex devices used for mission rehearsal. The first part of the discussion involves the visual input to a crewmember. This is followed by a discussion of the research relevant to visual input. The next subsection addresses the motion-base variables and is followed by a discussion of the research literature. It should be apparent that the visual and motion requirements are not independent and the next subsection will discuss their interrelationship. The final subsection will discuss the fidelity issue, as it pertains to other aspects of training devices, such as procedures trainers, tactics trainers, etc.

3.5.1 Visual-Motor Attributes

The term "visual-motor" is used in the present context because the primary concern of training devices is to present information (visual in this case) which the trainee will learn to interpret and respond to. The attributes appropriate for behavioral classification of visual inputs are discussed in this section. These attributes are generally continua that can be scaled at discrete points in a nominal and often ordinal fashion. The attributes interact, such as the case of color (hue) and brightness.

3.5.1.1 Format

This attribute is termed "Gestalt distortion" by Wolff (1971). The attribute is best defined by examples of the values than can be scaled along a continuum.

Point-lights. The information that can be portrayed in point-lights include: (1) number of lights (density), (2) brightness, (3) spatial pattern, and (4) movement pattern (relative movement of points). An example of an operational situation that can be represented by point lights is night flying with limited visibility (i.e., no horizon).

Lines. If point-lights are connected or placed adjacently, lines can be produced. The information in lines include: (1) the relative orientation, (2) extent, (3) brightness, (4) movement pattern, and spatial pattern.

Planar Surfaces. Proper geometric orientation of lines results in planar surfaces. In this format, the homogeneous surfaces involve the same information as lines with the addition of improved three dimensionality (reduction of perceptual reversals due to ambiguities).

Hyperplanar-Surfaces. In this case, the surfaces are non-homogeneous (shaded). This "shading" can be continuous or discrete (involving many planar surfaces). The most used techniques of "shading" are in terms of brightness and/or color. The information gained by this format is increased "appearance" of three dimensionality with curvature. Both planar and hyperplanar surface formats are generally described as stylized or cartoonish.

Rendition. This format is basically pictorial in nature. It usually consists of an artist representation (painting or model). The best example of this format is the Link Cyclorama (Williams and Flexman, 1949; Valverde, 1973). In this device, an artist's painted representation of the visual scene surrounded the simulator. The basic difference between this format and the previous ones is that the level of "abstraction" is reduced.

Photographic Reproduction. This format involves an optical translation of the "real world" visual information. The information included in this format generally involves more "detail," than the previous formats. The detail is a function of the optics, storage, and projection.

Actual Direct View. This format is self-explanatory. The "real world" instruments (controls and displays) or visual scene is viewed directly within the operational environment.

There are very little experimental data that evaluate the various formats (Kahrs, 1972; Palmer and Crown, 1973; Young, Jensen, and Traiche, 1973; Mays and Holmes, 1973; Stark and Wilson, 1973). The reason for this is obvious in that, as with other cue parameters, the requirements vary as a function of the tasks to be performed and the trainee experience level. For example, for many years, researchers have been discussing the fact that we do not know the "essential cues for landing." It is very possible that there are no "essential" cues. There are a multitude of cues to use, many of which may have sufficient efficacy for landing proficiency. An analogous situation is the refuelling task. It is the task of the training technologist to evaluate the potential possibilities, choose a minimum set of cues, and train the individual to use those cues correctly. This is basically what instruction is all about. A good example of research pertinent to this, is the experiment by Brown, Matheny, and Flexman (1950) in their study that illustrated the training effectiveness of a simple tilting plywood device, which provided the pilot only with the vertical geometry of the runway.

3.5.1.2 Color

The term color, as it is used in the present context, includes both hue and saturation. As previously noted, apparent color is also a function of brightness, as well as subjective factors, such as contrast with the surrounding area. The values of the color attribute are: (1) monochromatic, (2) limited color, (3) full color.

Monochromatic. This value involves only one color (i.e., brightness differences only). The particular color is dependent on the spectral characteristics of the display device (e.g., green in the case of the CRT phosphor of the ASUPT described in Section 2).

Limited Color. This value includes two situations. The colors could be discrete or continuous (color shading) within a limited range of the spectrum.

Full Color. In this case, the colors are "perceptually" continuous across the full range of the spectrum. The distinction between limited and full color is obviously subjective.

One of the only studies which investigated color as a parameter in visual scene presentation was conducted by Chase (1971). In this experiment, color was not found to be superior to monochrome (black and white) for landing tasks (using experienced pilots). The requirement for color depends upon whether color is being utilized as a cue parameter in any particular task. For example, a landing task utilizing slope indicator lights (red and white), or refueling using the director lights (green, amber, and red) would require color cues.

