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ARMY AVIATION
FIVE YEAR FLIGHT TRAINING SIMULATION
DEVELOPMENT AND MANAGEMENT PLAN
FISCAL YEARS 1976-1980



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Orlando, Florida 32813

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The report describes research and development efforts for the 1976 - 1980 planning period. These include exploratory (6.2), advanced (6.3), and engineering (6.4) development efforts. Also, planning and management concepts for facilities, maintenance and support, and training simulator validation, assessment, and certification are discussed.

Part-task and cockpit procedures trainers are described and the benefits derived from their utilization are discussed. Also presented are the state-of-the-art of computational technology relevant to Army aviation training missions, an overview of on-going and projected DOD and NASA research and development relevant to flight training simulators, and an overview of flight simulator visual technology.

Basis of issue and funding data for proposed efforts are presented under separate cover. These data are restricted to government agencies. Requests for the data should be addressed to:

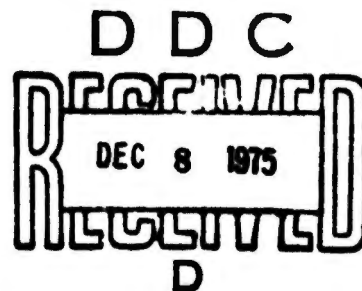
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Orlando, Florida 32813

OFFICE, PROJECT MANAGER FOR TRAINING DEVICES

ARMY AVIATION FIVE YEAR FLIGHT TRAINING SIMULATION

DEVELOPMENT AND MANAGEMENT PLAN

(1976 - 1980)



Approved: 7 October 1975

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FOREWORD

On 2 August 1974, the U.S. Army Training Device Agency, Orlando, Florida, was directed by the Project Manager, Training Devices (PM-TRADE), to conduct an in-house study of the training needs and flight training simulator requirements for Army rotary wing aircraft. The effort was to result in a comprehensive five-year (FY 76-80) development and management plan for the Synthetic Flight Training System (SFTS). Inputs were obtained from Army, Air Force, Navy, NASA, and industry personnel involved with training management. In the course of the effort it was determined that such areas as part task and cockpit procedures trainers were in need of consideration. Consequently, discussion of these is included in this plan.

The organization of this Plan is as follows:

SECTION I - INTRODUCTION

The purpose and objectives of the Plan are stated and a brief review of the advancements and potential benefits of flight simulators for training of Army aviators is presented.

SECTION II - SYNTHETIC FLIGHT TRAINING SYSTEM PROGRAM

This section summarizes the activities undertaken by Army aviation to introduce to aviation training the latest state-of-the-art advances in training device design and training technology. The time period covers the development in July 1967, of a Qualitative Materiel Requirement (QMR) for a Synthetic Flight Training System through the completion of test and evaluation in October 1971, of the engineering development unit of the UH-1H instrument flight simulator designated as Device 2B24.

SECTION III - FLIGHT TRAINING SIMULATION REQUIREMENTS

This section summarizes the performance requirements for all Army rotary wing aircraft training simulators that are either being procured or for which future procurement is anticipated.

SECTION IV - COST EFFECTIVENESS ANALYSES

This section presents estimates of the potential cost and fuel savings that may be realized from the introduction of flight simulators.

SECTION V - RESEARCH AND DEVELOPMENT PLANS

This section identifies priority exploratory (6.2), advanced (6.3), and engineering (6.4) development efforts needed to support the production of advanced subsystems for the Synthetic Flight Training System (SFTS). Details of the problem areas and program approaches are also presented.

SECTION VI - PLANNING AND MANAGEMENT CONCEPTS

A number of planning and management concepts are described in this section. Specifically, such concepts as planning for research and development, planning for training, planning for facilities, planning for maintenance and support, centralization of simulator management, and validation, assessment, and certification of training flight simulators.

SECTION VII - RECOMMENDATIONS

Specific recommendations for implementation of priority research and development tasks are presented in this section. Specifically, five exploratory and six advanced development tasks are recommended for funding in fiscal year 1976 and/or fiscal year 1976 transition.

APPENDIX A - PART-TASK AND COCKPIT PROCEDURES TRAINERS

A brief discussion of how Army aviation uses part-task trainers and cockpit procedures trainers and the potential benefit that may be derived from their utilization is presented. Since approved requirements were not available at the time this Plan was developed, they were not included. It is anticipated that such requirements will be available for inclusion in a revision of this Plan. This revision will be accomplished on or about July 1976.

APPENDIX B - COMPUTATIONAL TECHNOLOGY OVERVIEW

Army aviation flight simulation requirements are analyzed and compared with the state-of-the-art in computational technology. The deficiencies in computational technology relevant to Army aviation missions are discussed.

APPENDIX C - RESEARCH AND DEVELOPMENT OVERVIEW

This appendix presents an overview of on-going and projected research and development within the Department of Defense and NASA that is relevant to flight training simulators. The overview was derived from material obtained from a survey of a number of organizations within the U.S. Army, U.S. Air Force, U.S. Navy, and NASA.

APPENDIX D - OVERVIEW OF SIMULATOR VISUAL TECHNOLOGY

The Army aviation flight simulation visual system requirements are identified, the state-of-the-art is outlined, and the areas where the state-of-the-art is inadequate relevant to visual system development requirements are discussed.

APPENDIX E - PM TRADE CHARTER

The initial charter for the PROJECT MANAGER (PM) of TRAINING DEVICES (TRADE) is included as an appendix to the Five Year Plan. The charter identifies and discusses PM TRADE's mission, authority, responsibility, assigned efforts, and management controls.

APPENDIX F - INFORMATION SOURCES

A listing of the organizations which were visited and/or from which information was obtained is appended.

APPENDIX G - SUMMARY BASIS OF ISSUE FLIGHT SIMULATORS

Under separate cover.

APPENDIX H - SUMMARY OF FUNDING

Under separate cover.

APPENDIX I - BIBLIOGRAPHY

SECTION I
INTRODUCTION

PURPOSE AND OBJECTIVES

The importance to the U.S. Army of achieving maximum cost effectiveness in flight simulation equipment makes the full accomplishment of the program described in this plan essential. In order to take advantage of the valuable capability that would be made available by achievement of the program's objectives, the U.S. Army must be ready to exploit results produced by research and development efforts. To facilitate such exploitation, maximum consideration was given to obtaining inputs and views from Army planners, materiel developers and research installations.

Specific objectives are to establish realistic funding levels to assure availability of training simulators concomitant with delivery of operational aircraft and the integration of state-of-the-art technology relevant to Army aviation flight simulation requirements, and the delineation of research and development programs that can be effectively and efficiently managed by the PM TRADE in coordination with the other services and NASA. Recommendations regarding procurement, utilization, and support of flight training simulators and related training devices are also presented.

The prime example of needed development is for simulation of training for nap-of-the-earth (NOE) flight. Presently this NOE flight is defined as flying as close to the earth's surface as vegetation or obstacles permit, while generally following the contours of the terrain. Airspeed, course and altitude are varied as required by terrain, weather, deployment, and objective. In flight, the pilot uses a weaving route within a preplanned corridor while remaining oriented along a general axis of movement in order to take maximum advantage of the cover and concealment afforded by terrain, vegetation, and man-made features. The restrictive nature of this type of flight demands almost instantaneous reaction from the flight personnel involved. The importance of realistic and safe training for NOE flight emphasizes the need for flight simulators with wide angle field of view displays and high fidelity motion cues.

In November 1972, a group of Department of Defense and NASA experts in flight simulation (Joint DOD and NASA Aeronautical Research and Development Study) conducted a study to ascertain the critical deficiency areas in flight simulation technology. Although not all of the proposed research and development program recommended by this group concerns efforts that are applicable to Army aviation, it is very significant that this group considered research into wide angle field-of-view visual systems of the highest priority. Specifically, the group recommended that analytical and experimental investigations of a number of competing scene generation and display concepts be conducted. The high priority given this technology by the study group is an indication of the importance and the extent of the effort needed to develop suitable NOE simulation systems for Army aviation. Only by means of a

comprehensive development program aimed directly at solving these problems that inhibit the Army's training mission can there be any assurance that the full capabilities of flight simulators will be obtained.

BACKGROUND

Starting in 1964, the U.S. Army began a rapid expansion of its aviation capability to meet the demand of new Army Helicopter programs and the requirements of the Vietnam conflict. The huge increase in the cost of aviation training which accompanied this expansion led the Secretary of Defense in his memorandum to the Director of Defense Research and Engineering, the Assistant Secretary of Defense, Comptroller, and the Assistant Secretary of Defense, Manpower, on August 15, 1965, to state:

After reviewing last year's \$3 billion education and training program, I am struck by the absence of significant research and development activity to improve our effectiveness in this area. I am also aware that there is no social service research and development directed toward improving our education and training capabilities. A greater effort should be made to apply recently-developed modern training technique and education concepts to existing defense training and education programs.

In response to the above, the U.S. Army in 1967 approved a Qualitative Materiel Requirement (QMR) for development of a Synthetic Flight Training System (SFTS). The SFTS was developed to meet the need for improving the Army's training capabilities in aviation. Potential benefit in simulating such maneuvers as practice autorotations is evident from crash statistics. Table I-1 shows the number of accidents, major and minor, fatalities, and injuries resulting during practice situation autorotations by active duty, reserve, and National Guard personnel. Approximately one-third of the accidents occurred at the Aviation School, Fort Rucker, and two-thirds at field units. Ninety-six percent of the accidents occurred when the "touchdown" maneuver was practiced, the remaining accidents occurred when the "power recovery" maneuver was practiced.

Table I-1 also presents estimates of the aircraft damage costs resulting from these accidents. For the five year period from 1970 through 1974, the total is approximately \$11 million. This does not include the human investment cost that is lost to the U.S. Army. The U.S. Army Aeromedical Laboratory estimates that this investment cost averages several hundred thousand dollars. The loss of pilots due to death and injury is a financial burden that must be considered.

Commercial airlines have reported substantial savings through the use of flight simulators. American Airlines has significantly reduced the average flying hours for transition training for its Captains through the use of simulators. The data are presented in Table I-2.

TABLE I-1

PRACTICE SITUATION AUTOROTATIONS ACCIDENTS

Fiscal Year	Accidents	Fatalities	Injuries	Cost
1970	88	1	33	\$ 4,115,000
1971	71	1	17	2,963,000
1972	41	0	13	1,472,000
1973	15	1	3	816,000
1974	22	0	3	1,413,000
	237	3	69	\$11,179,000

TABLE I-2

AIRLINES COST SAVINGS FROM SIMULATION

Aircraft	Year	Aircraft Hours	Simulated Hours
Boeing 707	1966	18.3	0
	1970	5.1	22.0
Boeing 727	1966	20.6	0
	1970	2.5	24.6

Estimated savings for the Boeing 727 when training is performed in both aircraft and simulator versus aircraft alone, is approximately \$4.8 million per year.

In July 1973, the Office of Management and Budget (OMB) issued a report entitled "Department of Defense Aviation Programs Savings Possibilities through Increased Emphasis on Flight Training Simulation." The report was directed at the fixed wing programs of the Air Force and Navy and suggested a flying hour reduction goal of 50 percent for undergraduate pilot training (UPT) and transition training, and 20 percent for operational training. The OMB report raised three questions regarding the use of flight simulators: How much simulation is technically feasible? How much is militarily acceptable? How much is economically mandatory?

The importance of these questions cannot be minimized. The OMB report shows how military flight training costs can be reduced substantially and the projected shortages of fuel eased with increased use of flight simulators. The Assistant Secretary of Defense (Manpower and Reserve Affairs) has directed in view of the OMB findings and the reported savings from simulators, that the Department of Defense conduct in-depth studies to determine objectively the effectiveness of simulator concepts for military training.

Congress has also taken an ardent interest in the potential offered by flight simulators to minimize flight training costs. In August 1973, the General Accounting Office stated that the state-of-the-art in simulation research should be emphasized to exploit potential cost savings. These savings would help to offset projected high training costs for the complex and sophisticated aircraft systems under development. Specific recommendations were:

That higher priority be placed on developing improved simulators for the purpose of replacing the maximum specified amounts of flight training.

That the acquisition of flight simulators be considered as integral to the acquisition and modification of aircraft.

That simulators and automatic grading methods be used as much as possible.

SECTION II

SYNTHETIC FLIGHT TRAINING SYSTEM PROGRAM

BACKGROUND

Significant Army interest in flight simulators was indicated with the development of a Qualitative Materiel Requirement (QMR) for a Synthetic Flight Training System (SFTS) in July 1967. The QMR set forth the requirement for a family of flight simulators for Army rotary wing aircraft. Originally, the QMR called for an instrument trainer subsystem to simulate the UH-1H (Device 2B24), and an Operational Flight Trainer (OFT) to simulate the CH-47C (Device 2B31). During concept formulation the requirement to study the feasibility of an attack helicopter simulator (Device 2B33) was added. At present, these three Army rotary wing aircraft are the only ones for which simulators are being produced or developed.

In 1968, the U.S. Army contracted for concept formulation studies for the SFTS. The studies determined that the use of the SFTS would allow the U.S. Army Aviation Center to realize extensive savings by substituting simulator time for in-flight training time. A Systems Development Plan (SDP) was subsequently prepared and approved in 1968.

DEVELOPMENT PROGRAM

Two key operational concepts guided the SFTS 2B24 design. One, the modular concept enables the systems to be assembled from modules. Each of these modules performs one of the major functions of a synthetic flight trainer. Specific features are:

The trainee modules are mounted on motion modules that provide realistic motion onset cues.

The trainee modules are capable of independent and simultaneous operation by the computation module complex.

The computational modules are capable of real-time solution of the equations necessary to simulate the dynamics of the simulated helicopter. These modules also provide performance evaluation analysis and record keeping.

The other operational concept, automated training, is designed to maximize use of instructor skills, to enhance the standardization of training, and to provide a means for objective performance evaluation. The use of digital computers makes it possible to automate routine operations traditionally performed by the human instructor and to implement such techniques as adaptive training, demonstration, and programmed instruction, thus permitting more efficient use of instructor skills.

A feature of the automated training is the capability of automatically recording selected parameters of pilot and simulated aircraft performances and of measuring deviations of such performance from specified standards. This capability permits the SFTS to be efficiently used for the evaluation of individual lessons and for complete checkrides. This capability is applicable to both aviation school training and to training conducted at field units.

This automated training technique is of considerable importance. The value of self-paced instruction for training of Army helicopter pilots, using flight simulators, has been demonstrated by the U.S. Army Aviation Center, Fort Rucker, Alabama. From an assessment of a number of test and evaluation programs using Device 2B24 (UH-1H developmental model), the Aviation Center determined there was a significant reduction in the number of instrument flight hours required to bring the students to the proficiency level required to pass the final instrument checkride.

The SFTS Device 2B24 can also permit a means of meeting annual instrument checkride requirements for Army rotary wing aviators. For example, the U.S. Coast Guard uses its Variable Cockpit Training System (VCTS) simulator for this purpose. Amendment No. 1, November 1973, Revision to Air Operation Manual, CG-333, eliminates the requirement for annual in-flight instrument checks for aviators who have passed simulated instrument checks in the VCTS.

SFTS DESCRIPTION (DEVICE 2B24)

The engineering development model of the UH-1H instrument flight simulator, denoted as Device 2B24, construction was completed in late calendar year 1970. An artist's conception of this device is shown in Figure II-1. The device consists of a complex of four simulated cockpits driven by a single digital computer system. Each cockpit is mounted on a five degree-of-freedom motion base. A central instructor station is provided from which trainee performance in all four cockpits can be controlled and monitored.

The interior configuration of each of the four trainee stations is a replica of the cockpit portion of the UH-1H helicopter. As is shown in Figure II-2, the cockpit also contains a folding seat from which an observer may view the training activity. An intercom panel containing phone jacks and volume control, is located adjacent to the folding seat to provide communication with the trainee and/or the instructor station. A doorway through the rear bulkhead provides an additional means of entry into the cockpit.

There are two panels which contain switches and displays enabling the trainee to contact the instructor or computer directly. The problem control panel provides control over automated training features, freezing and re-setting the simulator, activates and deactivates the motion system, and has the capability to call the instructor. The trainee's information display panel indicates the operating status of the trainer systems and provides a trainee performance readout for automated adaptive training.

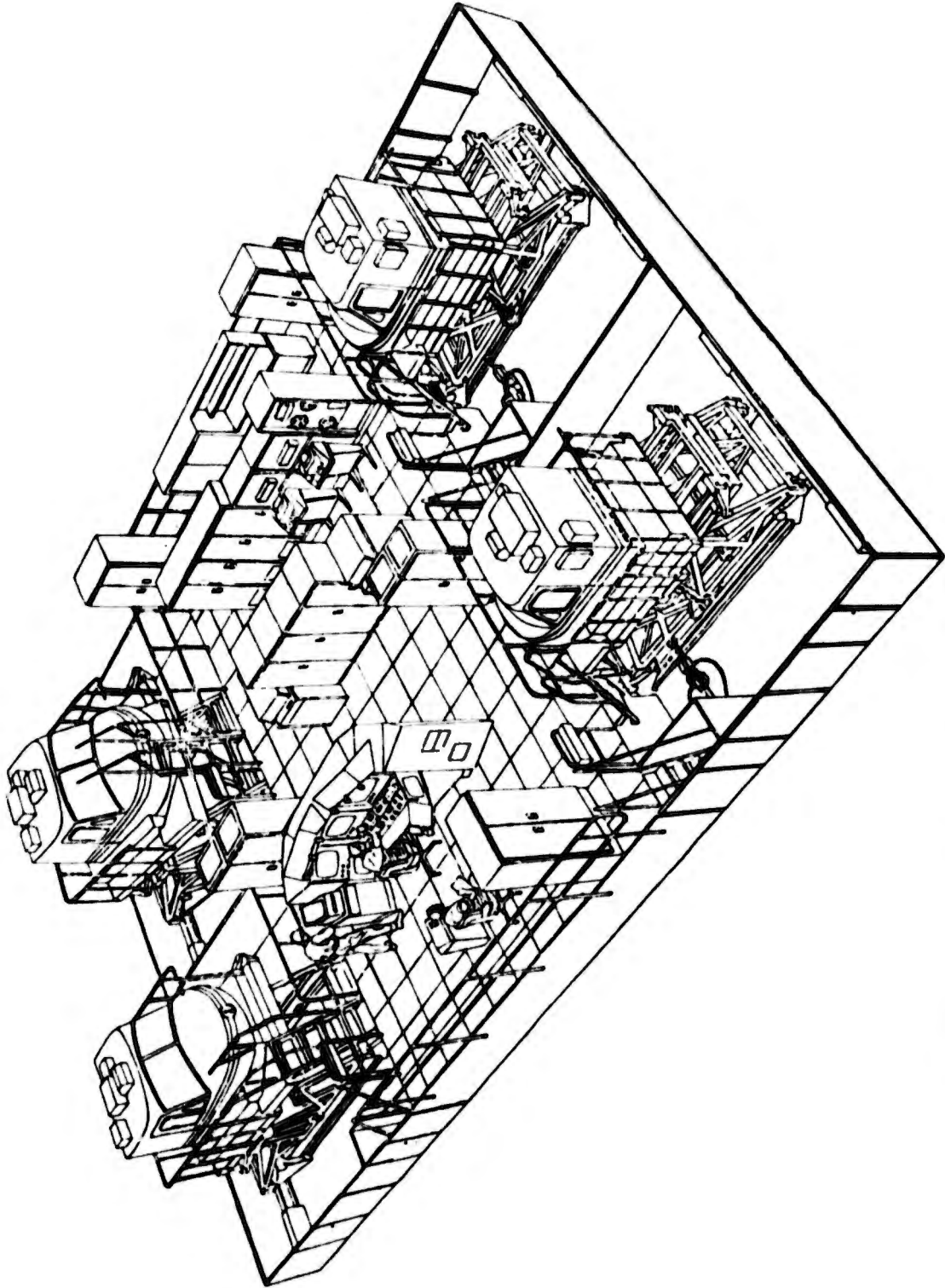


FIGURE II-1. ARTIST'S CONCEPTION OF UH-1H HELICOPTER SYNTHETIC FLIGHT TRAINING SYSTEM (SFTS), DEVICE 2B24

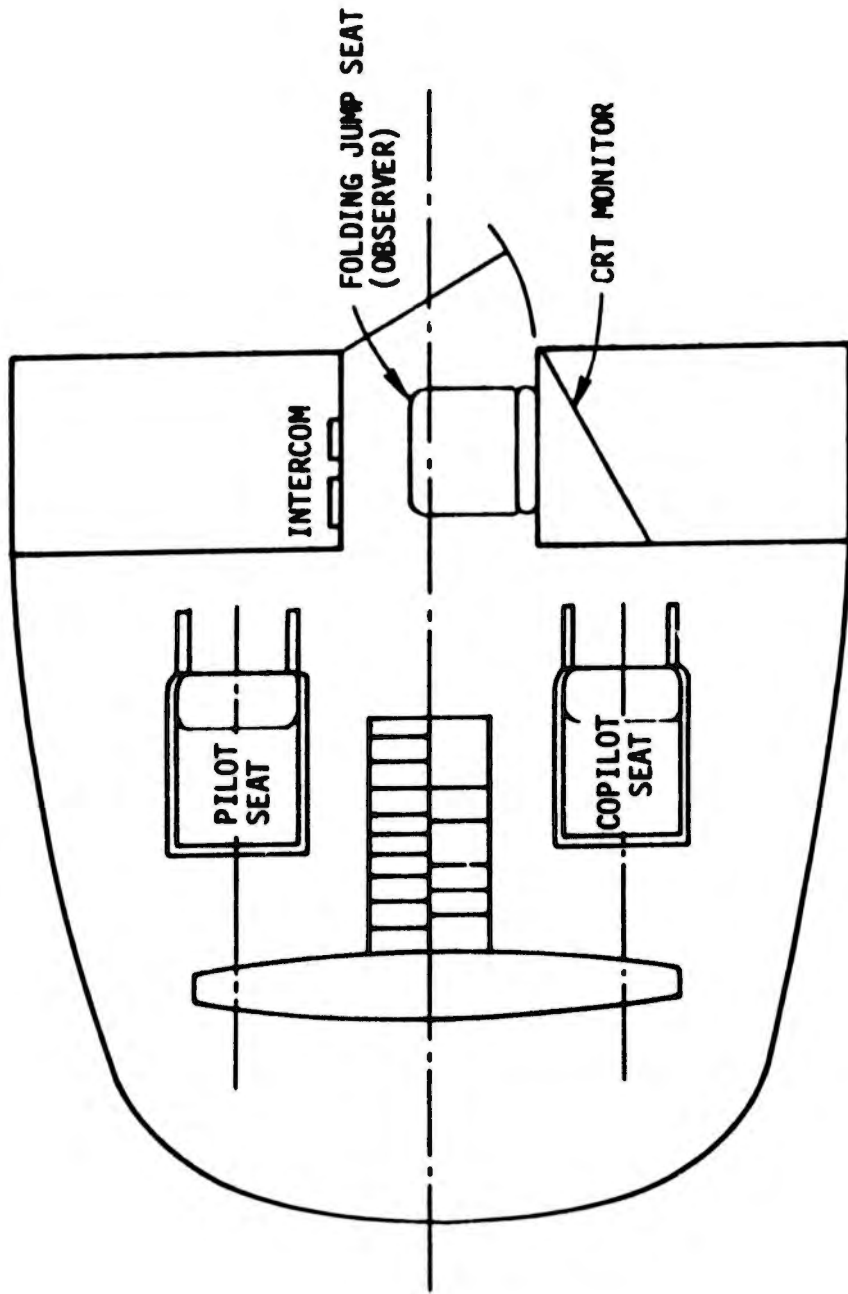


FIGURE II-2. TRAINEE STATION INTERIOR CONFIGURATION

A cathode-ray tube (CRT) monitor capable of displaying information from the instructor station graphic CRT display is mounted in each cockpit. The monitor is located behind the copilot (left) seat in a position where it can be seen by the trainee from his normal position in the pilot (right) seat.