3.5.1.3 Brightness

The brightness requirement for any visual display (instrument or external scene) is dependent upon the ambient illumination. For example, the brightness requirements for visual scene used for daylight operations are very high if the cockpit ambient illumination is to be close to its operational "real life" daylight level. The number of steps into which brightness level can be categorized into are:

(1) One. In this no-contrast case, color is the only discriminating factor.

(2) Two. This value includes the situation where the visual cue is "on" or "off" in nature.

(3) Discrete. In this case, the brightness is controllable only in discrete steps, rather than a continuous fashion.

(4) Continuous. This value involves perceptually, continuous brightness changes.

Two other considerations with respect to brightness are the range of brightness (high and low values) and the fine control of the brightness. The requirements for brightness must be considered in the context of discrimination and generalization as discussed in Section 3.3

3.5.1.4 Interaction

The attribute of interaction involves the extent to which the operator's response alters the subsequent events. The values within this attribute are (1) none, (2) open-loop, and (3) closed-loop. No interaction (none) occurs when the operator's response has no influence on the system. Open-loop interaction exists when the response of the operator has an effect on the system, but the appropriateness of his response is not fed back to the operator. An example of this value is when responses are being monitored (e.g., automatic performance measurement), but without knowledge-of-results. The closed-loop case involves knowledge-of-results being fed back to the operator such that his next response can be based on the success or failure of the previous one.

With respect to training devices, this aspect of simulation is dependent upon the characteristics of the operational equipment or situation and the stage of training of the trainee.

3.5.1.5 Movement

There are three values that are discernable within the attribute of movement: (1) static, (2) discrete, and (3) continuous. These values are self-explanatory.

3.5.1.6 Dynamic Fidelity

Within the continuous movement case, and in some instances the discrete case, the velocities and acceleration of the movement are important. An example of altering the dynamic fidelity of a visual display is the training involving the engine instruments. In the early stages of procedures training, it is possible that dynamic indications (e.g.. continuous) can be simulated by discrete motions (e.g., on-off). When this abstraction is utilized and the training is effective, large cost savings can occur in device requirement reductions.

3.5.1.7 Resolution

A quantitative measure of resolution is usable in the case of visual resolution (minutes of arc). Resolution can be qualitatively categorized as: (1) poor (greater than 10 arc min.), (2) low (7-10 arc min.), and high (less than 7 arc min.). The attribute of resolution in the context of radar simulation is important in terms of discriminable landmass features. In this case, the capabilities of the operational equipment, the landmass characteristics, and the phase of training must be considered.

There are research data that reflect the influence of visual scene resolution on performance. Reeder and Kolnick (1964) varied the resolution of a forward-looking TV system in a flight experiment. The task was to land (straight in approach) being totally dependent upon the TV for the forward view. The resolution of the display was seven to eleven minutes of arc. This presentation was adequate for approach, flare, and ground roll with regard to system performance measures. The only problem was in the area of exact height estimation during flare due to the fact that the resolution was not sufficient to judge height from ground texture cues.

Wempe and Palmer (1970) used pilot ratings to evaluate the effect of resolution in a simulated landing task. These investigations also found that the height estimation in the flare was the area that resolution had its greatest effect. They did, however, find that resolution could be degraded by a large amount (to 24 arc min horizontally and 48 arc min vertically) and still achieve pilot ratings of "acceptable." Wolff (1971) advocates putting the resolution where it is needed (central field-of-view, while sacrificing resolution in the periphery). Puig (1973) discusses the problems of making optical tolerance determinations for optics in visual scene systems.

3.5.1.8 Range

The attribute of range corresponds to direct sight range, as well as radar range. The range is a function of operational equipment capabilities (e.g., radar) and simulated atmospheric conditions (e.g., haze).

3.5.1.9 Extent

As separate from range, the attribute of extent is concerned with the maneuvering area (or gaming area) of the simulation (in terms of landmass). One example of differences in the extent capability is among programmed visual landing systems (e.g., film), terrain board systems, and computer generated imagery systems (Eberling, 1968, Pfeiffer, Clark, and Danaher, 1963). Of primary concern to the training device designer, with respect to extent, is the corridor limits that the operational mission dictates.

3.5.1.10 Field-of-View

The two dimensions of field-of-view (vertical and horizontal) are important with respect to visual scene simulation. Wolff (1971), on intuitive ground, states that 60 degrees of horizontal field-of-view is usually sufficient (that is, for most tasks requiring visual). For example, for landing on a long runway, 60 degrees may be sufficient, whereas for carrier landings, it is possible that 180 degrees may be necessary.