The cockpit shell is constructed of fiberglass-reinforced plastic and is attached to the welded steel cockpit frame by means of plates and fittings embedded in or bonded to the plastic shell. The side windows and windshields are of translucent plexiglass construction and are removable to permit the substitution of clear windows if an external visual display system is desired in the future.

The operational software provided with the UH-1H simulator consists of an executive program and the real-time system programs. The support software includes computer diagnostics, a daily operational readiness check program, and a Built-In Test Facility (BITF) which provides test diagnostics for verification of the simulator complex operation.

Each simulated UH-1H cockpit is mounted on a five-degree-of-freedom hydraulic motion system. Each degree of freedom operates completely independently of the other degrees of freedom, and sufficient overtravel capability exists in all actuators for safe termination of motion. The motion of the cockpit takes place along and about the simulated aircraft body axes. The motion system is capable of imparting proprioceptive cues representative of the sensations experienced in helicopter or V/STOL aircraft for all normal and abnormal flight conditions.

The following simultaneous motion capabilities are provided:

Pitch	$\pm 15^\circ$	15°/sec	25°/sec ²
Roll	$\pm 15^\circ$	17°/sec	70°/sec ²
Yaw	$\pm 15^\circ$	15°/sec	100°/sec ²
Vertical Translation	± 12 in.	12 in./sec	+0.8g, -1.0g
Lateral Translation	± 15 in.	15 in./sec	$\pm 0.2g$

SFTS TESTING AND EVALUATION (DEVICE 2B24)

Device 2B24 underwent a coordinated test program which ran from September 1970 through March 1972. The purposes of this test program were to determine the technical performance and safety characteristics of the test item, the degree to which the test item performed the training mission as specified in the QMR, and the suitability of the test item and its maintenance package for Army use.

The test program included both engineering tests and expanded service tests. The engineering tests of Device 2B24 were performed at the contractor's plant from September through December 1970, and at the installation

site, Fort Rucker, Alabama, through November 1971. It was determined that the technical performance, engineering adequacy, and safety characteristics were satisfactory.

The expanded service tests were initiated in April 1971. The testing was conducted in three phases. Phase I determined the workability of the 2B24. Phase II developed a preliminary program of instruction to be used in Phase III. In Phase III, the training program was administered to a group of initial entry flight students. The objective of the Phase III testing was to determine the cost effectiveness of the 2B24 for Army undergraduate pilot training.

The development of the training program in Phase II was necessitated since existing training programs were not applicable for the unique 2B24 device. In addition to its uniqueness, the device is significantly more comprehensive in its simulation of the training aircraft than other devices used in undergraduate level pilot training programs.

Phase II activity also included the training of instructor pilots to administer the new program. In this effort, the instructors conducted mock training using each other as trainees. The instructors were considered to be qualified upon successfully training two students.

Two studies were conducted to evaluate cost-effectiveness. In one, the effectiveness of training in the 2B24 was determined by subsequent trainee performance in a UH-1 helicopter. The second study involved comparison of the costs of training using the 2B24 program with the costs of the existing program.

The effectiveness of training, or transfer of training, was studied by the Aviation Division of HumRRO at Fort Rucker, Alabama. Sixteen students trained in the 2B24 were able to complete UH-1 transition in less time than regular course students. Whereas regular course students required 60 hours in a TH-13T instrument trainer and 26 hours in the 1-CA-1 device, students receiving from 40 to 50 hours training in the 2B24, needed less than 10 hours instruction in a UH-1 instrument trainer in order to meet course proficiency criteria. The examiners conducting the checkrides reported that the 2B24-trained students performed as well as, or better than, the regular course students.

The costs associated with the conduct of flight training using the 1971 program, TH-13T and 1-CA-1 trainers, and the 2B24 and UH-1 program are shown in Table II-1. The figures presented for the TH-13T and 1-CA-1 represent actual training hours flown and actual costs associated with Army undergraduate instrument training during October 1971. The figures for the UH-1 represent what the training would have cost if undergraduate instrument training had been conducted in the UH-1 instead of the TH-13T for the same period, a mode of training being studied at that time.

The figures for the 2B24 represent a projected monthly cost for eight of the devices with a total of 32 cockpits. The projections are based on the

TABLE II-1
 TRAINING COSTS COMPARISONS AS OF
 OCTOBER 1971*

Cost Item	Training Vehicle				
	TH-13T	1-CA-1	UH-1	2B24 Single Shift	2B24 Double Shift
1. Depreciation					
Aircraft/Trainer	\$ 80,465.00	\$ 7,623.76	\$ 310,827.18	\$170,301.00	\$170,301.00
2. Buildings and Facilities					
Depreciation	10,314.12	451.40	11,339.54	1,872.43	1,872.43
Utilities	1,917.16	378.84	1,917.16	585.48	1,096.34
Janitorial Services	748.95	300.68	748.95	202.50	202.50
Maintenance	2,712.28	220.55	2,712.28	589.62	589.62
3. Salaries: Trng Personnel	369,406.15	44,751.99	369,406.15	105,025.39	204,120.04
4. Training Contractor Fee	3,550.17	619.28	3,550 .7	N/A	N/A
5. Office Equipment	334.65	17.60	334.65	17.60	17.60
6. Aircraft/Trainer Maint.					
Personnel	298,431.96	2,389.00	729,360.54	7,997.18	9,967.10
Maintenance Equip.	3,155.09	19.49	12,081.38	85.00	85.00
Spare Parts	225,731.41	132.46	1,108,248.06	12,080.00	24,160.00
7. Transportation		N/A		N/A	N/A
Equipment Operation	1,607.07		797.69		
Drivers' Wages	1,724.48		919.68		
Equipment Depreciation	114.57		114.57		
8. Flight Clothing & Equipment	3,982.23	N/A	3,982.23	N/A	N/A
9. Aircraft Petroleum, Oil, Lubricants & Electricity	41,024.64	41.31	76,242.84	4,409.60	5,785.60
10. Aircraft Refueling Services	5,016.60	N/A	15,577.60	N/A	N/A
11. Navigation Facilities		N/A	N/A	N/A	N/A
Buildings	1,573.20				
Equipment & Furnishings	23,161.19				
Controllers	68,274.00				
Transportation	2,943.46				
Total	\$1,146,188.38	\$56,946.36	\$2,648,749.43	\$303,165.80	\$418,197.23
Training Hours	10,899	5,164	10,899	5,120	10,240
Cost per Training Hour	\$ 105.16	\$ 11.02	\$ 243.02	\$ 59.21	\$ 40.83

*Report of the Test and Evaluation of the SFTS (Device 2B24), HumRRO Draft Technical Report, May 1974, HumRRO Division No. 61 Aviation, Fort Rucker, AL.

actual costs encountered in operating the one engineering development device during October 1971. The costs reflect the materials and services anticipated for the operation of the 32 cockpit complex at the Aviation School.

Table II-2 illustrates the per-student savings which would accrue if the eight 2B24's were used to prepare undergraduate trainees for a Standard Instrument Rating. Table II-3 shows the per-student savings if the 2B24's were used for both instrument and proficiency training. The cost analysis based on October 1971 data determined that for approximately 7500 graduates per year, the yearly cost saving would be just under \$34 million.

It should be noted that the cost analysis accounted only for the operation of training vehicles, supporting personnel, facilities, and activities. The data do not account for the potential savings which would result from a reduction in the length of time the trainees would have to be in residence at the Aviation Center. Such cost savings would be in addition to those shown in Tables II-2 and II-3.

STATUS OF SFTS PROGRAM (DEVICE 2B24)

The engineering development model of Device 2B24 was type classified in June 1972. The device is now being used at the Aviation School in the Initial Entry Rotary Wing Course, the Rotary Wing Instructor Course, the Rotary Wing Qualification Course, and the Instrument Method of Instruction Course. Future use is planned for the Rotary Wing Instrument Flight Examiner Course and for Combat Readiness Proficiency Training, as well as for annual instrument checkrides and for flight instructor standardization at the Aviation Center and at aviation field sites.

Consideration is being given to adding a computer generated imagery (CGI) night visual system to the 2B24. A major concern is that the visual system must be compatible with and not require major modification to the existing 2B24 hardware. Also, the visual system incorporation is not to cause degradation of the 2B24's performance.

It is anticipated that the visual system would consist of cockpit mounted display units for the right front window and the right side window. The CGI equipment will provide up to 2000 light points updated at a cyclic rate sufficient to assure no noticeable flicker while tracking all aircraft maneuvers.

Major requirements are that the visual system react to all normal and emergency flight procedures programmed into the 2B24, permit hovering and ground operations, and provide effective transition from hovering to forward flight and vice versa. Other requirements are that the visual system will permit night autorotations to touchdown, and night takeoffs from confined areas, pinnacles, and stage fields using T-bar lighting. Also, the visual system is to have a capability to permit an instrument approach and the execution of a landing to an airfield with standard A lighting.

TABLE II-2

COMPARISON OF TRAINING COSTS FOR A ROTARY WING
STANDARD INSTRUMENT RATING AS OF OCTOBER 1971*

Training Program	Training Vehicle		Program Hours		Program Cost Per Student
	Aircraft	Device	Aircraft	Device	
Existing undergraduate training	TH-13T	1-CA-1	60	26	\$6,596.12
Projected undergraduate training	UH-1	2B24	6½	42½	\$3,314.90 ^a

^aAssumes double shift in 2B24

TABLE II-3

COMPARISON OF TRAINING COSTS FOR INSTRUMENTATION
AND TRANSITION TRAINING AS OF OCTOBER 1971*

Training Program	Program Hours and Vehicle	Cost
Current undergraduate training	60 hours in TH-13T	\$ 6,309.60
	26 hours in 1-CA-1	286.72
	25 hours in UH-1	6,075.50
		\$12,671.62
Projected undergraduate training	42½ hours in 2B24	\$ 1,735.27 ^a
	6½ hours in UH-1	1,579.63
	20 hours in UH-1	4,860.40
		\$ 8,175.30

^aAssumes double shift in 2B24

*Report of the Test and Evaluation of the SFTS (Device 2B24), HumRRO Draft Technical Report, May 1974, HumRRO Division No. 6 (Aviation), Fort Rucker, AL.

SECTION III

FLIGHT TRAINING SIMULATION REQUIREMENTS

The purpose of this section is to present Army requirements for rotary wing aircraft training simulators. Specifically addressed are the type and capability of the required hardware. Also presented are estimated delivery schedules and number of units to be procured. The estimates are based upon the anticipated amounts of simulator time that can be substituted for aircraft time.

CURRENT SIMULATOR DEVELOPMENT PROJECTS

1. Device 2B24. At present, five 2B24 devices have been installed at the Aviation Center, Fort Rucker, Alabama. In addition, the engineering development model is located at Fort Rucker. Present estimates of projected use of Device 2B24 are eight units for the Aviation School and twenty-four additional units for field installations. Anticipated locations and availability dates through production Unit No. 17 are noted in Table III-1. Anticipated aviator densities for potential sites are presented in Table III-2.

2. Device 2B31. A requirement for a CH-47 simulator subsystem of the Synthetic Flight Training System (SFTS). Development of this simulator began in FY 1972 and is continuing. A contract for an engineering development model was awarded in June 1973, and the device is expected to begin suitability testing in June 1976. The simulator will be used in transition, combat readiness proficiency, load operations, and instrument refresher training programs at the Aviation School and will play a major role in the standardization of CH-47 aviator performance. While the design of Device 2B31 is based upon state-of-the-art technology, advanced developments in the area of visual environment simulation and computer-controlled training and performance assessment were required. Figure III-1 shows an artist's conception of the completed training device.

The interior of the pilot-copilot trainee compartment is shown in Figure III-2. The compartment is identical to the interior configuration of the corresponding portion of the CH-47 with respect to size, arrangement, instruments, seats and other components. All equipment in this compartment required for ground operation as well as visual and instrument flight operations is functional and simulates the operation and function of the corresponding equipment in the aircraft. The cockpit also contains the instructor station aft of the trainees and an observer's position. A doorway through the rear bulkhead provides for entry into the cockpit.

An instructor-pilot/trainee problem control panel is located at the aft edge of the center pedestal. This panel provides the trainee and instructor-pilot with switches and indicator lights necessary to freeze and reset the trainer, to control the automated training features, to insert malfunctions and to control the CRT displays.

TABLE III-1.

ANTICIPATED AVAILABILITY OF 2B24 DEVICES

Production Model No.	Station	Ready Date
6	Fort Campbell	Apr 75
7	USAREUR	Jul 75
8	Fort Lewis	June 76
9	Hawaii	Aug 76
10	Alaska	Oct 76
11	Fort Bragg	Dec 76
12	Fort Hood	Feb 77
13	Korea	Apr 77
14	Fort Riley	Jun 77
15	Fort Stewart	Oct 77
16	Pennsylvania National Guard	Dec 77
17	Fort Knox	Feb 78
18	Fort Eustis	Not determined as yet
19	Fort Ord	Not determined as yet
20	Fort Sill	Not determined as yet
21	Fort Belvoir	Not determined as yet
22	Fort Carson	Not determined as yet
23	Fort Benning	Not determined as yet
24	Fort Devens	Not determined as yet
25	California National Guard	Not determined as yet
26	Fort Sam Houston	Not determined as yet
27	Illinois National Guard	Not determined as yet
28	Fort Bliss	Not determined as yet
29	Fort Polk	Not determined as yet
30	Fort Rucker	Not determined as yet
31	Fort Rucker	Not determined as yet

TABLE III-2.

ANTICIPATED AVIATOR DENSITIES

Stations	Active Army Assigned	Authorized USAR Aviators	Anticipated ARNG Aviators	Total
Fort Campbell, KY	1,141	0	115	1,256
USAREUR	1,200	0	0	1,200
Hawaii	391	0	60	451
Alaska	182	0	83	275
Fort Lewis, WA	546	0	77	623
Fort Bragg, NC	725	0	112	837
Fort Hood, TX	962	0	192	1,154
Korea	506	0	0	506
Fort Riley, KA	181	2	133	316
Fort Carson, CO	237	0	25	262
Fort Benning, GA	90	0	164	254
Pennsylvania National Guard	1	0	607	608
Fort Knox, KY	316	18	127	460
Fort Devens, MA	90	42	318	252
Fort Sill, OK	237	0	95	332
Fort Eustis, VA	353	16	90	459
Fort Belvoir, VA	247	63	11	321
Fort Ord, CA	322	27	0	349
Fort Sam Houston, TX	134	12	62	208
Fort Polk, VA	95	0	44	139
Fort Stewart/Fort Jackson	312	0	158	470
Illinois National Guard	0	0	185	185
California National Guard	0	81	179	260
Fort Bliss, TX	152	0	0	152