Armstrong (1970) conducted a flight experiment investigating landing performance with a restricted field of view (±25 degrees horizontal, unrestricted vertical) for military pilots. On the basis of system performance measures, he concluded that "landing performance in-flight is almost unaffected by loss of peripheral vision, even in poor visibility" (p. 1). The previously cited study by Reeder and Kolnick (1964) found ±21.5 degrees horizontally to be adequate for landing.

3.5.1.11 Time-of-Day

The attribute of time-of-day is important with respect to visual scenes and particularly important in forward-looking infrared (FLIR) simulation. For visual scenes, the continuum of values are as follows:

(1) Night - can include horizon glow.

(2) Dusk - includes runway shading and horizon glow.

(3) Full Daylight - represents an overcast or zenith sun.

(4) Sunlight - includes shadows, hot spots and glare.

The interaction of these values with "format" is obvious. With respect to FLIR simulation, relative temperature as a function of the time of day and sky condition is important.

3.5.1.12 Atmosphere

This attribute is applicable to visual scene presentation, FLIR, radar, and, in some cases, ECM. The values corresponding to visual scene and FLIR presentation are:

(1) None - unlimited visibility

(2) Haze - fog, smog, smoke, etc.

(3) Ceiling - flat or structured clouds

(4) Clouds - at various altitudes

(5) Precipitation - rain, snow, etc.

3.5.1.13 Viewing Position

This attribute corresponds to the bounds of correct perspective and imaging of a visual scene. The values are simply, (1) one seat, (2) two seats and (3) entire cockpit. Within each value are the head movement limits that allow correct viewing. Wolff (1971) has a thorough discussion of virtual image optical techniques.

3.5.1.14 Summary

Using the above attributes to define the minimum visual requirements for various tasks (training objectives), can result in specifying cost-effective training devices. Considering the research data on visual parameters independent of the other sensory systems, (kinesthetic in particular), however, can be misleading.* Puig states "Investigators can be mislead by trying to extrapolate the results of single variable experiments to complicated applications where many variables are present". (1973, p. 65).

The next section discusses the translation of physical bodily motion into "appearance." Subsequently, in Section 3.5.3, the interactiveness of the visual and motion perception systems is discussed.

3.5.2 Motion Attributes

The air vehicle system operates in a six degree-of-freedom environment. These six include three rotational (roll, pitch, and yaw) and three translational (lateral, longitudinal, and vertical) degrees-of-freedom. The excursions (velocities, accelerations, etc.) in this environment can be large. The training device environment, however, is restricted (with the exception of in-flight simulation) in terms of its excursions. This section discusses the issue of motion requirement on the basis of "psychological simulation."

The "motion issue" appears to be one of the most controversial issues within air vehicle simulation. As previously discussed the question is often posed "is motion necessary or not?", and, previously noted, this question, in itself, is absurd. The answer is obviously sometimes. The next question is "when is the sometime?" For this question, we have very little research information on which to base an answer.

A "non-motion" aspect of motion simulation that is presently being evaluated within the ASUPT and SAAC devices is the G-seat (and G-suit in SAAC). This device may provide very useful higher-frequency cue (up to 4 Hz in ASUPT), as well as sustained g's (Kron, 1973; Stark and Wilson, 1973).

There are really two questions involved in motion systems. First to be resolved is which motion degrees-of-freedom are necessary (if any), given a particular training situation. The second question is, what is the fidelity requirement for each degree of freedom. Many experiments have been conducted on these two topics. Many of them utilized system or human performance measures in a psychomotor tracking or controlling task (Bergeron, 1970; Bergeron and Adams, 1964; Bray, 1964; Bray, 1973; Jacobs, Williges, and Roscoe, 1973; Dinsdale, 1968; Klier, 1970; Shirley and Young, 1968; and Salmon and Gallagher, 1970; and many others). The research data pertaining to flight instrumentation is reviewed

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*This section has not discussed the extensive literature on target acquisition. The reader is referred to Bliss (1969) and Greening (1973) for excellent reviews of target acquisition data and models.

by Johnson and Roscoe (1972). The overall conclusion to be drawn from these studies is that motion versus no motion does affect behavior in tracking (controlling) tasks. This is intuitively satisfying in that bodily motion is an additional cue, particularly in high frequency control tasks. The problem arises when one attempts to interpret these results in terms of training. Huddleston (1966) in his review of motion requirement research concluded:

> "Attitude control tasks are those which most demand that the simulation include cockpit dynamics, and are those which can most easily yield subversive results from static stimulator work."