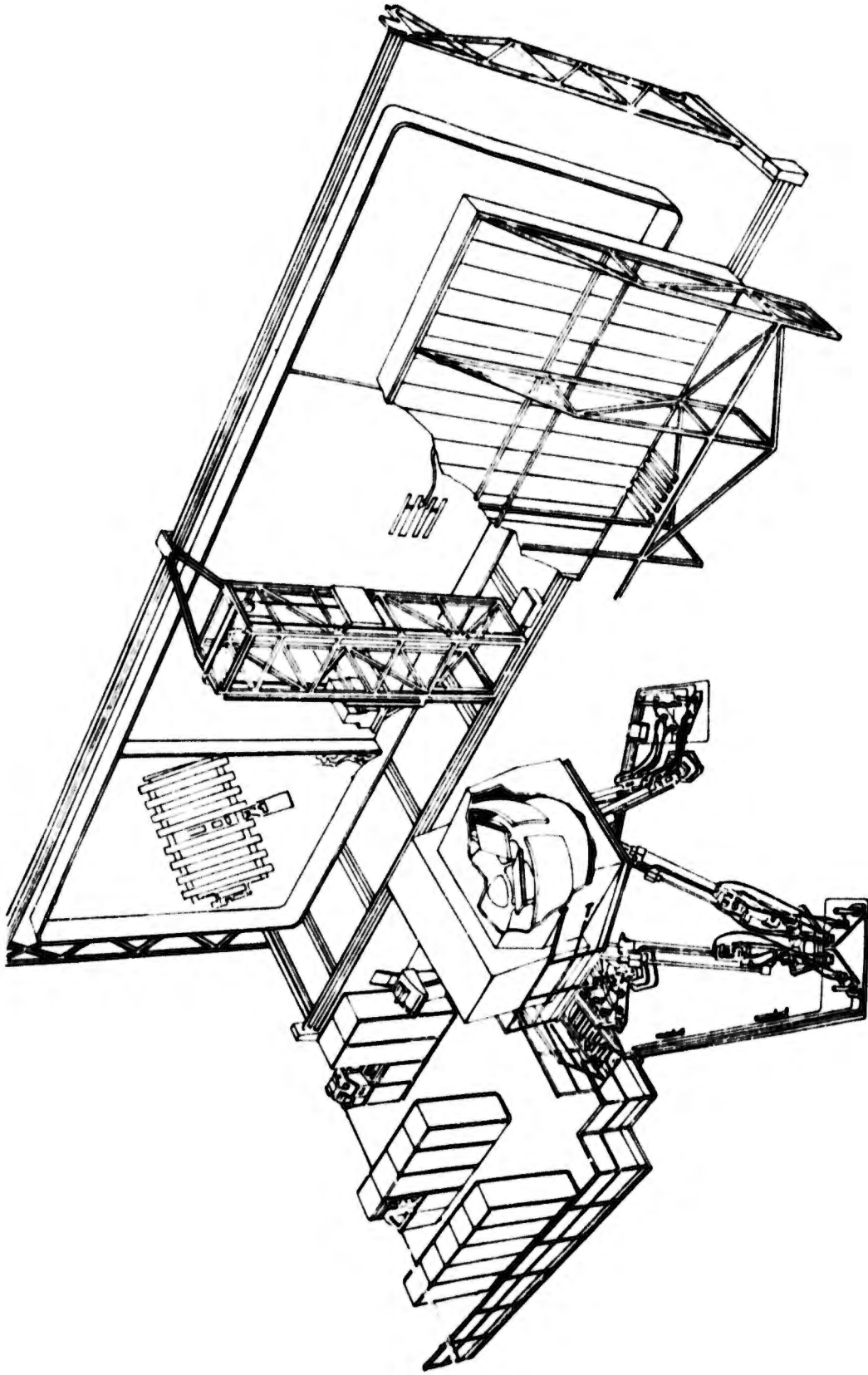


FIGURE III-1. 2B31 CONFIGURATION

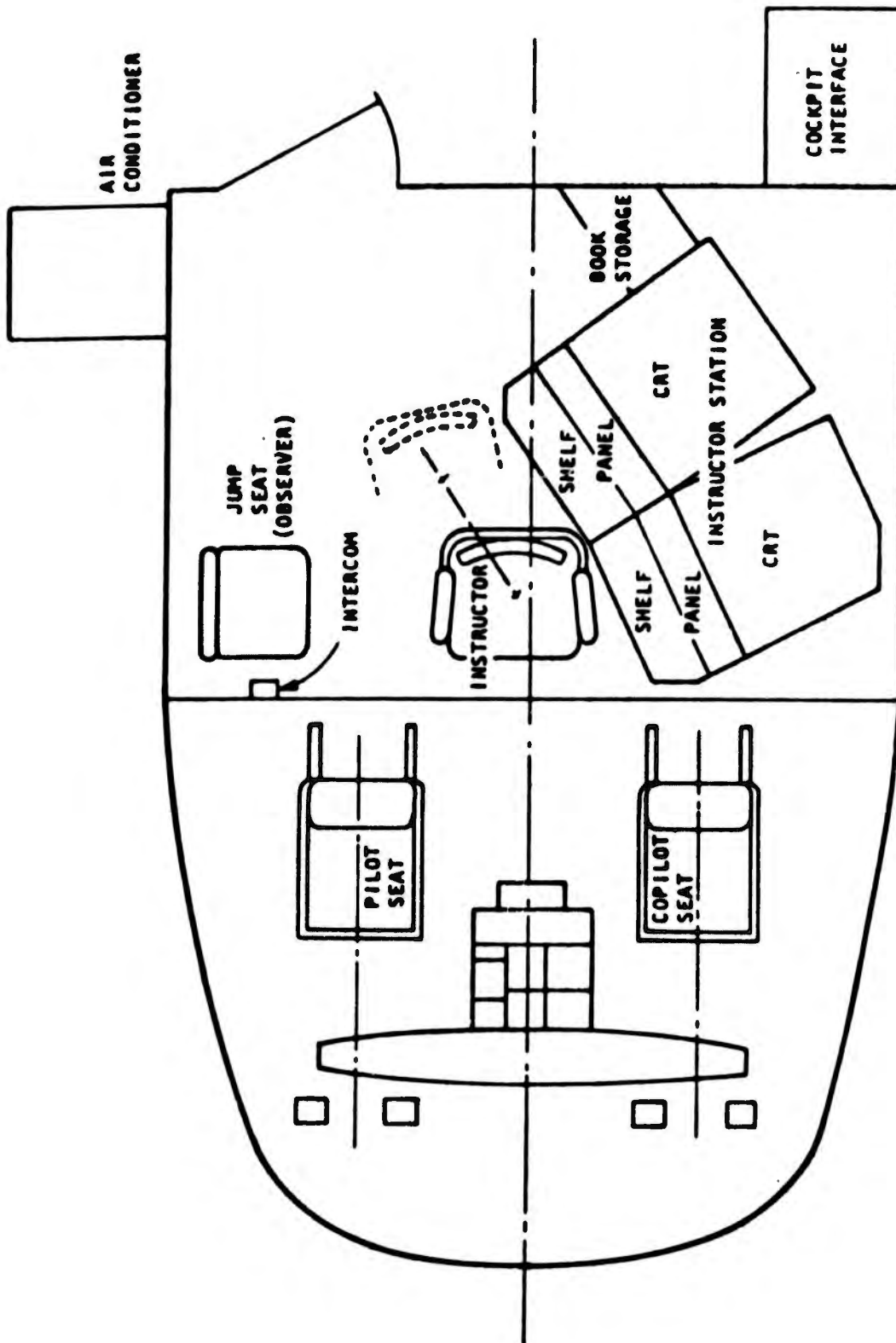


FIGURE III-2. TRAINEE/INSTRUCTOR COMPARTMENT

The CRT system is used for problem control and display. The two 12-inch by 16-inch CRT's of the console are mounted side by side, with their longer display surface dimension vertical. The CRT display surfaces are positioned for optimum viewing. Below each CRT is a sloping control panel.

The visual scene viewed by the pilots is in reality a closed-circuit color television presentation generated from a three-dimensional scale model of typical Fort Rucker terrain. The model is mounted vertically to minimize floor space requirements. Two different scale factors, 1:400 and 1:1500 are provided. The 1:400 area simulates the detail needed for taxi work and low-altitude hovering (i.e., below 25 feet off the ground), and confined area landing; the 1:1500 area is needed for the more general training tasks involving larger geographical areas for such tasks as basic flight maneuvers.

A special effects generator can introduce sky, cloud, haze, and limited-visibility effects into the displayed scene under control of the instructor. Day, dusk and night light conditions can also be simulated.

The visual presentation is generated by a system consisting of a 24 by 56 foot vertically mounted, three-dimensional terrain model viewed by a television camera and optical probe mounted on a movable gantry. Servo-mechanisms on the gantry position the camera and probe in accordance with the position and attitude of the simulated aircraft.

The visual image generated via the scaled terrain model and closed-circuit television camera is displayed to both pilot and copilot simultaneously in their forward window displays. The scene is provided via collimated displays. The total field of view visible by movement of the head is approximately 48 degrees horizontal and 36 degrees vertical. Additional computer generated representation of the terrain can be presented to each trainee through the "chin bubbles" of the simulator.

The simulated CH-47C flight compartment is mounted on a 48-inch-stroke, six-degree-of-freedom motion system. The system employed consists of a moving platform assembly driven and supported from below by six identical hydraulic actuators. The motion system is capable of providing pitch, roll, yaw, lateral, longitudinal, and vertical movement, either independently (without simultaneous motion in any other degree of freedom) or in any combination desired. All six actuators are driven in concert to produce real-time dynamic motion cues in response to computer commands.

The maximum operational excursion limits and the normal limits of performance of the motion system in each degree of freedom are as follows (all values measured at the motion platform):

	Maximum Excursion	Maximum Velocity	Maximum Acceleration
Pitch	+26°, -24°	+15°/sec	+50°/sec ²
Roll	+22°	+15°/sec	+50°/sec ²
Yaw	+29°	+15°/sec	+50°/sec ²
Vertical Translation	+32, -23 in.	+24 in./sec	+0.8g
Lateral Translation	+42 in.	+24 in./sec	+0.6g
Longitudinal Translation	+48 in.	+24 in./sec	+0.5g

The computer system enables the real time simulation of the CH-47 and management of all related advanced training, navigation/communication, aircraft subsystems, and visual display system programs, and operation of the simulator's built-in test and maintenance diagnostic programs. The computer system has sufficient capacity to absorb changes in simulation requirements resulting from aircraft modifications, new equipment additions to the CH-47, and expansion of advanced training programs. Computer peripheral equipment includes that necessary to make computer program changes and to produce hard copy records of student performance and maintenance checks. Advanced training features of the CH-47 simulator include computer-assisted performance monitoring, measurement, and recording; performance playback; automatically administered flight demonstrations; and visual and instrument checkrides.

3. Device 2B33. A requirement exists for an AH-1Q simulator subsystem of the Synthetic Flight Training System (SFTS). Development of this simulator began in FY 1973 and is continuing. A contract for an engineering development model was awarded in January 1974, and the device is scheduled to begin suitability tests in June 1976. The simulator will be used in transition, weapons systems familiarization and combat readiness proficiency at the Army Aviation Center and at aviation field units, and will play a major role in the Army-wide standardization of AH-1Q aviator performance. It will be used to train AH-1Q pilots and gunners independently or as crews.

The AH-1Q simulator includes one pilot cockpit and one gunner cockpit, both driven by a single digital computer complex. Each cockpit is mounted on a separate six-degree-of-freedom motion system. Separate instructor stations are mounted on each motion platform directly aft of the trainee position. Figure III-3 shows an artist's sketch of the 2B33 device's configuration. Two camera-model board visual image generation systems are used, and each cockpit has its own visual display system.

The interior of the pilot trainee compartment duplicates that of the pilot compartment of the AH-1Q aircraft with respect to size, arrangement, and appearance of panels, instruments, controls, seats and other components. All of the equipment required for ground operation as well as visual and instrument flight operations and weapons employment is functional and simulates the operation and function of the corresponding equipment in the aircraft. The helmet sight unit is simulated for this cockpit. Figure III-4 presents a layout of this cockpit.

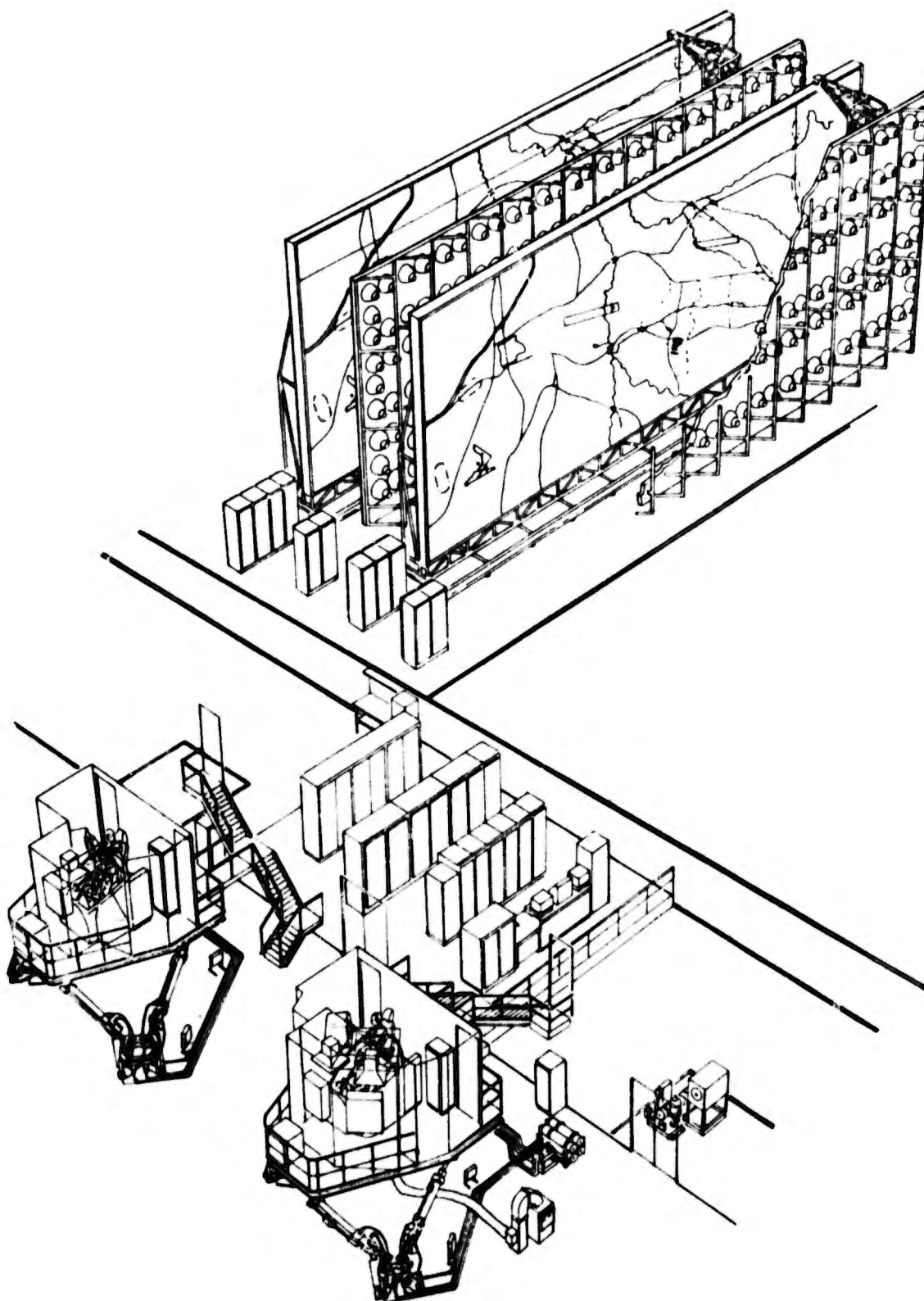


FIGURE III-3. DEVICE 2B33 CONFIGURATION

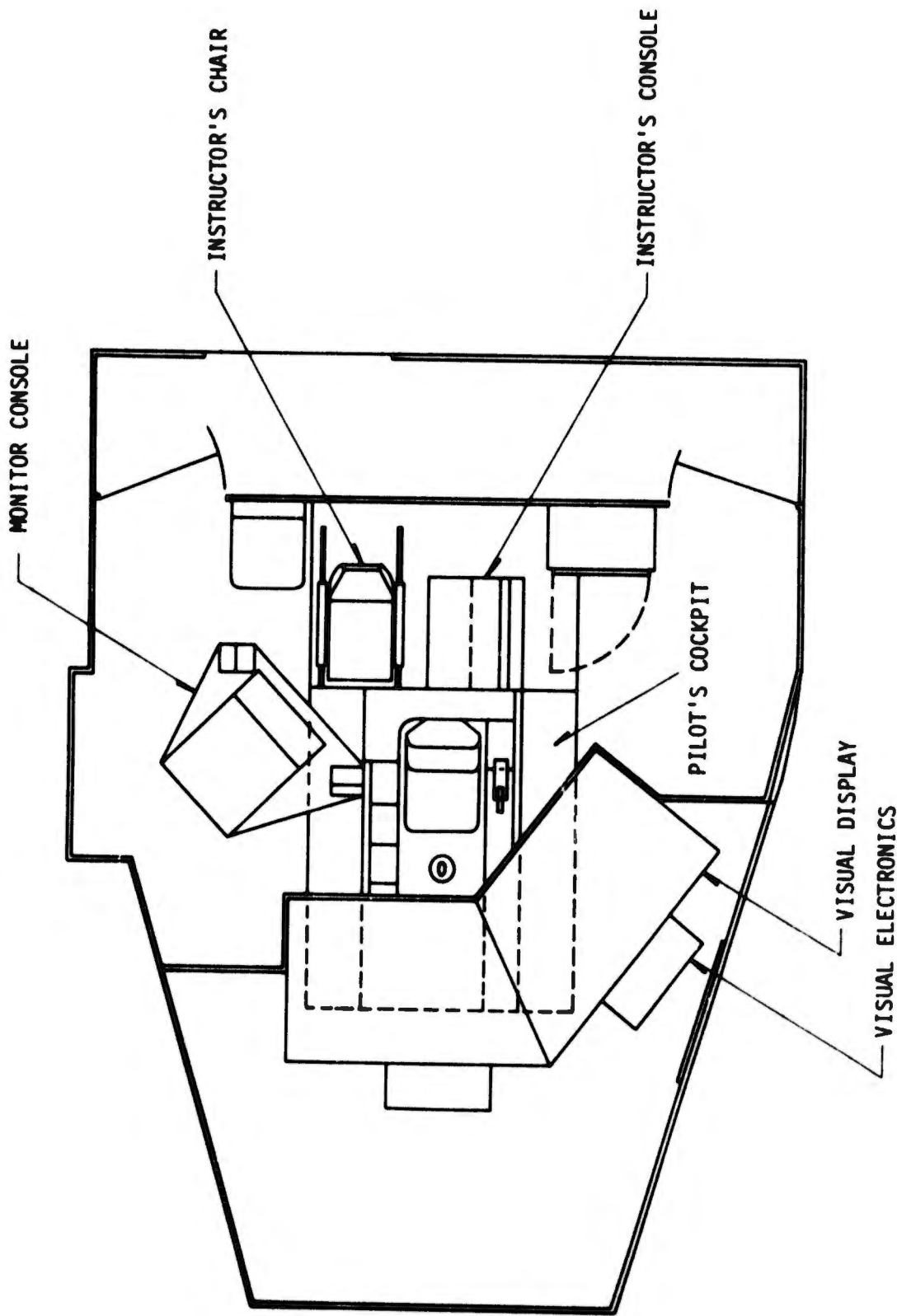


FIGURE III-4. 2B33 TRAINER, LAYOUT OF PILOT'S COCKPIT

The interior of the gunner trainee compartment is identical to the copilot-gunner compartment of the AH-1Q aircraft with respect to size, arrangement and appearance of panels, instruments, controls, and other components. All of the equipment is functional and simulates the operation and function of the corresponding equipment in the aircraft. Both the telescopic sight and helmet sight units are simulated for this cockpit. Figure III-5 shows the gunner cockpit configuration.

The pilot and gunner problem control panels are located in the respective stations in positions accessible to the trainees when they are seated. The functions of both control panels will be identical, i.e., to provide controls and indicators necessary to freeze and reset the trainer and to control the automated training features. The position of the control panel in the pilot's cockpit is near the bottom of the main instrument panel and is intentionally obscured by the pilot's knee. The position in the gunner's cockpit is on the small horizontal panel below the left air vent.

The instructor stations are mounted on each of the motion platforms at the right rear of the trainee position. The pilot and gunner instructor stations are almost identical, differing only in the design of a small panel area providing for pilot or gunner inputs by the instructor during independent operation.

Controls are provided at each instructor's console to permit him to communicate with either trainee, the other instructor, the maintenance stations, and the system computer and its data printout devices. He may communicate orally either over the intercom or through the simulated aircraft radio equipment. Although only a minimum of control activity is needed in normal system operation, flexibility is provided to permit the instructor to modify training conditions as he desires. Hard copy data can be obtained to permit evaluation of performance in either checkride or training modes of operation, adding utility to the system's basic flexibility.

The visual display system for Device 2B33 consists of two parallel high resolution camera-model systems with identical model boards. They may both be viewed by the pilot (forward and left side views) and one may be viewed by the copilot-gunner (forward only). During crew training, both trainees will view the same forward scene; during independent training, one system can be assigned to each trainee. Simulation of weapons trajectories and impact signatures is provided. Each display provides a 48 degree horizontal by 36 degree vertical color field of view.

Each visual image will originate from a closed-circuit color television camera viewing a three-dimensional scaled terrain model. The two identical scale models will afford scenic correlation between the pilot's forward and side displays and will further enable the same established training exercises to be conducted without depending on unique features of a particular model. The viewing position and the directed lines of sight will be controlled by the simulation computer to precisely track the simulated aircraft in all six natural degrees of freedom relative to the designated geographic location and orientation of the modeled area. The model boards

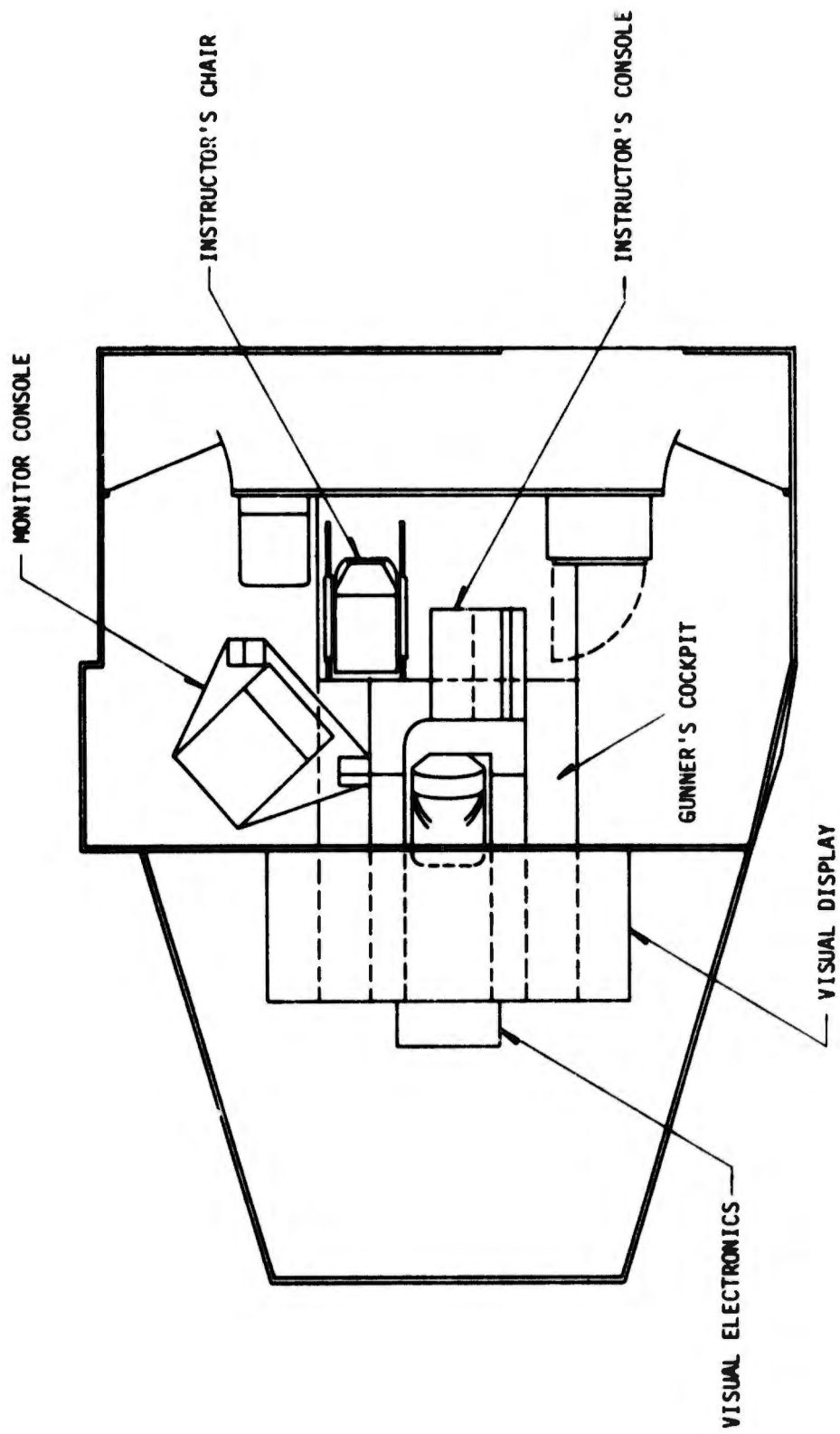


FIGURE III-5. 2B33 TRAINER, LAYOUT OF GUNNER'S COCKPIT

and visual simulation displays will be utilized as indicated below. Since the model boards are identical, either board may be chosen for any desired display based on its availability when required.

Day, dusk, and night light conditions will be simulated. A special effects generator produces the instructor-selected variation of cloud base and reduced visibility which are added to the terrain video in order to create the environmental variations of the outside world.

The pilot trainee station includes two through-the-window visual displays. One display is centered upon the cockpit centerline and will provide a horizontal coverage of 23.5 degrees on each side of the centerline. The vertical coverage of the displayed image extends from approximately +13.5 degrees to 17.5 degrees relative to the pilot's horizontal line of sight. The second display has the same nominal field of view, but is horizontally centered at about 53.5 degrees left of center (i.e., about 306.5 degrees relative bearing) with not more than a 6.5 degree gap existing between displays.

The gunner trainee station is provided with a forward window visual display which is identical to that of the pilot. In addition to the window displays, the gunner station will also be provided with an actively simulated Telescope Sighting Unit (TSU). The apparent field of view provided by the simulated TSU will be constant for both low (2 X) and high (13 X) magnifications. The TSU image will consist of symbolic target and horizon representations with an apparent TSU field of 36 degrees.

The pilot and gunner stations are each mounted on a 48-inch stroke, six-degree-of-freedom motion system. The system employed consists of a moving platform assembly driven and supported from below by six identical hydraulic actuators. The motion system is capable of providing pitch, roll, yaw, lateral, longitudinal, and vertical movement, either independently (without simultaneous motion in any other degree of freedom), or in any combination desired. All six actuators are driven in concert to produce real-time dynamic motion cues in response to computer commands.

The maximum operational excursion limits and the normal limits of performance of the motion system in each degree of freedom are as follows (all values measured at the motion platform):

	Maximum Excursion	Maximum Velocity	Maximum Acceleration
Pitch	+26°, -24°	+15°/sec	+50°/sec ²
Roll	+22°	+15°/sec	+50°/sec ²
Yaw	+29°	+15°/sec	+50°/sec ²
Vertical Translation	+32, -23 in.	+24 in./sec	+0.8g
Lateral Translation	+42 in.	+24 in./sec	+0.6g
Longitudinal Translation	+48 in.	+24 in./sec	+0.5g

The computational system is configured around three central processing units. Peripheral equipment includes a teletypewriter, a 20 megaword disc, a card reader, and a printer-plotter. The operational software supplied consists of an executive program and real-time simulation programs. The support software includes computer diagnostics, a daily operational readiness check program, and a test exercise program.

4. Status. Device 2B33 is scheduled to be ready for training at Fort Rucker in August 1976. Contracting for production models of the device is scheduled for FY 1977. Present estimates of projected use of AH-1Q simulators indicate that one engineering development model and five production models will be required.

FUTURE SIMULATOR DEVELOPMENT REQUIREMENTS

During the next decade the Army will introduce three new helicopters: the Utility Tactical Transport Aircraft System (UTTAS), the Advanced Attack Helicopter (AAH), and the Aerial Scout Helicopter (ASH). Based upon the mission of these helicopters, projected operating costs, and the probable numbers of aircrews to be trained, simulators and other training devices will be required for the conduct of cost effective training for each helicopter. The major components of the three simulators are denoted in Table III-3.

1. UTTAS Simulator Project. The objective of the UTTAS Simulator Project is to develop a training simulator for use in UTTAS training at the Aviation Center and at selected aviation field sites. Training to be conducted in these devices will include transition, combat readiness proficiency, and visual/instrument refresher training. The simulator will play a major role in the Army-wide standardization of UTTAS aviator performance. While the design of this simulator will be based upon state-of-the-art technology, advanced developments in the areas of visual simulation and computer-controlled training will be required.

The project will be initiated in FY 1975 with the conduct of engineering and training design concept studies. Final design will await selection of a UTTAS aircraft design, but simulator procurement will be expedited by contracting for an engineering development model visual display attachment in FY 1977 and aircraft simulators in FY 1978.

2. AAH Simulator Project. The objective of the AAH Simulator Project is to develop an AAH simulator for use in AAH aircrew training at the Aviation Center and at selected aviator field sites. This device will be used in transition, weapons qualification, combat readiness proficiency, and visual and instrument refresher training programs, and will enhance achieving Army-wide standardization of AAH aircrew training.

The design of the AAH simulator will be similar to that of Device 2B33, the Attack Helicopter Simulator which is under development. The data generated during the suitability testing of the 2B33 device will be used

TABLE III-3.

MAJOR COMPONENTS OF FUTURE SIMULATORS

• Pilot and Copilot Trainee Compartment

Identical in size, arrangement, panels, instruments, controls, seats, and other components to the operational aircraft.

• Flight Instructor Station

Contains complete set of controls and displays.
Capability to monitor trainees and their visual displays.

• Visual Display System

Capability for performing visual and instrument maneuvers.

Employs state-of-the-art optics and electronics.

Provides a full color field of view display for nap-of-the-earth (NOE) eye heights.

Scene content provides stagefield-type training and tactical training.

Provides for night operations.

• Motion System

Six-axis system for pilot and copilot.

• Computer System

Enables real time simulation.

Capable of absorbing changes in design of aircraft and aircraft subsystems.

Print out of student performance and maintenance checks.

in the design of the AAH Simulator. The simulator will be capable of providing training for AAH pilots and gunners separately or as a crew. It will have two separate trainee compartments, one each for the pilot and for the gunner. Each compartment will be modeled after the corresponding portion of the aircraft. Each trainee compartment/instructor station will have its own visual display and will be mounted on a six-axis motion system. The device will be driven by a digital computer programmed to perform, in addition to computations necessary for aircraft and weapons systems and environmental simulation, all operations associated with advanced training and maintenance troubleshooting features of the simulator.

Engineering and training design concept studies will be initiated in FY 1976 and will overlap Device 2B33 testing. A contract for an engineering development model will be awarded in late FY 1977. It is anticipated that the device will be delivered to the Aviation Center in FY 1979 or FY 1980 for suitability testing. It will be used in transition, combat readiness proficiency training (CRPT) and instrument refresher training, and in the Army-wide standardization program for ASH qualified aviators. Advanced developments will be required to provide acceptable visual simulation of nap-of-the-earth (NOE) and night operations and computer-controlled training and performance assessment.

3. ASH Simulator Project. This training device will be a state-of-the-art operational flight trainer for the ASH aircraft and will include a visual system to simulate the ASH operational environment. The simulator will be used in conjunction with the operational aircraft and other training devices to provide training for ASH aircrews at the Army Aviation Center and at selected aviation field units. It will be used in transition, combat readiness proficiency training (CRPT) and instrument refresher training, and in the Army-wide standardization program for ASH qualified aviators. Advanced developments will be required to provide acceptable visual simulation of nap-of-the-earth (NOE) and night operations and computer-controlled training and performance assessment.

Development of an ASH simulator was recommended to DA by the ASH Project Office in August 1974. Following final definition of the ASH, documentation for a simulator will be prepared by TRADOC if a simulator is determined to be justifiable. Development of the simulator would be initiated with an engineering and training concept study beginning in FY 1976. Procurement of this device will be time-dependent upon the selection of an ASH design. Present projections indicate delivery of an engineering development model for suitability testing in FY 1979 and ultimately for use in ASH aircrew training.

SECTION IV

COST EFFECTIVENESS ANALYSES

The purpose of this section is to present the potential cost and fuel savings that might be realized from the introduction of the Synthetic Flight Training System into training programs.

Although the exact amounts of the savings to the U.S. Army cannot be ascertained due to non-availability of adequate data, the estimates do indicate significant potential. Also, an analysis of U.S. Navy and Air Force simulators indicates that large savings would occur from greater utilization. The results of the analysis which was conducted by the General Accounting Office (GAO) in March 1973, are shown in Tables IV-1 and IV-2.

TABLE IV-1

GAO COMPARISON OF SIMULATOR AND AIRPLANE OPERATING COSTS^a

Airplane Type	Hourly Operating Cost		Hourly Savings with Simulators
	Airplane	Simulator	
Military:			
A-7 attack and F-4 fighter (average)	\$ 853	\$ 80	\$ 773
P-3 patrol airplane	450	60	390
FB-111 and B-52 bombers (average)	1,473	90	1,383
Airline A:			
Various commercial airplanes	400-1,500	60	340-1,440
Airline B:			
Boeing 727	420	90	330
Boeing 747	970	140	830

^aBased on Navy, Air Force, and commercial airline cost data for fuel, spare parts, maintenance salaries and overhead, and simulator operator pay. Development and procurement costs for aircraft or simulators are not included.

TABLE IV-2

GAO ESTIMATES OF LOWER TRAINING COSTS^a

	Flying Hours ^b	Savings Per Hour Using Simulators	Estimated savings by replacing flying hours with simulator hours ^c	
			25 Percent Replacement (millions)	50 Percent Replacement (millions)
Navy ^d				
Fighters ^e	619,089	\$ 773	\$119.6	\$239.3
Patrol	276,949	390	27.0	54.0
Air Force ^f				
Fighters	1,077,775	773	208.3	416.6
Bombers	294,426	1,383	<u>101.8</u>	<u>203.6</u>
Total			<u>\$456.7</u>	<u>\$913.5</u>

^aExcludes costs of airplane crashes during training.

^bTotal hours shown are for all operational aircraft in the categories shown.

^cDoes not include costs of developing and producing simulators.

^dFlying hours during fiscal year 1972.

^eExcludes flying time while assigned to aircraft carriers.

^fFlying hours during calendar year 1971.

Table IV-1 shows the data presented by the GAO regarding hourly simulator and airplane operating costs for certain military and commercial aircraft. Table IV-2 presents the GAO estimates of training costs for the U.S. Navy and U.S. Air Force if simulators replaced 25 and 50 percent of the hours currently flown in aircraft for training purposes. The GAO data show that for a 25 percent replacement, an annual saving of \$455 million would occur. If 50 percent of the flight training were conducted in simulators, the annual saving would approach \$910 million.

The GAO cost analysis models are based upon substituting one hour of flight simulator time for one hour of aircraft flight time. This ratio of substitution assumes that the transfer of training from aircraft to simulators may be made on a one-to-one basis. At present, data on transfer of training is inadequate to permit accurate specification. Thus, the data of Tables IV-1 and IV-2 should be viewed only as indicative of the potential cost savings.

The data, assumptions, and results of the analysis for the SFTS are shown in Table IV-3 and Figures IV-1 through IV-5. Table IV-3 lists the cost data and assumptions used in the analysis. The cost effectiveness model used in generating the data assumed the transfer of training was one-to-one.

TABLE VI-3

COST EFFECTIVENESS ANALYSES DATA AND ASSUMPTIONS

	2B24	2B31	2B33	2B38	2B40
Simulator Operating Cost Per Cockpit Hour, Dollars	38.20 ^a	94.88 ^b	69.33 ^b	275.00 ^b	180.00 ^b
Number of Cockpits per Simulator	4	1	2 ^d	1	2 ^d
Aircraft Operating Cost Per Hour, Dollars					
UH-1	238.00 ^c				
CH-47		858.00 ^c			
AH-1			285.00 ^c		
UTTAS				748.00 ^b	
AAH					847.00 ^{b*}
Aircraft Fuel Usage, Gallons Per Hour					
UH-1	90 ^c				
CH-47		497 ^c			
AH-1			103 ^c		
UTTAS				138 ^b	
AAH					138 ^b
Yearly Simulator Hours Per Pilot or Gunner	15	15	15	20	20
Simulator Availability, Calendar Days	225	225	225	225	225
Procurement Cost of Simulator and Building, Millions of Dollars	3.0 ^b	5.0 ^b	7.0 ^b	7.5 ^b	4.5 ^b

^aBased on FY75 usage of devices.

^bProjected HQDA estimate.

CHQDA cost figures.

^dOne pilot and one gunner.

*Subject to upward adjustment due to inflation being experienced in labor and material costs.