He also concluded that:

> "The more gentle flight modes (take-off, landing, straight and level flights) can be more thoroughly treated in static simulators than the more vigorous, maneuvering modes (target chasing, terrain following, investigating boundaries of pilot acceptability)."

With respect to cost-effectiveness, Huddleston concluded that:

> "Yaw, sway and surge accelerations would be progressively more difficult to justify, in terms of cost, for flight training associated with conventional lift aircraft" [as opposed to V/STOL] (p. 3).

Rather, Creer, and Sadoff (1959) also conclude that:

> "In a broad range of airplane characteristics that might be termed conventional, however, the fixed simulator with adequate instrument presentation appears to be a realistic and useful device for pilot-proficiency training." (p. 8).

The point is made by Roscoe (1974) that "while cockpit motion makes a simulator easier to fly, thereby improving pilot performance in the simulator... there is as yet, no evidence that cockpit motion in a ground-based trainer improves pilot performance in an airplane. There are studies that compare performance in a simulator (with and without motion) with performance in the aircraft (Rolfe, Hammerton-Fraser, Poulter, and Smith, 1970; Bray, Drinkwater, and Fry, 1971; Newell, 1967; Kuehnel, 1962). As with the other research data, extrapolation to a training context results in the fact that the characteristics of the task situation are very important (psychological simulation). Koonce (1974) conducted a study that investigated the predictive capabilities of using three configurations of a general aviation trainer (Link GAT-2) to a general aviation aircraft (Piper Aztec). The three configurations consisted of: (1) the trainer without motion, (2) the trainer with linear, scaled-down analog motion, and (3) the trainer with washout (in roll). The findings of this study illustrated that a fixed-based device is more difficult to "fly" than one with motion cues. However, performance in the aircraft was not found to be different after training in any one of three devices (e.g., not statistically significant). As a result only of the difference between conditions (motion vs. no-motion) in the sim lator and no difference in the aircraft, there is a statistically reliable interaction between simulator and airplane performance as a function of cockpit motion in the simulator. Roscoe (1974) interprets the results in this way: the "disproportionate improvement by the group tested with no cockpit motion in the simulator strongly indicates differential transfer". Roscoe continues to state that "apparently, pilots trained in moving simulator cockpits learn to depend upon acceleration cues, which they must learn not to depend on in the air because much airplane motion occurs at subliminal acceleration levels." This latter statement is intuitively reasonable, but does not follow from Koonce's data. That is, the fact that no difference among the groups existed in the aircraft means that you can not conclude that there is differential transfer. One must also guard against the conclusion that transfer was the same (i.e., proving the null hypothesis). The interaction effect to which Roscoe refers is not relevant to transfer-of-training. For example, if a device were included in the study that was even more difficult to "fly" than the fixed based trainer (e.g., lagged instrument indications), but did not result in negative transfer (performance in aircraft not found to be different), then, using this interpretation of the magnitude of the interaction effect, this device would indicate even more differential transfer.

As previously mentioned, although the data do not support Roscoe's conclusion, it is intuitively appealing to the authors for the following reason. The bodily orientation cues provided in a sustained system are much greater than are provided in the aircraft flight environment (due to apparent gravity). Therefore, the no-motion situation is much more difficult in that these bodily orientation cues are not present. This would require the trainee to develop his instrument interpretation abilities to a greater extent. In the transfer task (to the aircraft), these instrument capabilities (e.g., scan pattern) are more important to proficiency in instrument flight than the motion cues. Therefore, it is very reasonable that the no-motion case would transfer more than the incorrect motion case. The results of the study might have much more to do with "what needs to be transferred?", rather than "is motion necessary"?

As was discussed in Section 3.2, the human is variable in his sensitivity to physical parameters. This variability is contributed to by task loading. Conrad and Schmidt (1971) in their evaluation of motion washout characteristics found that the ability to detect motion cues is very much a function of workload factors. Another factor that affects motion perception is the attitude of the operator (trainee). For example, Johnson and Williams (1971) found that the human's confidence in a visual display greatly affects his perception of rotation. The relationship between visual and motion perception is discussed in the next section.

3.5.3 Visual-Motion Interaction

There is no question that the human perceptual systems (e.g., visual, proprioceptive, haptic, etc.) interact in the formation of what has been termed in the present paper as "appearance." That the modalities interact may be quickly demonstrated by the reader by standing on one foot, first with the eyes open, and then with the eyes closed. The change in the ability to maintain equilibrium is dramatic. As the previously cited quote by Puig (1971) contends, extrapolation from research data that are investigating single modalities (e.g., visual or kinesthetic) can be very misleading to the training device designer.