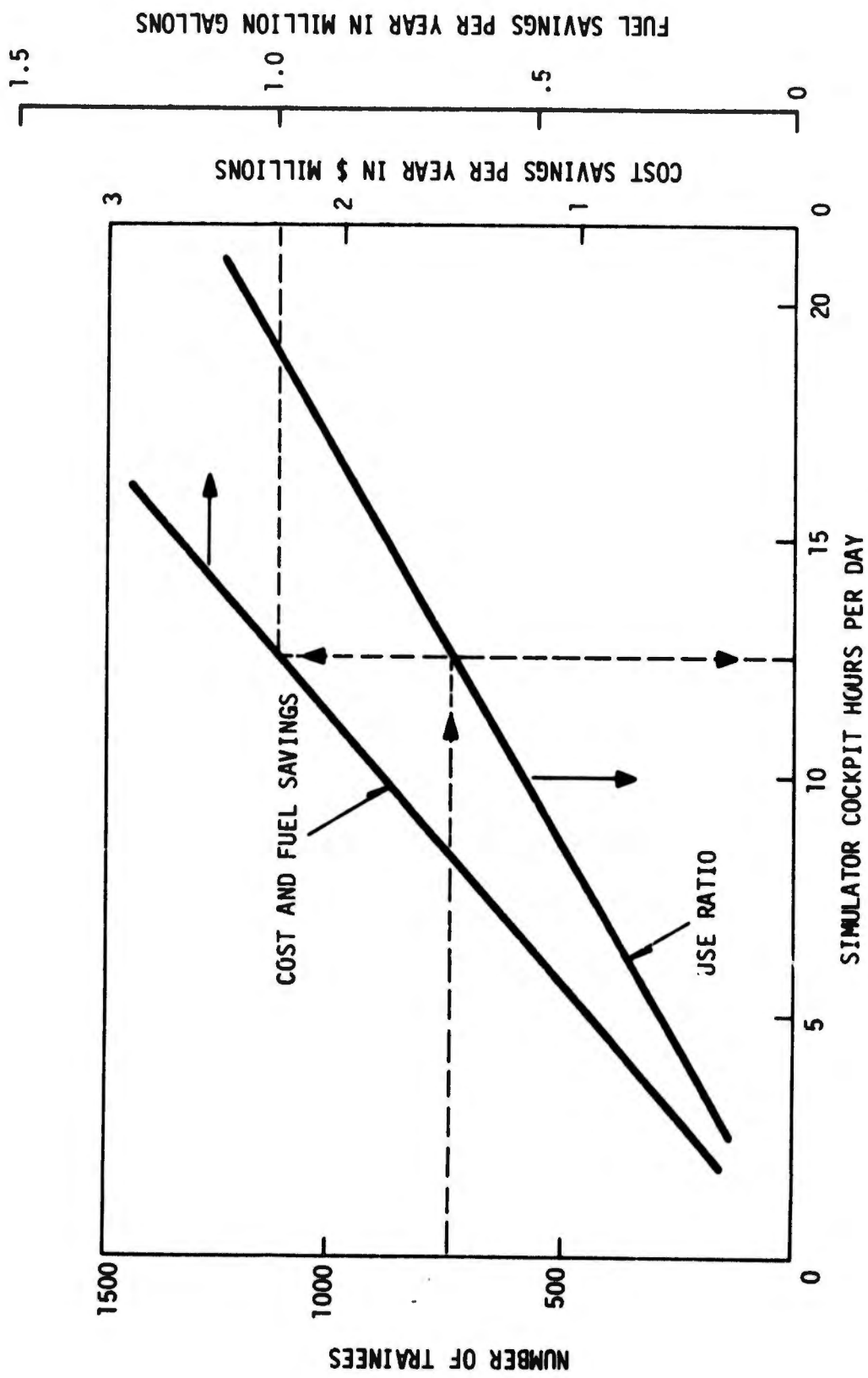


FIGURE IV-1. 2B24 COST AND FUEL SAVINGS PER YEAR AS A FUNCTION OF AVIATOR DENSITY

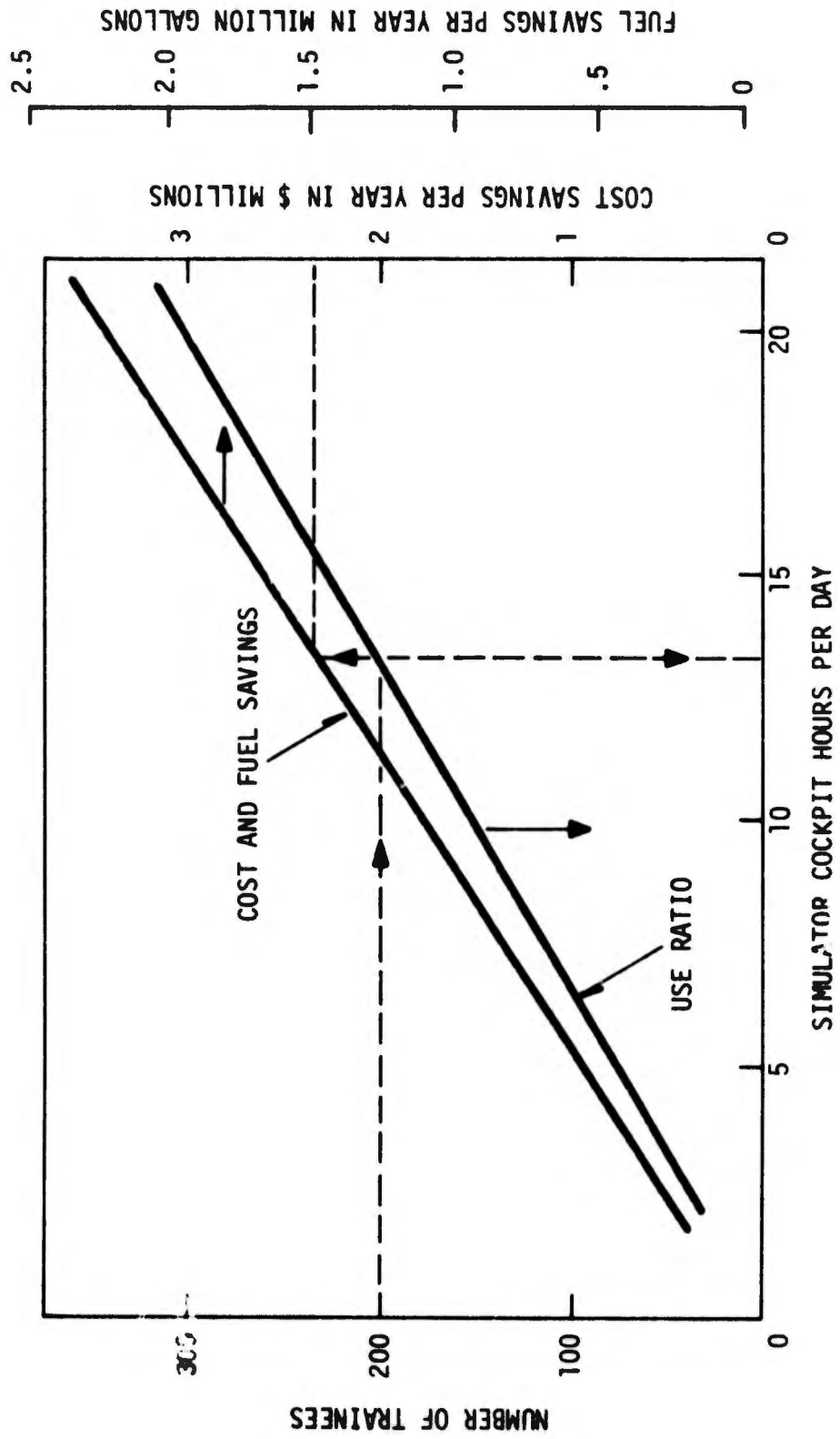


FIGURE IV-2. 2B31 COST AND FUEL SAVINGS PER YEAR AS A FUNCTION OF AVIATOR DENSITY

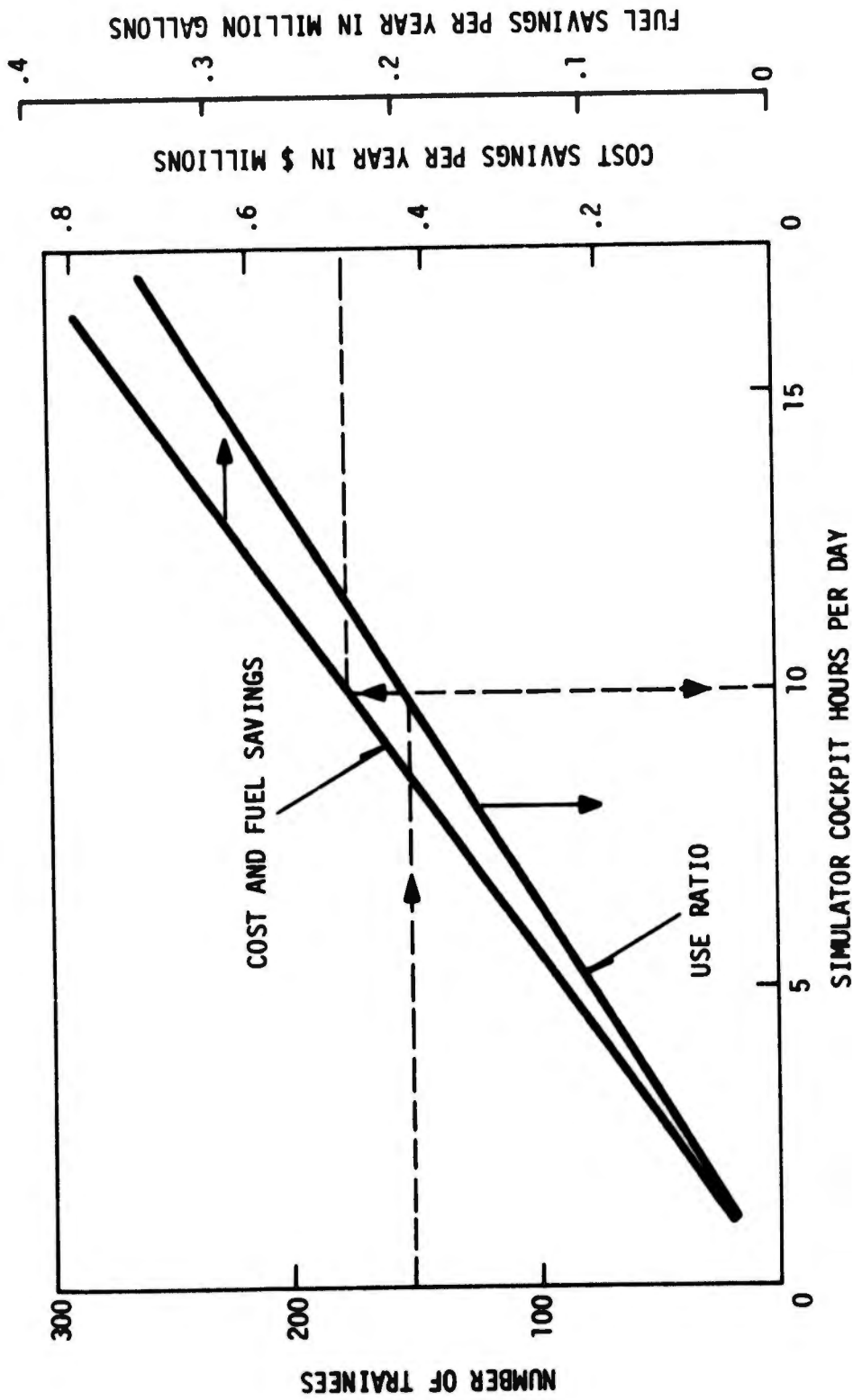


FIGURE IV-3 2B33 COST AND FUEL SAVINGS PER YEAR AS A FUNCTION OF AVIATOR DENSITY

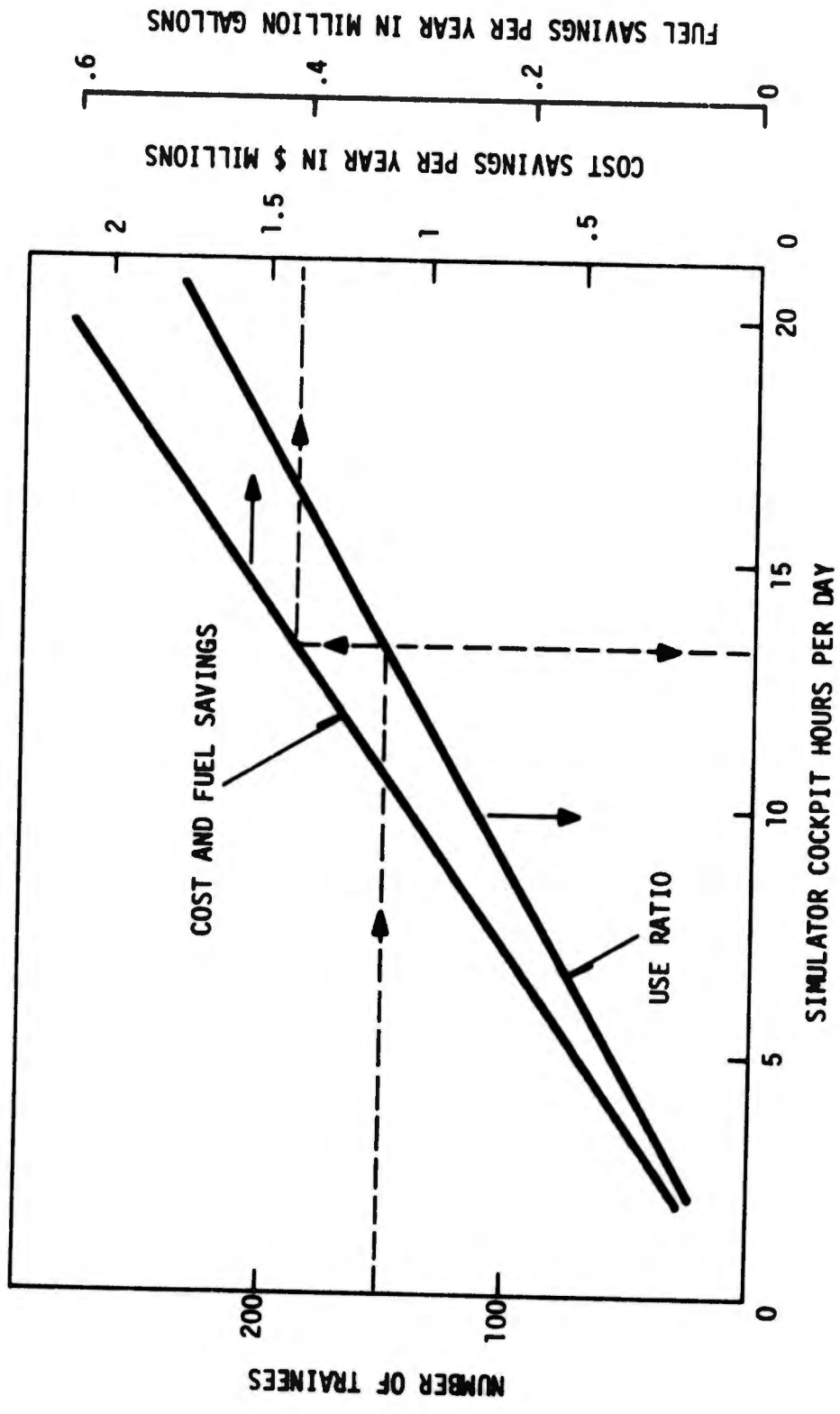


FIGURE IV-4. 2B38 (UTTAS) COST AND FUEL SAVINGS PER YEAR AS A FUNCTION OF AVIATOR DENSITY

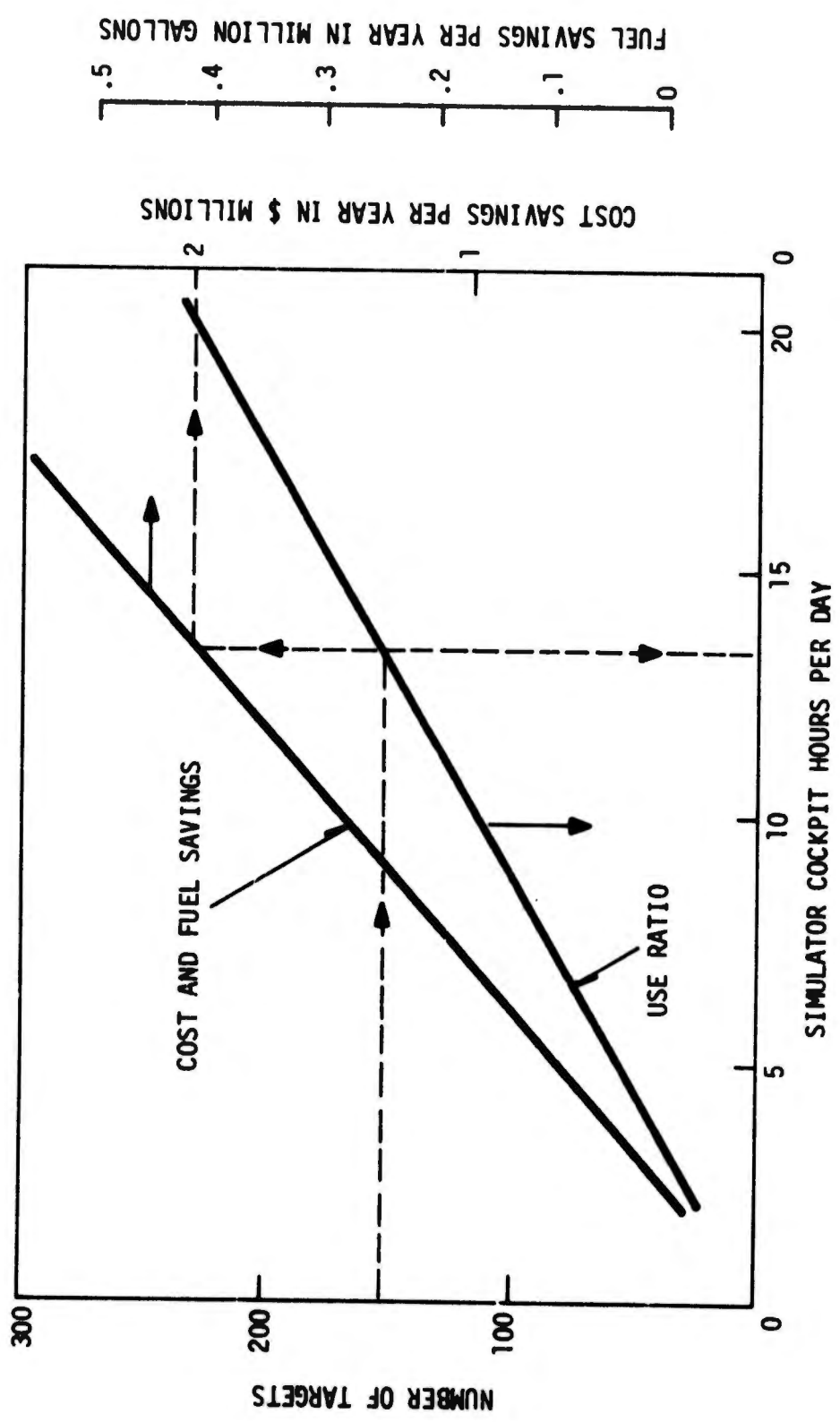


FIGURE IV-5. 2B40 (AAH) COST AND FUEL SAVINGS PER YEAR AS A FUNCTION OF AVIATOR DENSITY

Figure IV-2 presents the results for the UH-1 instrument simulator. The use ratio line was calculated from the following expression:

$$\frac{(\text{Number of Aviators}) (\text{Yearly Simulator Hours per Pilot})}{(\text{Number of Cockpits}) (\text{Simulator Availability, Calendar Days})} = \text{Simulator Cockpit Hours Per Day.}$$

The cost and fuel savings were computed from the following:

$$\frac{(\text{Number of Aviators}) (\text{Yearly Simulator Hours Per Pilot})}{(\text{Aircraft Operating Cost} - \text{Simulator Cockpit Operating Cost})} = \text{Cost Savings Per Year, and}$$

$$\frac{(\text{Number of Aviators}) (\text{Yearly Simulator Hours Per Pilot})}{(\text{Aircraft Fuel Usage})} = \text{Fuel Savings Per Year.}$$

The example shown in Figure IV-1 is for 750 aviators. For this number of aviators, each of the four identical cockpits of the 2B24 would be operated 12.5 hours per day. Cost savings, assuming a one-to-one transfer of training are \$2,247,750.00 per year. Fuel savings are 1,012,500 gallons per year.

Figure IV-2 presents the results for the CH-47 simulator. For 200 aviators, the single cockpit would be used 13.3 hours per day. The cost savings for this usage rate amount to about \$2.3 million per year. Fuel savings are about 1.5 million gallons per year.

Figure IV-3 presents the results for the AH-1 simulator. This simulator has two cockpits, which are not identical (one pilot and one gunner), and were thus counted separately. The example of Figure IV-3 shows that for either 150 pilots or 150 gunners, the appropriate cockpit would be used ten hours per day. This use rate, assuming that an instructor pilot would be flying the aircraft and only one trainee would be aboard, would produce a cost savings of approximately \$485 thousand per year. The fuel savings in this case would be about 232 thousand gallons per year. Thus, to train 150 crews for the AH-1, use of a simulator would produce total cost and fuel savings of \$970 thousand and 464 thousand gallons per year. Also, since the AH-1 device simulates the firing of the TOW missile, there is an additional potential cost savings of approximately \$2500.00 per missile.

For integrated crew training, the potential cost savings are less than that shown in Figure IV-3. For a crew of 300 trainees, both cockpits would be integrated, and the cost difference between the simulator and inflight training would be \$146.34 per hour (see Table IV-3). The cost savings in the mission role, assuming no firing of TOW missiles would be about \$300 thousand per year. The fuel savings for the mission case is 232 thousand gallons per year.

The larger cost and fuel savings resulting from independent training of the trainees are typical for the Aviation Center. Field sites would produce lower cost and fuel savings as much of the training done in the field would be of the integrated crew type.

Figures IV-4 and IV-5 show the calculated results for the 2B38 (UTTAS) and 2B40 (AAH) simulators respectively. As noted in Table IV-3, the cost and fuel savings are based upon projected estimates for both the aircraft and simulator. Although large potential savings are indicated, the results should be considered as very approximate.

SECTION V

RESEARCH AND DEVELOPMENT PLANS

At present, the Army's major efforts are the development of advanced subsystems of the Synthetic Flight Training System. The programs are oriented to producing cost-effective training simulators for such missions as air-to-ground weapons delivery, formation flight, and low-level navigation. Key programs are aimed at developing technology in such areas as wide field of view with high resolution, color, and data storage to describe large geographical areas in great detail and in color. The major effort is directed at component research which will lead to high fidelity flight simulator training systems with motion platforms, computerized instruction, and keyed to nap-of-the-earth flight, both day and night. The objective of this section is to identify specific exploratory (6.2), advanced (6.3), and engineering (6.4) development efforts of priority to the accomplishment of technology needed to support the production of advanced subsystems for the SFTS. Details of these programs are presented in the following paragraphs.

EXPLORATORY DEVELOPMENT PROGRAM (6.2)

1. Visual Simulation Analysis. The rising cost of operations and reduced supplies of fuel have restricted the use of operational equipment for Army training. Many visual simulation techniques are available today with the potential to reduce Army training costs and fuel consumption. An analysis of these visual simulation techniques is needed to determine how they can be used to provide cost-effective training. A survey of visual simulation techniques will be conducted to define those visual subsystems in use and those planned that require technology development to insure successful engineering development for Army applications. Special consideration will be given to those systems that may be candidates for Product Improvement Programs (PIP's) as well as such advanced technology areas as holography.

During the first fiscal year, a survey of state-of-the-art visual simulation techniques will be conducted. Visual systems having potential for Army applications will be identified and recommendations for further visual technology development will be made. The visual systems survey will be updated annually to include all new visual techniques and development recommendations.

2. 360 Degrees Annular Visual System. This research is directed towards determining the feasibility of using annular optics and charge coupled devices to provide a 360 degree color visual presentation of dynamic real-world tactical scenes for Army training applications. There is a need for a non-programmed real-time, wide-angle dynamic display that can present the maximum degree of realism for the SFTS. Presently, film presentations are used extensively by commercial airlines as visuals but they present a "canned" real-time capability. Closed circuit TV systems are capable of

real-time non-programmed presentations, but the viewing angles are small. Recent advances in optics, electronics, and laser technology make possible a new visual system that has the potential for meeting training requirements for wide-angle, high resolution, real-time and full color presentations.

The research will involve the study and analysis of a recently designed annular optical lens capable of taking and projecting a 360 degree by 42 degree picture. The lens is composed of both refractive and reflecting elements. By using such lenses for both the probe and projector a 360 degree non-programmed, high resolution visual presentation may possibly be realized. An image transfer system between the two optical units would be assembled by using arrays of electronic charge coupled devices (CCD's) in contact with the probes image. This presentation of the scene is then transferred, electronically, to a series of laser modulators. The modulated light from each is then deflected, either by rotating multi-faceted mirrors or through beam steerers, into an image rotator. The image rotator sweeps the image across the rear of the projection lens and the visual is presented on a spherical screen.

3. Wide-Angle Laser - Scan Visual System. This effort would be directed at developing a cost-effective wide-angle visual system with the capability to present dynamic real world scenes in color for helicopter flight simulation. Such a system is needed to train such Army visual flight tasks as nap-of-the-earth (NOE) flight, navigation, and target acquisition. The laser scan technique has the potential to provide efficient and relatively inexpensive wide-angle visual simulation for the SFTS.

The primary thrusts of the research will be: (1) to analyze the critical component and signal processing requirements for a laser-scan visual system; (2) to study the safety requirements for such a system, and (3) to demonstrate the feasibility of a synchronized laser-scan with a 100 MHz video chain. The demonstration will be oriented toward showing the capability of the system for the SFTS.

4. Improvement of Training Programs Through Incorporation of Accident Research Results. This proposed research effort is designed to incorporate the results of on-going accident research into training programs. Simulators will be used to enhance the development of remedial measures and to train against the causes of accident errors. The goals of the research will be to determine which factors or procedures may be conducive to training by simulation and incorporate these into existing and proposed systems of the SFTS.

The effort will involve identification of the factors amenable to simulation and development of a simulation program with input into three levels of training; initial entry, transition, and proficiency. The effort will include analysis of factors to identify flight task errors and critical situational aspects which may become the training content of a simulator program for all three levels of training. Simulators will be used in these analyses enabling precise control of conditions.

5. Aviator Target Identification and Acquisition Training Research. This research involves the development of training programs and related training techniques to enhance the aviator's ability to detect and identify enemy targets, both camouflaged and uncamouflaged. The program will support various weapons sighting systems including helmet mounted, rocket, and gun systems, the TOW missile, and HELLFIRE. Development of the training research program will be concurrent with development and acquisition of the required equipment.

The training programs in addition to providing realistic practice with the unaided eye, will also be used to promote optimal use of variable magnification monocular and binocular viewing devices. Depending upon whether the aviator is expecting camouflaged or uncamouflaged targets, and whether, at a given moment, he is attempting to detect or identify a target, there is a magnification - area of coverage trade-off which can be optimized through training.

6. Computer Animated Visual System. Current visual simulation systems have objectionable characteristics that may be overcome through the use of computer animated image generation techniques. Camera-model visual systems require large expensive model boards which require much power for lighting and large buildings for housing. Film visual systems are less costly and require less power and space, but they limit the excursions of the simulated vehicle path. Computer animated visual techniques will be developed to provide a simulated visual scene with flexibility and realism of a camera-model system but without the use of a model board and without the vehicle path constraints of a film system. Existing hardware will be updated and modified to investigate the computer controlled animation of multiple still visual scenes to simulate non-programmed visual flight. Efforts will be directed toward nap-of-the-earth (NOE) flight and the insertion of tactical targets.

During the first fiscal year, a systems design analysis will be conducted to investigate computer animation techniques to simulate nonprogrammed visual flight. Alternate techniques for the simulation of NOE flight and insertion of tactical targets will be analyzed. The techniques with the potential to be most cost-effective will be developed and integrated with existing hardware for test and evaluation. During the second fiscal year, the breadboard system will be updated to simulate high speed NOE flight with tactical targets. A performance specification for a computer animated visual system will be prepared based on the performance of the breadboard model.

7. Special Purpose Algorithms for Computer Generated Imagery (CGI). There is a need for such training applications as aerial weapons delivery, nap-of-the-earth (NOE) flight, and general aerial maneuvers. The objective of this research is to develop the needed algorithms for application to the above training needs.

The effort includes a study of the feasibility of achieving real-time generation of portions of displays that may be appended to a general scene to provide a complete complex real-time dynamic scene for sensor displays,

simulated operational displays, and tactical displays. The effort will determine what general purpose scene displays or portions of displays could be generated by specific algorithms in real-time, and an analysis of the advantages and disadvantages of using such means for generating portions of the display, that is, trees, wooded areas, buildings, and vehicles. The feasibility study would be conducted during FY 77 and the development of the cost effective algorithms would be started in FY 78.

8. Instructor Station Design Research. There is not adequate data to enable assessing the efficiency of instructor station designs and hardware. As a consequence, there does not exist any criteria by which there may be determined the usage efficiency of presently available features or capabilities of training devices. Also, the lack of criteria constrain the identification of redundant and other unwarranted features or capabilities and/or what features are needed and should be added.

The effort will include: (a) A review of research and development relevant to the design and use of instructor consoles with emphasis on instructor stations for mission simulators; (b) The conduct of a series of experiments in existing simulator facilities; and (c) The validation of design criteria for instructor consoles. In FY 77, a study will be made of instructor pilot usage of consoles. This effort will require nine man-months. The follow-on efforts will be programmed for FY 78. It is anticipated that efforts will be continued beyond FY 78 to ascertain criteria for advanced flight training simulators for the UTTAS, AAH, and ASH aircraft.

9. Nap-of-the-Earth (NOE) Technology Study. The perception of distance and depth is vital in the judgement of terrain contours during NOE flight. Conventional two-dimensional display systems do not permit the human operator to make full use of a highly refined sense of depth. With depth added to the display, the operator will be able to perform more efficiently by taking advantage of depth perception capabilities.

Recently conducted research indicates that the use of stereo television displays permit more efficient low-altitude terrain-following flight. Whether stereo display would permit improved operator performance during NOE flight is a question, as yet, not fully answered. Also, not certain is whether flight training simulators could be adapted for stereo display if such were found to provide an advantage in NOE flight. The NOE technology study would be directed toward obtaining data applicable to answering both of these questions.

Starting in fiscal year 1977, an effort will be conducted to include: (a) a survey of the stereo-display systems in use and those planned to ascertain the applicability of these for NOE display systems; (b) the delineation of design criteria for incorporating such equipment into flight training simulators; and (c) the conduct of a series of experiments in existing simulator facilities. The experiments will be designed to ascertain the feasibility of using stereo displays for NOE flight training.

ADVANCED DEVELOPMENT PROGRAMS (6.3)

The objective of this program is to conduct research that will lead to high fidelity simulator training systems with motion platforms, computerized instruction, and keyed to nap-of-the-earth flight both day and night.

1. Visual Systems Research. In the future, the Army must continue to rely heavily upon the use of simulators for pilot training. Present technology permits generally adequate simulation of present and planned Army aircraft in an instrument flight environment, but the bulk of Army flying takes place in a visual flight environment. Existing visual display system technology was developed primarily for high performance fixed wing aircraft simulators and is limited in the extent that the visual environment of Army rotary wing aircraft can be simulated.

Particular deficiencies exist with respect to the environment needed for nap-of-the-earth, night, and helicopter-to-helicopter engagement training. Based upon present technology, an NOE visual display would have to consist of a large scale model board that is expensive to fabricate and house, and, in order to provide adequate protection to the optical probe, requires extensive programming to locate surface obstructions in computer memory. Areas where technology advances are needed include the following:

a. Present terrain model construction does not permit the simulation of scene content at the level of detail required for low airspeed flight near natural or man-made objects at economical scale sizes. Large amounts of energy are required to provide adequate lighting of the models.

b. Existing optical probes are bulky, fragile, and limited in field-of-view and depth-of-field. Because they are easily damaged or misaligned if contact is made with the model board, training at tasks such as nap-of-the-earth navigation involves equipment risk. The angular field-of-view coverage of existing probes (and display optics) is far less than that which the Army aviator is believed to need.

c. Techniques do not exist at present to simulate the environment as viewed through night and limited visibility viewing devices such as infra-red goggles and forward looking infra-red.

d. Techniques for simulating the "other" helicopter in an NOE day or night environment as it seeks cover among the features of the simulated terrain, do not now exist.

During the first fiscal year, criteria for a visual systems research tool will be defined. The effort will include an evaluation of color versus black and white presentation effectiveness. The initial demonstration of a visual research tool involving a laser scan concept will be conducted during this first fiscal year.

During the next fiscal year, in conjunction with the development of visual research systems field-of-view studies will be conducted. The development effort will culminate in a visual display system designed for use in conjunction with training simulators in use during the period 1980-85 (e.g., AAH, ASH, and beyond). Research will be conducted to expand the data base in NOE, night, and air-to-air tactics (e.g., the scene content, field-of-view, etc., required to conduct a specific aircraft maneuver), concept definition studies, development of laboratory and breadboard devices to test engineering concepts, fabrication of an advanced development model, modification of one or more then-existing simulators for use with it, and tests to determine the value of the system in an operational training system.

2. Training Research Conducted with Simulators. This effort involves research that would be conducted in such simulators as Devices 2B24, 2B31, and 2B33. Blocks of time on each of these types of the aircraft simulators located at the Aviation Center, Fort Rucker would be set aside for research purposes. The time, arranged so not to interfere with training schedules, would permit the use of these high fidelity devices in research that requires close duplication of the aircraft environments. This use of existing simulators could result in less dollars having to be spent for pure research simulators. Specific projects recommended for this effort are:

a. Development of Automated Training Techniques. The purpose of this proposed research is to develop training programs for validating and exploiting the automated training features of the 2B24, 2B31, and 2B33 devices and to develop an adequate data base, using that equipment, to allow the design of a second generation of automated training features in future simulators to be based on validated, empirical data. The experimentation should furnish sufficient information to facilitate the effective use of the automation capabilities of present Army simulators.

The initial phase of this program will be an analysis of first generation automated training programs, i.e., use and problem areas. For example, how do instructors use automated training? How is automated training used in conjunction with traditional training? What should be the characteristics of an overall training program in which automated training programs are used? Are all of the automated features desirable at different stages of training?

The final phase will be experimentation using the simulators. The results of the experimentation will answer the questions concerning the use of automated training. The results will provide sufficient information to allow the automation capabilities of Army simulators to be developed and utilized effectively, and provide information on which to design automated training features for future simulators.

b. Development of Automated Performance Measurement Techniques. The purpose of this proposed research is to develop automated performance measurement techniques to provide meaningful and valid assessment of trainee capabilities. Research is needed to define aviator performance requirements and the parameters which best define optimum performance. The utilization of performance recording in training program design needs to be defined to

permit effective standardization of trainee evaluations. Where adaptive variation of training difficulty is desired, the evaluation of trainee performance must be based on accurate and significant performance criteria. The deviation and validation of standards of performance will be a significant part of this effort.

The primary thrust of the research will be to derive specific techniques for the generation and use of automated performance measures in Devices 2B24, 2B31, and 2B33. As part of this initial phase a number of representative measures will be generated. These measures will be drawn from the on-going UH-1, CH-47, and AH-1Q training programs.

The selected automated performance measures will be incorporated in the simulators and the programs will be tested for reliability and validation. The evaluation will include instructor's analyses of the automated measures for interpretability and usefulness. Since the goal of this research is to devise valid and meaningful methods of automatically measuring pilot performance in the aircraft, the evaluation will be conducted within a framework of actual training.

3. Device Management and Application Studies. The effectiveness of simulation in Army aircrew training can be enhanced through research yielding information related to the design and procurement of training devices. The research would be in the form of multiple, low level of effort studies addressing the major Army simulator training problem areas.

a. Part-Task Trainers Studies. This research will be directed at analyzing Army aviation part-task training device designs. These devices are widely used for both air and ground crew training by all aviation training establishments. Many of these devices are often quite expensive to procure and operate. Unfortunately, these devices are not subjected to the level of systematic design that is required to assure optimal utilization of the devices.

The effort will include an analysis of existing Army part-task training devices, their design, utility, and employment practices. A prime objective will be the determination of the extent to which these devices could be improved by use of relevant engineering and training technologies.

b. Simulator Programming Language. This study is directed towards the development of a higher level language for simulators that would permit increasing the efficiency and effectiveness of existing programming techniques. Use of higher level languages has increased in order to reduce programming costs and time by shifting the burden of programming details onto the computer hardware thus taking advantage of the faster, lower cost third generation machines. Development of these languages is important due to the much reduced time required for programming. Other advantages are that a problem written in a higher level language is shorter in length and easier to debug, standard programs can be executed on different machines with only minor revisions, a reduced level of programmer experience is needed, and programs are in user-oriented language so maintenance costs are reduced.

The approach would involve identifying the key problem areas as regard applying a higher level language to the Synthetic Flight Training System. An assessment of the applicability of applying a higher level language would be made and would include the impact of such application upon the cost of computer hardware. The study would also consider such alternatives as restructuring the higher level language to the full or broad program or to only a specific segment of the full program.

c. Simulator Procurement Practices Studies. At present, data purchased in conjunction with a simulator may account for as much as twenty percent of the cost of the engineering development model. This cost is incurred due to the legal requirement that a data package be submitted in support of competitive procurement of production models of the simulators, and to assure Army maintenance of these simulators at remote locations. In view of the limited quantity of any given flight simulator likely to be procured, and the option of the use of contract maintenance for these simulators, it is highly possible that systematic study of procurement practices would yield indications of significant dollar savings for the Army.

The approach would involve analysis of the procurement methods of the commercial airlines to determine whether such practices could suffice for the Army. Also, present Army simulator use, maintenance, and management practices would be reviewed for the purpose of identifying areas of potential cost savings. The approach would also consider the potential of developing and adapting a design-to-cost model for simulator procurement.

4. Special Purpose Hardware. The objective of this task is the development of hardware that may be appended to existing visual systems for the purpose of providing real-time displays of such items as trees, wooded areas, buildings, vehicles in order to enable a complete complex dynamic real-time scene.

Starting Fiscal Year 1979, specific computer generated imagery (CGI) algorithms would be realized into software and hardware. In Fiscal Year 1980, the effort would involve installation of the special purpose hardware. Such facilities as the Naval Training Equipment Center's AWAC CGI simulator would be used for the demonstration.

ENGINEERING DEVELOPMENT PROGRAM (6.4)

The objective of this program is to develop high fidelity, flight simulators with computerized, programmed instruction and six degree of freedom motion platforms.

1. Device 2B31 (CH-47C) Simulator. This effort is directed at developing a CH-47 simulator. This simulator includes a CH-47 cockpit, a terrain board visual system, a lower quadrant digital visual system, and a six degree of freedom motion system. Automated training features briefing, demonstration, playback, check rides, and grading capabilities. Problem capabilities include instrument takeoff and flight, VFR takeoff, approach autorotation, confined area approaches and pinnacle approaches. Special effects include

sky, cloud, haze, and limited visibility effects as well as day, dusk, and night training. This training simulator will be used in transition, combat readiness proficiency, load operations, and instrument refresher training programs at the Aviation Center and will contribute towards standardization of CH-47 aviator performance.

An engineering development model of the 2B31 device including front and lower quadrant visual systems permitting hover and sling load operations simulation will be ready for training at Fort Rucker in August 1976. Engineering development is being done on contract.

2. Device 2B33 (AH-1Q) Simulator. This simulator includes one pilot cockpit and one gunner cockpit, both driven by a single digital computer complex. Each cockpit is mounted on a six degree-of-freedom motion systems with separate instructor stations mounted on each platform directly aft of the trainee position. Two camera-terrain board visual systems (front and left side) are capable of independent or integrated operation. Automated briefing, demonstration, record, playback, checkride, and grading are incorporated. Full VFR flight includes hover, takeoff, approaches, landings, autorotation, dives from 0 to 40 degrees, and nap-of-the-earth flight. Gunnery capability includes machine gun, grenade launches, free rockets, 20 mm cannon and TOW missiles by use of helmet and telescopic sights. This device will be used in transition, weapons systems familiarization and combat ready proficiency programs at the Army Aviation Center and at selected field sites. The device permits the training of AH-1Q pilots and co-pilot gunners independently or as crews.

An engineering development model that includes both front and left side visual systems, permits training on TOW missiles and 20 mm cannons will be delivered to Fort Rucker in June 1976, for second phase operational testing. Development effort is being conducted under contract.

3. Device 2B38 (UTTAS) Simulator. The objective of this simulator is to provide UTTAS training at the Aviation Center and at selected aviation field sites. The training to be conducted in these devices will include transition, combat readiness proficiency, and instrument refresher training.

The project will be initiated in FY 1975 with the conduct of engineering and training design concept studies. Final design will await selection of a UTTAS aircraft design, but simulator procurement will be expedited by contracting for an engineering development model visual display attachment in FY 1976 and aircraft simulators in FY 1977. The initial device will be delivered to the Aviation Center for suitability testing in FY 1979.

4. Device 2B39 (ASH) Simulator. This training device will be a state-of-the-art operational flight trainer for the ASH aircraft and will include a visual system to simulate the ASH operational environment. The simulator will be used in conjunction with the operational aircraft and other training devices to provide training for ASH aircrews at the Army Aviation School and at selected aviation field units. It will be used in transition,

combat readiness proficiency training (CRPT) and instrument refresher training, and in the Army-wide standardization program for ASH qualified aviators.

Development of an ASH simulator was recommended to DA by the ASH Project Office in August 1974. If approved, development of the simulator will be initiated with an engineering and training design concept study beginning in FY 1976. Procurement of this device will be time-dependent upon the selection of an ASH design. Present projections indicate delivery of an engineering development model for suitability testing in FY 1979 and ultimately for use in aircrew training.

5. Device 2B40 (AAH) Simulator. The objective of the AAH Simulator Project is to develop an AAH simulator for use in AAH aircrew training at the Aviation Center and at selected aviator field units. This device will be used in transition, weapons qualification, combat readiness proficiency, and visual and instrument refresher training programs, and will enhance achieving Army-wide standardization of AAH aircrew training.

The AAH simulator will be capable of providing training for AAH pilots and gunners separately or as a crew. It will have two separate trainee compartments, one each for the pilot and for the co-pilot gunner. Each compartment will be modeled after the corresponding portion of the aircraft. There will be an instructor station with the controls and displays necessary to administer and monitor training. Each trainee compartment/instructor station will have its own visual display and will be mounted on a six degree-of-freedom motion system. The OFT will be driven by a digital computer programmed to perform, in addition to computations necessary for aircraft and weapons systems and environmental simulation, all operations associated with advanced training and maintenance troubleshooting features of the simulator.

The basic configuration of the AAH simulator is expected to be similar to that of Device 2B33. The AAH simulator design will make use of data generated during suitability testing of Device 2B33. The concept studies will be initiated in FY 1976 and will overlap Device 2B33 testing. A contract for an engineering development model will be awarded in late FY 1977. It is anticipated that the Device will be delivered to the Aviation Center in FY 1979 or FY 1980 for suitability testing.

SECTION VI

PLANNING AND MANAGEMENT CONCEPTS

INTRODUCTION

The purpose of this section is to present planning and management concepts that will insure an effective program for present and planned procurement, utilization, and support of Army flight training simulators and other aircrew training devices.

Development of training simulators is a lengthy process. Training requirements reflecting both the characteristics of the aircraft concerned and operational mission factors must be carefully specified. There must be a constant interaction between the aircraft developer and the simulator developer. The process itself consists of five distinct steps.

1. Step 1 - Training System Concept Design. The first step is to design a training system responsive to the training requirements associated with the aircraft. This involves the specification of training goals to be assigned to training simulators, part task trainers, and supporting devices; the definition of each simulator's configuration, its interface with other training and maintenance equipment, and design features which will assure that the intended training can be accomplished and that the simulator incorporates the latest state-of-the-art in relevant training and engineering technologies. The products of Step 1 are (1) comprehensive performance specifications for the full-task trainer and other related devices; and (2) a training plan defining how this equipment will be employed, in conjunction with the aircraft, in future aircrew training.

Experience, to date, is that a period of six to seven months is needed to assure a thorough study of relevant engineering and training technologies, review of the training mission of the proposed device, and investigation of the vehicle being simulated. It should be noted that Step 1 does not involve the development of justification for the procurement of a training simulator. Step 1 can be initiated only after the Army has already approved the requirement for a particular training system.

2. Step 2 - Contract Award. This step involves preparation of a solicitation package, obtaining proposals from potential training simulator developers, evaluating these proposals, and negotiating and awarding an engineering development contract. Based upon recent Army experience, a period of approximately six to nine months is required for this activity because of the sequential nature of the steps required to award the contract. The bulk of the activities associated with Step 2 cannot be initiated until the performance specification developed during Step 1 is completed.

3. Step 3 - Development of an Engineering Development Model. This step consists of development and delivery of an engineering development model or prototype training simulator and associated training devices

meeting the design requirements identified in Step 1. The time required for Step 3 depends mainly on the amount of new design required by the system. If little new design is required, delivery may be in as little as 18 to 24 months. Since the present state-of-the-art may not be fully developed with respect to the simulation of certain important aspects of the Army's unique mission environment, it is more likely that the delivery time requirement for each engineering development model will be 24 to 36 months.

Step 3 concludes when the new training simulator has complete final acceptance testing by the Army at the delivery site.

4. Step 4 - Operational Test. The purpose of the fourth step is to assess the training simulator's suitability for its intended role in Army training as defined during Step 1, to evaluate the effectiveness of its associated training program and to identify any deficiencies in its design which should be corrected prior to further procurement. The amount of time required to accomplish Step 4 has historically been from six to twelve months. At the end of Step 4, the initial device is available for training activities on a limited basis while undergoing any design changes resulting from findings of the operational test (OT II). In addition, a revised procurement package will have been prepared to enable the Army to obtain production models of the device which reflect the findings of these tests.

5. Step 5 - Production Procurement. Step 5 is the procurement of production models of the training simulator. If the suitability test results confirm the basic device design, initial deliveries may be obtained within 15 to 24 months. Meeting this schedule requires expeditious Army approval of the procurement plan and contract award. Should it be necessary to procure production models of the device on a competitive basis, Steps 2, 3, and 4 would probably have to be repeated, extending the time requirement by approximately 36 to 57 months.

Table VI-1 summarizes the approximate time required, following the above five-step procedure, for the development of a new Army flight training simulator. It can be seen that a minimum of 42 months should be allotted, following an Army decision to procure a particular helicopter simulator, before the initial simulator will be available for training. At least an additional 15 months will be required before production models will be available. Meeting this minimum procurement schedule requires careful management.

The importance of planning for training simulators early in the development program of the aircraft is apparent if flight training simulators are to play an effective part in flight training. Postponing initiation of the process and subsequent attempts to "catch up" have historically resulted in excess costs, overlooked training requirements and a less than optimal training system. Planning and management concepts which offer opportunities to reduce the development time while still resulting in a cost and training effective system are presented herein for consideration.

TABLE VI-1

SIMULATOR DEVELOPMENTAL STEPS AND TIME REQUIREMENTS

Step	Estimated Months Required	Accumulated Months Required
1	6 - 7	6 - 7
2	6 - 9	12 - 16
3	24 - 36	36 - 52
4	6 - 12	40 - 64
5	15 - 24*	55 - 88

*Months to delivery of the first production unit on production prototype

PLANNING CONCEPTS

A list of planning concepts is presented covering the full time span from initiation of the aircraft requirement through field support and utilization of production flight trainers.

1. Planning for New Aircraft Development. The development of the flight training simulator requirement is as important and should receive as much attention as any unit of maintenance or support equipment during new aircraft development. Development of flight training simulators and their potential utility during prototype aircraft operational testing dictates a coordinated development program between the aircraft Project Manager, the Project Manager for Training Devices, and the TRADOC user organization. A flight training simulator offers unique opportunities for test pilot familiarization pre-test exploration of the prototype aircraft test configuration and development of emergency and safety procedures. The availability of a flight training simulator and part task trainers identified for both aviator training and enlisted maintenance training at this stage offers the Army valuable insurance during the relatively risky development and operational testing of new aircraft prototypes, and at a relatively low cost. Furthermore, training simulation readily lends itself to tactics and mission development which could be accomplished prior to training mission start up.

Optimum efficiency can be achieved by tasking and funding PM TRADE for the development of the flight training simulator simultaneously with the go ahead for the prototype aircraft. This will separate the simulator development from any aircraft problems which do not directly affect its design and will add the expertise of the PM TRADE simulation personnel to the aircraft development team. A similar recommendation has been made in the USAF Five-Year Plan for Air Crew Training and is based on USAF experience with simulator funding channeled through the individual aircraft System Program

Offices (SPO's). Their recommendation is that simulator funding be directly channeled to the Simulator System Program Office (SPO).