There is extensive information available with respect to visual perception as indicated by the number of books on the topic. Simiarly, there is a lot of information as to man's motion perception capabilities (Meiry, 1966; Clark, 1962, 1970; Young, 1969; Shirley and Young, 1968). Clark (1967) published a very good review article on the topic of thresholds to bodily motion. As is stated throughout this report, "threshold" information is of little value to the training device designer. It helps determine the maximum fidelity requirements, but the task of the device designer is to determine the minimum fidelity requirements.

An example of the type of interaction of the visual and proprioceptive systems is illustrated by the work of Young, (Young, 1971; Young, Dichgans, Murphy, and Brandt, 1973; Young and Henn, 1974; Young, Oman, Curry, and Dichgans, 1973). Dichgans, Feld, Young, and Brandt L972) found that rotating a visual field produced "apparent" body tilts (from vertical) up to 40 degrees, depending upon the angular velocity of the visually rotating stimulus.

There is some agreement to the hypothesis that the relative influence of visual and motion perception changes as a function of the frequency of the cue dynamics. That is, the visual sense dominates over the proprioceptive sense of low-frequency inputs. Stapleford, Peters, and Alex (1969) concluded that they are comparable in the frequency range of 5 to 10 radians per second in the context of a control task, when no low-frequency pilot phase lead is required. When low-frequency lead is required, they are of comparable magnitude in the frequency range of 1.5 to 2.0 radians per second.

These results, as with essentially all of the results within simulation research, demonstrate the requirement of careful inspection of the characteristics of the training tasks in conjunction with the structure of the entire training program. That is, what may be a conflict in one phase of training, may not be a conflict in another phase. The research results discussed in this section, in conjunction with the principles of training, will be discussed in the context of B-1 training in Section 4.

SECTION 4

IMPLICATIONS FOR B-1 AIRCREW TRAINING

4.1 INTRODUCTION

The development of an entire training system must include the following steps: 1) analysis of the operational mission (tasks), 2) establishing training objectives, 3) specification of training device requirements, 4) instructor (manager, commander) training, 5) training program implementation, and 6) training program evaluation and validation. An attempt to accomplish any of these steps separately from the others is not possible and would compromise the training system extensively. The purpose of utilizing a Systems Approach to Training (SAT) is to develop a coherent training system by progressing through the steps sequentially. This technical memorandum serves as a "decision aid" in transitioning from Step 2, establishing training objectives, to Step 3, establishing training device requirements. The behavioral considerations discussed in Section 3, along with the state of engineering technology discussed in Section 2, must be considered in determining the training device capabilities required to satisfy the B-1 aircrew training objectives.

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" [p. 21]. Other authors have also discussed the problem of devices not being effectively utilized (Muckler, Nygaard, O'Kelly, and Williams, 1959; Mackie, Kelley and Moe, 1972; and Mackie, 1971). For example, both Hall, Parker, and Meyer (1967) and Browning, Copeland, and Lauber (1972) state that often the device capabilities are not being effectively utilized due to a discrepancy between design criteria (proposed use) and operational (instructor) use of simulators. This is, to a large degree, due to inadequate (if existent) training of the instructors. This instructor-training should include instructional techniques, as well as device capabilities.

The following subsections discuss specific requirements of the B-1 training system, part-task training, and automated performance measurement with conclusions and recommendations included in the respective discussions.

4.2 REQUIREMENTS SPECIFIC TO THE B-1 TRAINING SYSTEM

As was discussed in Section 2, the required capabilities of training devices are a function of the operational procedures and air vehicle flight characteristics. The description of procedures and flight characteristics is unique to the main situations encountered in the operational mission. For example, the segments comprising a B-1 EWO mission are: 1) alert procedures, 2) alert reaction, 3) taxi, 4) take-off, 5) climb, 6) cruise, 7) refuel,

8) loiter, 9) penetrate high, 10) weapon delivery, 11) descend, 12) penetrate low, 13) withdraw, 14) recovery, 15) land, and 16) post-flight. It is obvious that the various phases of flight (and tasks within them) have different simulation requirements. The SAT process establishes training objectives that result from an analysis of the mission. The training objective is the unit of behavior used to determine device requirements based on the stimulus information requirements of the situation (e.g., cueing, controlling, or task loading). In addition to the information requirements, other considerations such as the phase of training, instructional strategy and setting, and feedback requirements affect the required device characteristics. The process of determining the requirements is basically the same across the spectrum of training devices. Therefore, these same considerations are important in establishing the requirements for simple devices, such as audio-visual presentations in a carrel, or complex full-mission trainers.

The B-1 air vehicle is a far more sophisticated system than its predecessors (e.g., B-52). This sophistication is especially exhibited in the malfunction diagnostic capabilities of the Central Integrated Test System (CITS) and capabilities of the Stability and Control Augmentation System (SCAS) to mention two of the many B-1 systems that challenge the state-of-the-art. One of the primary purposes of this sophistication is to assist the human operator in successfully accomplishing the desired mission ("bombs on target"). 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., automotion) of the operational system.

4.2.1 Defensive Systems Simulation

The electronic warfare simulation used for training the Defensive Systems Operator (DSO) of the B-1 is a very good example of the effect of "sophistication" on training devices. Added sophistication with respect to the DSO operational hardware (e.g., panoramic display and threat situation display), results in presentations of alphanumerics and simple symbology on CRT displays that are relatively simple to simulate. Another example is the emitter-audio. In the B-1, the emitter audio presented to the DSO is synthesized by the computer. Therefore, the characteristics of the audio presentation in the simulation are known exactly. As a result, it is not necessary to "simulate" the electronic signals, process the signals, and present the audio to the DSO trainee. Rather, it is sufficient to skip the first two steps and present the trainee with the "high fidelity" representation of the audio.

The complexity in developing a defensive systems simulation is in determining the multitude of logical contingencies involved in realistic scenarios. The problems and expense involved in DSO training devices are primarily software, rather than hardware. Oberlin (1973) discusses the various approaches to electronic warfare simulation. The state-of-the-art in simulation technology does not appear a constraining factor with respect to DSO training devices.

4.2.2 Offensive Systems Simulation

The offensive systems simulation for the B-1 can be grouped into six "component" systems:

1) Navigation Systems (e.g., inertial and doppler).

2) Attack Radar (e.g., landmass).

3) Stores Management System (e.g., conventional, nuclear, and SRAM weapons).

4) Central Integrated Test System (shared with DSO).

5) Logic Trees (integrated keyboard)

6) Forward-Looking Infrared.

Each of these components has specific simulation requirements and problems to be discussed in this section. The simulation of the navigation systems is apparently not a technical problem for the B-1 in that it is understood that none was encountered with other similar aircraft systems (e.g., FB-111).

The Strategic Air Command (SAC) mission of the B-1 is important to consider when determining the radar simulation requirements. The corridor of operation for a SAC mission is relatively small. That is, the "extent" (for maneuvering) laterally and in altitude are well-defined in that the air vehicle should be on-track and should maintain the desired altitude plus or minus a small amount. Performance outside of these limits does not meet the criterion and is not acceptable. The implications of the restricted corridor for B-1 operation is that it is probably costly and useless to carry the radar landmass simulation beyond these limits. The trade-off to be made in this situation is to provide more longitudinal (track) extent at the expense of lateral extent. This is particularly the case for proficiency training when landmass simulation of forward target areas is extremely expensive and the performance criteria are stringent.

Another consideration of importance in radar landmass simulation is the placement of the high resolution (landmass data) where it is needed. For example, the resolution required for high altitude flight phases is much lower than the resolution needed for low altitude flight, however even greater resolution then both may be needed in the target area. Because the routes and corridors of SAC missions are known, great savings can be obtained by analyzing both the training and emergency war order (EWO) missions in the determination of the needed resolution of the landmass simulation.

For the purposes of training, as well as some parts of EWO mission rehearsal, the use of "generic" landmass (and maps) rather than "actual" landmass can result in cost savings without reducing training effectiveness. Through modeling techniques, it is possible to produce appropriate landmass and cultural features that can enhance the training effectiveness of the attack radar simulation. A third alternative is a combination of generic and actual landmass, in which selected actual features are superimposed on generic landmass. Because of the great amount of ground that is covered during B-1 operations (much of which is irrelevant), this third alternative has great utility for B-1 training.

The simulation of the B-1 Stores Management System (SMS), as with the navigation system, does not appear to pose technical problems beyond the state-of-the-art. Other air vehicle systems (e.g., FB-111 and B-52) are presently simulating stores management effectively.