Effective implementation of this concept will also require the simultaneous early development of the training task analysis by the TRADOC user to achieve the total development of an effective training system at a date that will provide maximum effectiveness.

2. Planning for Research and Development. Planning for research and development is currently hampered by a lack of central control and direction. Centralization of management of all R&D on training simulation is required to determine what areas are under study and what areas need future work. A multi-year plan presenting the total training simulation research program would provide the depth of planning required to insure maximum effective dollar utilization and assignment of priorities. The training simulation expertise present at PM TRADE suggest this organization as a focal point for monitoring, forecasting and planning the simulation research effort.

As is pointed out in Appendix D, there are visual simulation requirements and areas of flight training simulator development which are beyond the current state-of-the-art. To depend on the state-of-the-art to advance without directed research increases the risk to successful incorporation of new training features. This also leads to increased development time for the simulator. Only by means of a vigorous R&D program aimed directly at solving outstanding problems can the Army assure that the full capabilities of flight training simulators will be realized. Both the state-of-the-art and the particular areas needing research are highlighted in this study. As the chartered proponent of training devices and the main focal point of training simulation expertise, PM TRADE should be funded not only for specific programs, but also with block funding for projects and studies which offer substantial advantages or improvements in training capabilities when implemented immediately.

An additional planning concept for R&D involves the use of existing flight training simulators for training research, safety investigation, instructional program development and other tasks for which the existing simulators are exceptionally well suited. Based on availability and utilization, blocks of time designated for research, arranged on a not-to-interfere-with-training schedule, should be set aside on each of the aircraft type training simulators at Fort Rucker for use in research programs. Utilization of simulator time could be made available to all laboratories whose programs affect flight simulation and who could use the simulator as a research vehicle. Proper coordination of this valuable asset could result in substantial savings of R&D dollars spent for pure research simulators. For example, a benefit of the current level of high flight fidelity being procured in training simulators is that aircraft condition during emergency conditions can be duplicated exactly. Flight training simulators could be used in accident investigations to determine what actually occurred prior to an accident. Such data could lead to the development and testing of new emergency procedures and to training programs incorporating these procedures.

3. Planning for Training. Effective preparation for and utilization of flight training simulators requires a coordinated plan for the development of a complete training program and the preparation and training of the instructors who will use the equipment. Far too often a flight training simulator has been developed and then a training program designed to use it. The lack of specific training objectives existing during the design of the simulator has resulted in designs for maximum fidelity and training capabilities with the hope that the user can make effective use of them. Instead, an orderly development of a training system beginning with analysis of the training tasks and the training objectives is required. From these tasks and objectives a trade off analysis can determine such factors as the costs of various training media, student populations, instructor skill and availability, and a cost effective mix of training aids and devices. The determination of training tasks to be accomplished for each type of training device then guides the simulation designer in producing the most cost effective method of presenting the required simulation.

Figure VI-1 describes an order and hierarchy of training simulators and training devices. An understanding of the nature, characteristics and capabilities of each of the tiers of this structure is necessary to develop the most cost effective training program.

a. Aircraft. At the top of the order is the actual aircraft. Except for emergency procedures and maneuvers in unsafe flight regimes, virtually all training can be done using the aircraft as a training device. Of all the hierarchy, it is by far the most expensive to operate and maintain. Use for training removes availability and life expectancy for mission use. Aircraft should be used for training only when it is not practical, possible, or cost effective to use a lesser member of the order.

b. Mission Simulators. Mission training simulators are designed to provide full flight characteristics and weapons delivery training with out-the-window visual displays. While not true mission simulators, instrument flight trainers such as Device 2B24 are generally ranked in this category.

Within the limits of the simulation capabilities, all actions required to operate the aircraft may be trained for in the simulator. While complex and expensive, the simulator offers training economy with operating expenses one fifth or less that of the actual aircraft. Emergency procedures and high risk operations are ideal training subjects.

c. Cockpit Procedures Trainers. About one tenth as expensive as a simulator, a cockpit procedure trainer (CPT) typically provides training in start up, shut down, and emergency procedures for the simulated aircraft. The simulation characteristics are limited to those providing a feedback for training task. No visual or motion simulation are presented and automated instruction is rudimentary. CPT's offer cost effective means of partially reducing the training load on mission simulators.

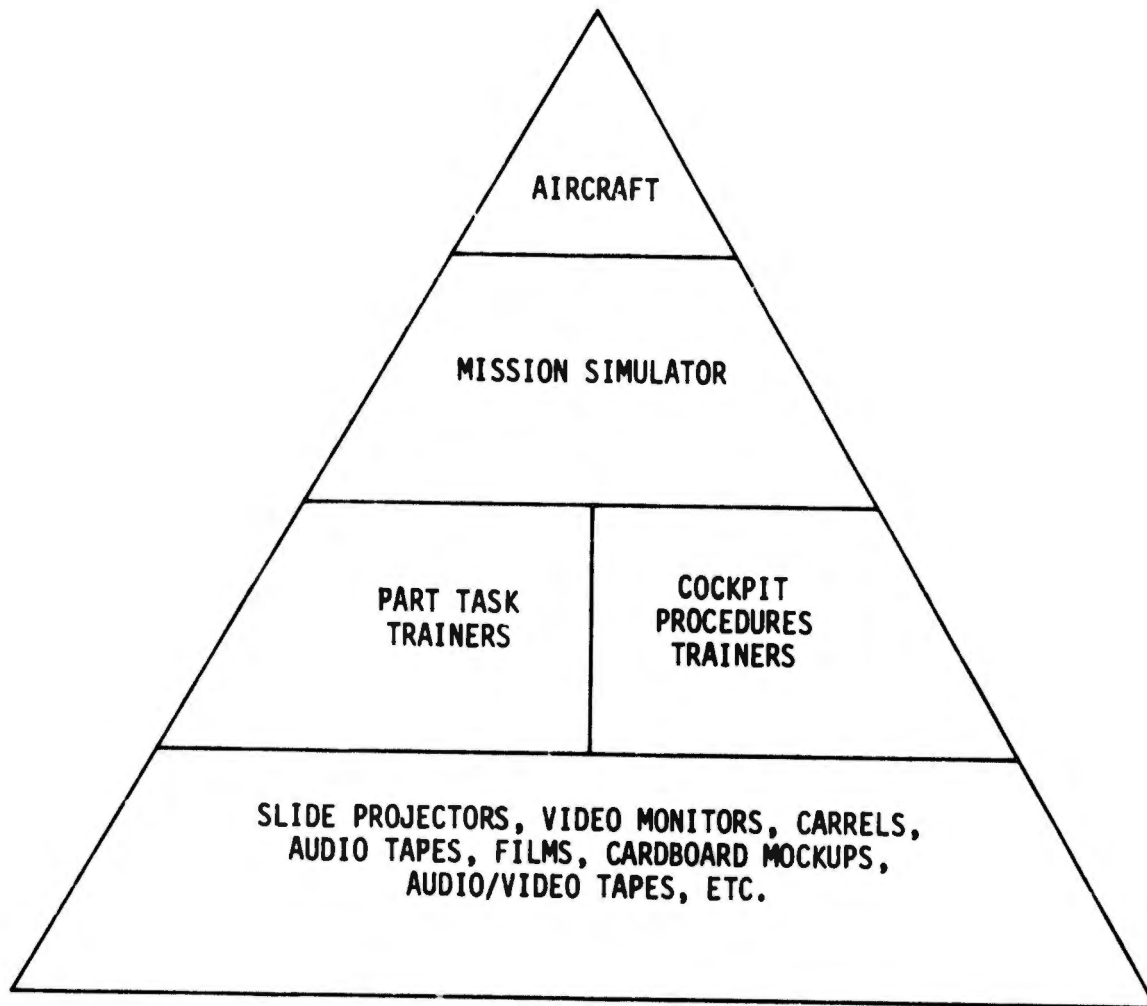


FIGURE VI-1. THE ORDER AND HIERARCHY OF SIMULATORS AND TRAINING DEVICES

d. Part Task Trainers. Part Task Trainers are incomplete simulators in that they offer capability for only part of the training task. They may range from complex weapons delivery trainers to simple cockpit familiarization trainers and their prices and operating costs range accordingly. A cockpit familiarization (FAM) trainer, for example, may cost only one tenth the price of a CPT, but can be used for training in many of the cockpit procedures in addition to familiarization.

e. Training Media. At the bottom of the order are a family of training media designed to support, enhance, or substitute for classroom ground school. Offering the most economic form of training, these media assist or relieve instructors, reinforce text materials, and provide capability for a self paced proficiency progression program.

The hierarchy of training operates on the principle that the maximum possible effective training is conducted at the lowest level of the diagram which also coincides with the most cost effective level. Close cooperation between the user organization, the aircraft developer and the training device developer is required to produce the training system design. The TRADE-TRADER interface offers a unique capability for preparation and coordinated of a total aircraft training program based on the system's approach to training and structured by the principle illustrated in Figure VI-1.

PM-TRADE assistance to the TRADOC training system developers will be required to achieve effective utilization of simulation technology in training. Sophisticated automated training features and instructor assistance programs are of little value if they are not understood or do not reflect current aircraft training philosophy.

Ideally this training system definition precedes Step 1 of the previous five steps of simulator procurement. It is estimated that 6 to 12 months may be required for task analyses, objectives determination and program of instruction concept design before TDR's can be adequately defined and Step 1 can begin.

Of equal importance to the development of the basic training program is the training program for instructional personnel that will make the training system operate. Only knowledgeable, well-trained instructors will have the ability, insight, and motivation to operate the training system at maximum effectiveness.

4. Planning for Flight Training Simulator Facilities. One of the characteristics of flight training simulators is the requirement that they be housed in a controlled environment. Control of both temperature and humidity within specified limits is required for stable operation of the digital computer system upon which simulators are based. Conversely, the requirement for controlled environment relieves the equipment designer of the need for expensive ruggedization normally required for Army equipment. Historically, flight simulators have been housed in permanent type facilities provided through base MILCON, and, historically, poor coordination of facility funding, construction, and preparation with simulator delivery has resulted in substantial expense and delay to the government when the facility was not ready for simulator delivery.

During the 1950's and 60's, attempts were made by the Navy to circumvent the problem by housing their flight trainers in mobile trailers, but subsequent studies indicated that this resulted in reduced maintainability, greater simulator expense (over 10 percent increase), prohibition of substantial motion simulation, and less than satisfactory operating conditions. In addition, the mobile feature has never been used without the requirement for complete refurbishment of the simulator.

Coordination of facility planning can best be achieved by delegation of responsibility to PM TRADE. By developing standard facility designs and making maximum use of multiple device facilities for sites where future requirements for additional flight training simulators are known to exist, maximum economy and efficiency may be achieved.

5. Planning for Maintenance and Support. The life cycle for the SFTS devices is estimated at fifteen years. A wide variety of simulation equipment is projected for the program, including state-of-the-art digital and visual technology. To realize optimum performance and return on investment, life cycle support planning must be flexible to meet the initial technical requirements, as well as the long range stable operational period.

Substantial savings can be achieved in the procurement of flight training simulators by taking advantage of maintenance and support capabilities that already exist. The current and projected policy for flight simulator maintenance and support is through the use of contract personnel. By planning for a life cycle of contractor support from the beginning of the program, costs incurred or planned for parts and maintenance data items may be avoided or greatly reduced since these data are required to adhere to strict government formats which are not used under the contract or support concept.

During the initial years of operation, for each device in the SFTS inventory, a history of required maintenance tasks, associated costs, and spares usage will be maintained. This data will aid in continuing the most cost effective life cycle support philosophy and will be used during subsequent years contract negotiations.

Planning considerations for maintenance and support can only achieve maximum effectiveness when integrated into the life cycle plans for the training system. An effective system for life cycle planning and management is proposed in the following sections.

MANAGEMENT CONCEPTS

Of prime importance to the management of flight training simulators is the acceptance of the concept that a flight training simulator is a unique type of equipment, substantially unlike other Army commodities. It, therefore, requires treatment different from normal Army commodity management if it is to be developed, procured, supported and maintained in an efficient and cost effective manner. Creation of a separate Project Manager for Training Devices is official recognition of the uniqueness of training devices.

Characteristics of flight simulators which highlight their uniqueness are: (1) relatively few copies of each device type with high dollar value;

(2) extreme device complexity with maintenance requirements beyond the capabilities of the standard Army maintenance technician abilities; (3) operation in controlled environment for training missions only and normally not in combat areas; and (4) susceptibility to a substantial number of changes during their lifetime to accommodate aircraft modifications or variations in training program methodology. Continuity of management philosophy throughout the life cycle of a flight simulator is necessary to achieve maximum cost and training effectiveness. The management concepts presented herein can lead to maximum training effectiveness.

1. Centralization of Training Simulator Management. A study of Device 2B24, based on a 15 hour annual training requirement per aviator, has shown decentralization of training simulator locations to be cost effective. Increasing the number of hours through the creation of additional training capabilities for this device would swing the cost figures more in favor of simulator dispersion. Future mission training simulators such as Devices 2B31 and 2B33 are designed to present continuous training opportunities for maintenance of proficiency and therefore gain increased utilization through location at the highest concentration of aviator populations. Recognizing that the required support for the SFTS program will cover many military installations throughout the world under various commands, it is important to establish a policy of centralized management and decentralized execution both for Army flight training program and contractor support services.

Since it is presently planned that at least one unit of each type of aircraft training simulator procured by the Army will be located at Fort Rucker, that site should coordinate training on simulators, develop standardized training programs for use with all SFTS subsystems, and conduct device validation, assessment and certification.

2. Utilization and Training Management Concepts. If one thinks of "simulators for research" instead of research simulators, a quick appreciation for the value of the unused training time is gained. Many of the research projects described can be performed on the existing SFTS flight training simulators as well or better than they could on specially designed research simulators. As examples of possible uses, all training program research or flight training research could use these devices without any requirement for modification. Indeed, research on the automatic performance assessment and training features of a given simulator would probably require the use of that simulator only. Most of the research projected could be conducted on Devices 2B24, 2B31, and 2B33 if adequate access to them could be assured. The visual systems on Devices 2B31 and 2B33 and the existence of flight training simulators with full motion and computational capacity offer opportunities to accomplish this needed research with significant cost reductions. In addition, the Army Agency for Aviation Safety and Aeromedical Research Laboratory of Fort Rucker have proposed programs which could efficiently use existing simulators. The full mission training simulators also offer opportunities for development of aircraft tactics for areas such as weapons delivery, air to air combat and terrain avoidance training and use of new aircraft weapons and avionics.

Proper management of training simulator time will develop blocks of available time for this research in such a manner as not to impact priority training programs but still significantly improve simulator utilization.

Further increases in training utilization could also be obtained by shifting all non-mission assigned aviator training to simulators. That is, all qualified aviators whose present assignment is of a non-flying nature could maintain their rating and meet annual qualification requirements using flight simulators only. The capability of training simulators under development such as Devices 2B31 and 2B33 and a potential configuration of Device 2B24 with a visual attachment for maintenance of flying proficiency should be demonstrated by means of a carefully structured research program.

3. Validation, Assessment, and Certification. Present practice is to type classify all flight training simulators as standard (STD). This practice is not only costly and inefficient, but under effective implementation of life cycle contract maintenance, a flight simulator will never meet the criterion of AR 71-6 paragraph 1-3d. This criterion states that "...the elements of integrated logistics support will be used as the basis for assessing the readiness of the system for type classification STD" cannot be met since the support data package need not be procured to Army standards. The intent of type classification is to insure that the product is operable, maintainable and meets all the specification and training requirements. This requirement must be met. However, other means of achieving this goal result in more meaningful data at a lower cost and in less time.

The most meaningful operational test for a flight training simulator is the operational suitability assessment in which the training value and transfer of training are assessed using the training program developed for the new training system. An efficient method of determining and reporting this information would consist of assembling a team of PM TRADE and USAAVNC people. PM TRADE can prepare the final results report simultaneously with the preparation of the data package for the Development Acceptance IPR. All personnel would be familiar with the operation of the training simulator and the results could be obtained in a time frame which would shorten the interval before initiation of limited production. At the same time, experience in the characteristics of the new device would be gained by the USAAVNC personnel who would be responsible for future re-validation and certification of the flight characteristics of the training simulator.

Another factor mitigating against a standard (STD) type classification designation for flight training simulators is the amount of change normal to such a device over its lifetime. Changes resulting from aircraft modification, weapons system addition, avionic improvements or training program modifications sometimes affect flight trainers to the extent that substantial changes to such modules as the device computer may be required. This procedure for type classified equipment is complicated, costly, and unwarranted for the limited number of simulators.

Testing efficiency can be improved with accompanying cost savings if flight simulators are recognized as a special category deserving of a limited production (LP) classification. In addition to the test procedure detailed above, a special team consisting of qualified test pilots would perform operational tests of the flight characteristics of the simulator and certify each device as to its acceptability relevant to the design basis aircraft. Furthermore, a special inspection and validation team from the USAAVNC would travel to all flight simulator sites to perform an inspection of the configuration, utilization and availability of the simulator and revalidate its certification status. Through this method the configuration, performance, and training capabilities of the equipment can be maintained at a high level and confidence in the training effectiveness of each simulator will be enhanced for both instructor personnel and trainees.

The Navy has developed a certification concept which has brought about substantial improvements in the flying qualities of flight simulators and greatly enhanced their user acceptability. A team was formed consisting of aircraft fleet pilots, test pilots, flight engineers, computer specialists and simulator specialists. Conventional flight test methods were used to obtain flying qualities data from instrumented aircraft. After the flight data is collected, the training simulator is similarly instrumented and the tests repeated. After the data are reduced, the simulation software program can be corrected to match the aircraft data and the revised program verified by the test pilots. The fidelity improvement concept was applied to two simulators, Devices 2F101 and 2F90 and in both cases substantial improvement in fidelity was obtained, followed by an immediate increase in simulator acceptance by the user.¹

Implementation of this concept would allow Army certification of the flight fidelity of its simulators, establish a data base for annual revalidation checks and provide a plan for incorporation of flight test data in simulators of aircraft still under development. This latter is especially important since the requirement schedules for the UTTAS, AAH, and other new aircraft make it likely that the training simulator will be fabricated before the actual flight test data is fully developed.

4. Procurement Management Concepts. The limited quantity of each type of flight training simulator procured and the technical complexity involved in the simulation program virtually mandate a single contractor for the total procurement of each device. The Army may still obtain the benefits of competitive environment by requiring competition on the engineering development model and including design to cost criteria with purchase options for the total basis of issue in the initial contract. Using a

¹CDR M.D. Hewett, CDR J.C. Murray, and Mr. R.T. Galloway "On Improving the Flight Fidelity of Operational Flight/Weapons Systems Trainers." Paper presented at the 7th NTEC/Industry Conference, Orlando, Florida, 19-21 Nov 1974.

contractor support arrangement for the life cycle of the simulators, data requirements can be substantially reduced and data can be procured in contractor formats in compliance with DoD Data Management Guidelines. The close management scrutiny of PM TRADE will further insure that the Army's simulator dollars result in the most cost effective training system.

Although the training simulator development steps and time requirements previously shown in Table VI-1 show a minimum of 42 months to make a first unit available for training, options are available to reduce the time cycle provided that the need is sufficient to balance the risks and costs incurred. One option could utilize a sole source contract for the total procurement of a single device based on the superior capabilities of a single contractor to meet the Army's requirements. This option may reduce Steps 2 and 3 by three to six months, but could result in increased costs because of lack of competition. Another option involves contracting for the total system development, including Step 1. If the development model and its contract definition are contracted for using a cost type contract with production based on a design to cost basis, the contractors ability to participate in the program development from the onset and to advance-order long lead items as they are defined could lead to reductions of as much as 12 months from the 42 month cycle.

Reductions in the time to procure production models can be obtained by authorizing the contractor to proceed with ordering long lead items prior to completion of Step 4. Based on preliminary evaluation of the engineering development model during Step 3, determination can be made of the amount of hardware redesign which may be required by the operational assessment. If hardware changes are minimal, the contractor may be permitted substantial head start in production with only slight risk of costs incurred because of further changes.

5. Maintenance and Support Concepts. The maintenance support of the 2B24 subsystems at USAAVNC has been performed by the Support Operations group of the present contractor. Currently, there are six devices at the site. This support contract is managed by the USAAVNC at Fort Rucker. During this time, device utilization requirements have increased from an initial eight hours per day to the current 15 hours per day for three cockpits and 12 hours per day for the fourth cockpit on each device. Although contracted to deliver at minimum 90 percent availability for these utilization schedules, Table VI-2 shows that over 95 percent has been achieved while the contract support cost for each hour of cockpit availability has been continually reduced. This support base offers the optimum means for expansion to include the field sites of Device 2B24 and future SFTS subsystems.