The Central Integrated Tests System (CITS), which is shared with the DSO, tests and displays malfunction information to the crew. The displays consist of switch-lights and alphanumerics presented on seven-segment lights. The real complexity in the simulation is in the software logic required to present realistic malfunctions and combinations of malfunction. The area of "malfunction insertion and manipulation" is one of the areas of simulation that has received far too little attention. As with the DSO scenario development, the simulation of malfunctions requires extensive analysis of the possible contingencies and their probabilities. To this extent, the problems in CITS simulation are "logical", rather than technical.

The logic trees utilized in conjunction with the integrated keyboard (IKB) also involve alphanumeric displays and keyboard controls. They do not appear to pose a problem in terms of simulation.

The last offensive system "component" is the forward-looking infrared system (FLIR). Simulation of FLIR in a real time, interactive mode is a problem within the present simulation state-of-the-art. Due to the fact that most FLIR training can occur in a noninteractive mode (e.g., FLIR interpretation and target detection), interactive simulation of FLIR may be unnecessary. Interactive FLIR training can probably occur in the air vehicle without increasing flight time since the training is short in duration and not high in criticality.

4.2.3 Flight Station Simulation

The systems included in the front station (pilot and copilot) of the B-1 involve the following major "components":

1) Air Vehicle Instrumentation

2) Annunciator Panel (malfunctions)

3) Terrain-Following Radar

4) Forward-looking Infrared

5) Flight Equations (e.g., vis-a-vis wing sweep)

6) Stability and Control Augmentation System (SCAS)

The air vehicle instrumentation component consists of most of the front station controls and displays. The simulation of controls and displays that are similar (at least in the complexity of simulation) presently exists in many military and commercial training devices. This simulation area is well within the state-of-the-art. One concern, with respect to simulator instrumentation, is whether to use operational aircraft equipment or "simulated" equipment. The primary advantage of using aircraft instruments is the logistics involved in repair or replacement. One problem with this approach, however, is that aircraft instrumentation, while designed for severe environments, is not capable of withstanding the duration of continuous utilization that is required of training device equipment. The malfunctions displayed on the annunciator panel have the same complexities as the CITS system previously mentioned. Simulation technology is not a constraining factor, other than with respect to the malfunction (degradation) of the other components.

The terrain following radar (TFR) is basically the same system as is now being used in the FB-111 aircraft and simulator. The same data base can be used for the TFR as for the attack radar (radar landmass) and the two presentations must be correlated appropriately. The FLIR system in the front station has the same problems as it does for the OSO station. If FLIR were simulated, however, correlation with a visual scene presentation and the FLIR must be appropriate to ensure that inconsistencies do not occur in the cues provided by the two presentations.

The variable wing sweep and the fuel and center-of-gravity control aspects of the B-1 have implications for the fidelity of flight equation modeling. It is possible to experience cost savings by utilizing "high fidelity" equations, only at selected (possibly discrete) values of wing sweep and center-of-gravity, rather than continuous across the entire range of values. With respect to SCAS failures, it is also necessary to analyze the probabilities and criticalities of the various combinations of failures in order to include only the "important" situations. SCAS failure is a good example of the requirement for the trainee to be able to "discriminate" among the possible failures to ensure an appropriate action.

The other two components of flight station simulation, visual scene and motion base, pertain to the cues imposed by the environment that is external to the air vehicle cockpit. As is evidenced by the research discussed in Section 3, the requirements for training devices are very much a function of the characteristics of the task involved, the air vehicle, and the experience level of the trainee. With respect to the B-1, visual scene presentation is necessary for three flight phases" (1) take-off, (2) refueling, and (3) landing. Due to the extensive previous experience of pilot trainees entering into the B-1 program (previous B-52 and FB-111 pilots), a limited-cue presentation (e.g., narrow field-of-view, night-visual) appears to be sufficient for the take-off and landing phases.

The refueling phase poses a problem for the present state-of-the-art in visual scene presentation. It is not presently known which cues are necessary for refueling, other than possibly the boom director lights.

It is the case that different pilots use different cues. Therefore, an approach that is consistent with the SAT philosophy and results in extensive cost savings is to choose the cues and train the pilot to refuel, using those cues. This approach is apparently effective in training pilots to fly in formation, which is a station-keeping task not unlike refueling. When the pilot practices refueling after training, the additional cues that he adopts assist him; however, most of the available cues are not necessary for "successful accomplishment of the mission" which is the only truly valid criterion of device effectiveness. For example, night refueling using only the director lights is a good baseline case of the "necessary" cues for refueling and, if chosen, would greatly simplify the functional requirements of the simulation.

The requirements for cockpit motion in simulation are also dependent upon the tasks being trained. For example, there are situations, such as an engine failure on take-off, where the "immediate" cue to the pilot is proprioceptive. Another situation in which motion cues are important is in refueling, when coordinated flight is sacrificed in order to maintain air vehicle position (e.g., "kick" in rudder to yaw the air vehicle). The refueling task is one of the most critical tasks with respect to correlating the visual and proprioceptive inputs to the pilot. Another flight phase in which air vehicle motion is prevalent is low-level, high-speed flight. The motion cues in this task involve both long-term (sustained g's) and short duration accelerations. The sustained accelerations cannot be provided by motion base systems, but a g-seat can be used to help provide the proper cues.

For the majority of the tasks (e.g., procedures) involved in a B-1 mission sortie, motion is not a cue and, therefore, is not required for the device used to train these tasks. This is a result of the fact that B-1 crewmembers (including the pilots) are "system operators" far more than in precedent air vehicles. Motion is only necessary when it is an initiation of completion cue, or if its presence (in flight) changes the behavior of the crewmember performing the task.

4.3 PART-TASK TRAINING

The value and limitations of part-task training are well documented in the literature (e.g., Adams, 1957; Burrows, Brown, and Stone, 1971; Miller, 1960). The research has spanned the spectrum of tasks, including "procedures" (Cox, Wood, Boren, and Thorne, 1965), visual approach and landing, flight maneuvering (Hufford and Adams, 1961; Adams and Hufford, 1961; Sitterly, Zaitzoff, Berge, 1972), low-altitude flight (McGrath, 1973), and formation flight (Wood, Hagin, O'Connoer, and Myers, 1972; Fulgham and McLean, 1973; and Fulgham, Reid, Wood, and McLean, 1973). One of the primary advantages of part-task training (and trainers) is minimization of resource utilization. When a trainee is learning a particular task that requires a small amount of hardware (and software), the remaining components of a whole-task simulator are made unavailable and idle.

One concern that is difficult to quantify (or even qualify) when evaluating part-task training is "crew coordination." It is imperative that when different crewmembers interact in a task, the cueing components of that interaction be included. The B-1 training program should make maximum use of the resource utilization advantages of part-task-training, while not sacrificing the context and crew coordination involved in the "whole-task."

4.4 AUTOMATED PERFORMANCE MEASUREMENT

The term automated performance measurement is ambiguous, and often misleading. It can range in complexity from simple "repeater" instruments provided to the instructor to very involved "adaptive training" packages. As was illustrated in Section 3.4, the various measures of performance have implication with respect to training device complexity and cost. There has been extensive work conducted on automated performance measurement (e.g., Charles and Johnson, 1972; Charles, Johnson, and Swink, 1973; Connelly, Schuler, and Knoop, 1969; Connelly, Schuler, Bourne, and Knoop, 1971; Knoop, 1968 and 1973; Hill and Goebel, 1971; Faconti, Mortimer, and Simpson, 1970; and Zesking, 1975).

Adaptive training techniques make use of feedback provided by automated performance measurement. The problem with adaptive training is that the appropriate (and meaningful) adaptive variable is not presently definable. It is obviously multidimensional and is, therefore, difficult to quantify and generalize across tasks. There has been a number of recent reports on adaptive training (McGrath and Harris, 1971; Kelley and Waigo, 1968; Ellis, Lowes, Matheny and Norman, 1971; Feuge, Charles, and Miller, 1974). Automated adaptive training techniques have, to date, not proved to be effective to the point that they could be considered as a requirement for this program.

Records of trainee performance have two functions. One is an "on-line" feedback function to inform the trainee and the instructors of the trainee's performance. The second function, of equal importance, is to provide the training system designers with data to be used for training system evaluation and modification.

With respect to the B-1 training system, the inclusion of automatic performance measurement (even without adaptive training) impacts upon the computational capability of the simulation. Also, the amount of performance assessment done automatically, has an effect upon the operator (instructor) console capabilities. Recent reviews of the state-of-the-art in consoles include Murphy (1971) and Smode (1973). As was the case in scenario development discussed in Section 4.2, the problems involved in console development are not of a hardware nature, but rather are of a "logical" nature.

4.5 SUMMARY

This memorandum has summarized the present state-of-the-art in both the engineering and behavorial aspects of simulation technology. It is this information which the B-1 technical personnel are using in the formulation of recommended requirements for B-1 training devices. Although primary emphasis is on simulation used in training applications, the technology derived from other applications is often pertinent and its relevance to training is integrated into the discussions and assessments contained herein. This memorandum is not to be considered a "textbook" of simulation and its usage, but rather, a description of some of the important factors which impact upon the training device requirements for the B-1 training system.

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