In developing the management and contractual control of the "Contract Support Service" a single contract approach should be employed. This allows the contractor to reduce the administrative and management burden within the support operation. It also allows the cost efficiencies of centralized spares procurement, personnel acquisition, and training within the program, without conflict between several separate support contracts.

In this approach, a single contract would be issued for support of all the units of a particular subsystem such as Device 2B24 including those at field sites as well as those at Fort Rucker. Further consolidation can be made where the same contractor has developed more than one subsystem. While all subsystems of the SFTS, to date, have been procured from a single source, this approach does not preclude maintenance contracts to more than one contractor should the competitive market result in another manufacturer building a subsystem for one of the current development helicopters. All units of that subsystem would still be covered by a single support service contract with that contractor, administered by the USAAVSCOM.

The contractor base operation for the 2B24 support is shown in Figure VI-2. This would have to be expanded as required to meet the overall SFTS requirements and to supply those support functions which are more efficiently performed at a central location rather than disseminated throughout the program.

TABLE VI-2

2B24 AVAILABILITY AND SUPPORT COSTS

Period	Devices	Availability	Contractor Cost/Cockpit Hr
2/71-3/72	Dev. Unit	97% (Approx)	\$32.00
3/72-10/72	Dev. Unit	97% (Approx)	29.45
10/72-1/73	Dev. Unit	97% (Approx)	19.85
1/73-6/73	Dev. Unit	97.88% *	19.85
7/73-6/74	Dev. Unit	97.93% *	18.57
	Prod. Unit 1 (3/15/74)		
	Prod. Unit 2 (5/15/74)		
7/74-10/74	Dev. Unit	97.24% *	12.50
	Prod. Units 1 & 2		
	Prod. Unit 3 (7/15/74)		
	Prod. Unit 4 (9/1/74)		
	Prod. Unit 5 (10/15/74)		

*Actual availability data

Some specialized repair which requires specific skills and test equipment should continue to be handled within the base operation for all field units, the primary category being instrumentation.

By handling most spares acquisition through the base support facility, experience gained concerning qualified vendors, cost, and availability

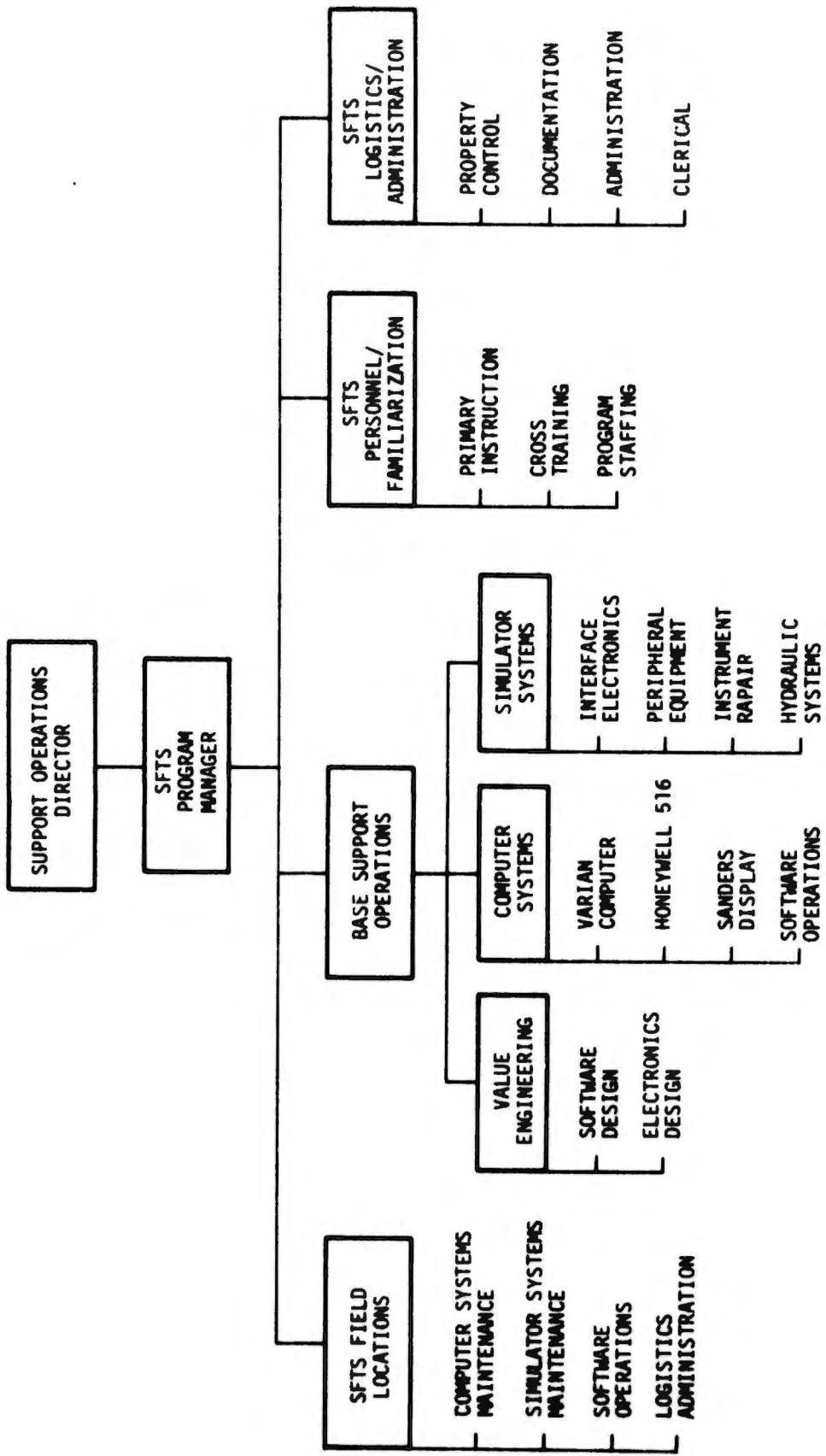


FIGURE VI-2. CONTRACTOR SUPPORT OPERATIONS FOR DEVICE 2B24 (Example)

along with the efficiencies of quantity purchase for a large program will yield the most cost-effective and responsive spares procurement. During the initial years of device support, continuing consideration should be given to spares usage parameters, availability of vendors, and possible procurement of special or unique items for long range needs. This area should be monitored closely by the USAAVSCOM to insure a flexible posture towards completing the service contract or developing an in-house capability.

All support manpower acquisition and maintenance training for the SFTS program should be handled through the contractor base support operation. This will allow the flexibility to establish and replace, if required, the necessary technical skills at each SFTS location. A formal and on-the-job training activity, established at Fort Rucker for the 2B24 program should be expanded to cover the additional devices as they are developed within the SFTS program.

This single contract principle and the associated base support operation provides an inherent configuration management point and a capability to minimize program engineering change proposal (ECP) costs. Within the base operation, the contractor must supply highly competent technical personnel to handle several functions:

- 1) Stand-by coverage for the operational shifts at the USAAVNC.
- 2) Primary familiarization instruction and cross-training for field engineers assigned to the program, for both Fort Rucker and the field sites.
- 3) On call emergency assistance for field locations. This level of technical capability, within the program, is required to meet the contracted availability parameters. Since the productive man hours associated with the above mentioned tasks are flexible, there will be some time which can be applied to the design and checkout of ECP requirements.

Handling ECP activity through the support contract not only economizes on available manpower but also takes advantage of the lower overhead and administrative burdens and procurement costs within the support activity. All required ECP action can be directed to the contractor support group for investigation and evaluation as to make or buy recommendations. The Configuration Management activity at USAAVSCOM will then provide the direction for implementation. Some ECP's may be subcontracted to the appropriate vendors for completion but many may be handled within the contractor support program at a significant savings to the Government.

By using the contractor base operation for this activity and applying the appropriate Government surveillance and approval, configuration management of the SFTS program can be maintained.

While the actual administration of the support and maintenance contract would be through USAAVSCOM, guidance and support from PM TRADE through ATDA will allow maximum continuity for support from the beginning of the planning cycle and take maximum advantage of the cost savings that can be obtained

by recognizing the implication of the contractor support system and incorporating the many cost saving opportunities in contracts through the life cycle of the project.

SECTION VII

RECOMMENDATIONS

EXPLORATORY DEVELOPMENT PROGRAM

At present there is no approved exploratory development (6.2) program pertaining to the Synthetic Flight Training System (SFTS). The initiation of such a program is considered to be of highest priority. Section V of this Plan describes eight tasks which were determined, from the survey conducted, to be of fundamental need to further advances desired for the SFTS.

The tasks are as follows:

1. Visual Simulation Analysis. The goal of this research is to determine whether new developments in visual simulation techniques have cost-effective potential for Army aviation training. It is recommended that this effort be implemented in fiscal year 1977 and updated in following years. The majority of this effort will be performed by in-house personnel at the Army Training Device Agency.

2. 360 Degree Annular Visual System. The goal of this research is to enable the eventual production of a non-programmed, real-time, wide-angle dynamic visual display for systems of the SFTS. It is recommended that a feasibility study be undertaken for a new type of lens developed by the U.S. Naval Training Equipment Center (NTEC). This effort, funded by the Army, would be conducted by NTEC under contract.

3. Wide-Angle, Laser-Scan Visual System. This effort is an alternate approach to the goal of achieving a non-programmed, real-time, wide-angle, dynamic visual display. It is recommended that in view of the importance of such achievement this and the preceding approach be carried through technical feasibility demonstration. Upon completion of this both methods will be evaluated to determine that which has the most cost-effective potential. The technical feasibility effort would be conducted under contract.

4. Improvement of Training Programs Through Incorporation of Accident Research Results. The goals of this research are to determine which of the factors underlying accidents may be minimized through training, equipment, and procedures and to incorporate these changes into existing and proposed systems of the SFTS. Since the research effort requires the use of simulators with visual displays as well as without visual displays, the major portion of this research cannot be done until the mission type simulators, the 2B31, and 2B33, and a visual equipped 2B24 are made available. Since these would not be available until late calendar year 1976, it is recommended that the initial efforts of this task consist of developing detailed task statements and performing preliminary checkout testing in available 2B24 devices. This effort will be coordinated with the U.S. Army Agency for Aviation Safety.

5. Aviator Target Identification, Acquisition, and Training Research. The goal of this research is to enhance the capabilities of the SFTS for training in detection and identification of targets, both camouflaged and uncamouflaged. It is recommended that this effort be coordinated with the U.S. Army (Aeromedical Research) Laboratory.

6. Computer Animated Visual Research. Computer animated visual techniques will be developed to provide a simulated visual scene with the flexibility and realism of a camera-model system but without the use of a model board and without the vehicle path constraints of a film system. Existing hardware will be updated and modified to investigate the computer controlled animation of multiple still visual scenes to simulate non-programmed visual flight. Efforts will be directed toward nap-of-the-earth (NOE) flight and the insertion of tactical targets. During the fiscal year 1979 a systems design analysis will be conducted to investigate computer animation techniques to simulate non-programmed visual flight. Alternate techniques for the simulation of NOE flight and insertion of tactical targets will be analyzed. The techniques with the potential to be most cost-effective will be developed and integrated with existing hardware for test and evaluation. During fiscal year 1980 the breadboard system will be updated to simulate high speed NOE flight with tactical targets.

7. Special Purpose Algorithms for Computer Generated Imagery. The effort includes a study of the feasibility of achieving real-time generation of portions of displays that may be appended to a general scene to provide a complete complex real-time dynamic scene for sensor displays, simulated operational displays, and tactical displays. The effort will determine what general purpose scene displays or portions of displays could be generated by specific algorithms in real-time, and an analysis of the advantages and disadvantages of using such means for generating portions of the display, that is, trees, wooded areas, buildings, and vehicles. The feasibility study would be conducted during fiscal year 77 and the development of the cost effective algorithms would be started in fiscal year 78.

8. Instructor Station Design Research. The effort will include:
(a) A review of research and development relevant to the design and use of instructor consoles with emphasis on instructor stations for mission simulators; (b) The conduct of a series of experiments in existing simulator facilities; and (c) The validation of design criteria for instructor consoles. In FY 77, a study will be made of instructor pilot usage of consoles. This effort will require nine man-months. The follow-on efforts will be programmed for FY 78. It is anticipated that efforts will be continued beyond FY 78 to ascertain criteria for advanced flight training simulators for the UTTAS, AAH, and ASH aircraft.

ADVANCED DEVELOPMENT PROGRAM

At present the approved advanced development program includes the following three projects:

- Visual Systems Research
- Research Conducted with Simulators
- Device Management and Application Studies

For fiscal years 1976 and 1976T, it is recommended that five tasks be implemented under these three projects.

Under the Visual Systems Research project, the following two tasks are recommended:

1. Definition of Visual Systems Criteria. The goals of this effort are to develop design specifications for a visual systems research tool. In conjunction with the development of these criteria, fields-of-view requirements relevant to Army rotary wing aircraft will be defined. This effort would be performed on contract and would be initiated in fiscal year 1976.

2. Feasibility Demonstration of Wide Angle Visual Systems. This effort would be the "breadboarding" phase for the follow-on to the wide-angle visual exploratory development effort. The effort would be conducted on contract and would be initiated during fiscal year 1976T.

Under the Research Conducted with Simulators project, the following two tasks are recommended.

3. Development of Automated Training Techniques. The goal of this task is to develop training programs for validating and exploiting the automated training features of present and future subsystems of the SFTS. This effort would be conducted under contract and would be initiated in fiscal year 1976.

4. Development of Automated Performance Measurement Techniques. The goal of this effort is to develop automated performance measurement techniques that will provide meaningful and valid assessment of trainee capabilities. This effort would be conducted under contract starting in fiscal year 1976.

Since these two efforts must be closely coordinated, it is recommended that both tasks be considered as a single contractual effort. During fiscal years 1976 and 1976T, the effort would not require the use of simulators. Starting in fiscal year 1977 sufficient data will have been developed to allow the validation of the data and programs which does require the use of simulators to be initiated.

Under the Device Management and Application Studies project, the following three tasks are recommended.

5. Part-Task Trainers Study. An analysis of existing part-task trainers is required to ascertain whether the designs are compatible with the desired training objectives. It is recommended that a study be initiated in fiscal year 1976 under contract to determine the extent to which these devices

reflect the state-of-the-art in relevant engineering and training technologies. The results of the study will furnish criteria for developing cost effective designs for general type aviation training devices.

6. Programming Language Study. Development of a higher level programming language will permit a reduction of programming costs. Development is also important due to the much reduced time for programming enabled by use of such a language. The results of the study would include identification of critical problem areas in programming the advanced systems of the Synthetic Flight Training System, and would include the impact of such application upon the cost of computer hardware.

7. Procurement Practices Study. It is anticipated that this systematic study of procurement practices will yield indications of significant dollar savings for the U.S. Army. The effort will include analysis of the procurement methods of commercial airlines to determine whether such practices are applicable for the U.S. Army. Also, present Army simulator use, management, and maintenance practices would be reviewed to ascertain the areas of potential cost savings. The study would also consider the potential of having a design-to-cost model for simulator procurement.

In addition to the above described seven projects which are approved, it is recommended that the following project be implemented starting in fiscal year 1979.

8. Special Purpose Hardware for Computer Generated Imagery (CGI). In fiscal year 1979, specific computer generated imagery (CGI) algorithms would be realized into software and hardware. In fiscal year 1980, the effort would involve demonstration of the special purpose hardware and software.

ENGINEERING DEVELOPMENT PROGRAM

It is recommended that one minor change be made to the approved engineering development program denoted in Section V. It is planned that the AAH Simulator design will make use of data generated during the suitability testing of Device 2B33. This testing is now anticipated as starting on or about October 1976. Thus, the funds programmed for AAH concept studies in fiscal year 1976 should be reprogrammed to fiscal year 1977 thus permitting advantageous use of the 2B33 data.

PLANNING AND MANAGEMENT

The most important planning recommendation is that detailed coordination procedures be formalized to assure that simulators are considered at an early stage in the development programs of new aircraft. This planning must also include consideration of part-task and cockpit procedures trainers in order to develop an optimal training system. So that maximum utilization may be made of the expertise of PM TRADE, that office should be the focal point for planning the simulation development effort. In

order to facilitate such planning. PM-TRADE should be funded for the specific programs under consideration. PM-TRADE should also have a block funding in order to expedite the implementation of needed studies and/or projects, the results of which offer substantial potential improvement to the Army's training capabilities.

In Section VI, it was indicated how substantial savings may be achieved by making use of contract personnel for simulator maintenance and support. It is strongly recommended that this policy be projected for the five year period FY 1976 through FY 1980. By planning for a life cycle of contract support, costs incurred or planned for a number of maintenance data items may be reduced or eliminated.

APPENDIX A

COCKPIT PROCEDURES AND PART-TASK TRAINERS

COCKPIT PROCEDURES TRAINERS

The Army presently uses Cockpit Procedures Trainers (CPT's), as do the other military services and the commercial airlines, to qualify and transition aviators in the operation of transitorial and new aircraft. These devices have generally provided effective training at reduced costs.

Prior to flight training in a new aircraft or a sophisticated flight simulator, student pilots should receive cockpit familiarization and operating procedures instructions. In addition to learning the locations of instruments and controls, the students will develop proficiency on various procedures including engine startup and runup, inflight emergency actions and aircraft shutdown procedures. In the past, procedures training was accomplished using actual aircraft on the ground and in flight. This was expensive and made the aircraft unavailable for other flight training. With the introduction of CPT's, the required skills are taught economically and safely, with reduced loss of aircraft flight training time. A representative listing of skills to be acquired through use of CPT's is at Table A-1.

In the past, training of each student using the OV-1 and U-21 aircraft involved a total of 25 hours. This was comprised of 2½ hours of procedures and configuration familiarization training and 22½ hours of actual flight instruction. Through the use of CPT's and 2½ hours of procedures and configuration familiarization training is accomplished at a considerable cost savings and in a more efficient manner. This allows the entire 25 hours in the OV-1 and U-21 to be devoted to flight instruction which increases the effective utilization of the aircraft training by 2½ hours or 10 percent.

At the Aviation Center, Fort Rucker, the UH-1H CPT Device 2C35, has been introduced recently in the first phase of instrument training. Following completion of primary flight training and preceding the 20 hours of instrument training he receives in the 2B24 simulator, each initial entry student is given an eight hour introduction to the UH-1H helicopter in the CPT. There are eight of these devices used in conjunction with the 2B24 at Fort Rucker.

Actual dollar savings realized through effective use of CPT's by the Army is not firmly established. However, as an example, training in the 2C35 CPT costs approximately \$6.00 to \$8.00 per hour excluding instructor costs. The costs per training hour for the 2B24 and UH-1B are approximately \$38 and \$238 respectively. Use of the 2C35 for eight hours at a net savings of \$30 per hour results in savings of approximately \$240 per student. An even greater saving is realized by making more hours available in the 2B24 for its primary purpose, instrument training.

TABLE A-1

SKILLS ACQUIRED DURING CPT INSTRUCTION

1. Cockpit orientation and familiarization
Location and function of all instruments, indicators, controls, and other cockpit furnishings.
2. Normal procedures
 - A. Check seat and pedal adjustments, belts and harness
 - B. Perform all prestart checks
 - C. Perform engine start procedures
 - D. Perform engine runup
 - E. Establish engine settings for takeoff, climb, cruise, descent, go arounds, and landings.
 - F. Control and monitor flight instruments through takeoff, climb, level flight, pitch, roll, and bank maneuvers, descent, and landing.
 - G. Perform engine shutdown
 - H. Operate auxiliary systems
 - a. Electrical
 - b. Engine and pilot anti-ice
 - c. Flight
 - d. Fuel
 - e. Communications (radio, intercom)
3. Emergency Procedures
 - A. Execute procedures for aircraft fire on the ground and in the air.
 - B. Execute emergency exit procedures.
 - C. Execute emergency/malfunction procedures.
 - a. Engine failures, before takeoff, during takeoff in the air
 - b. Engine airstart
 - c. Fuel system failure
 - d. Electrical system failure
 - e. Communication failure

Ideally, CPT's should be developed and procured jointly with flight simulators and the corresponding aircraft so that all three can be integrated into the flight training program. When this can not be accomplished, it is important to procure additional funds for the required CPT's to insure training and cost effectiveness. It is clear that CPT's will continue to play an increasingly important role in the Army's aviation training program.

Cockpit procedures trainers consist of three major interdependent components: The trainee's station, the instructor's station, and the control equipment. The training effectiveness of the configuration depends heavily on the simulation fidelity of the trainee station, and the flexibility with which the instructor can monitor and control the training situation.

The trainee station is so designed that the interior appearance and layout conform to the aircraft simulated. All instruments, indicators, gages, controls, lights, panels, consoles, circuit breakers, switches, marking, seats, cockpit shell, and other furnishings of the aircraft cockpit for the pilot and co-pilot are included in the trainer cockpit either as actual aircraft parts or replicas. Dimensional relationships are maintained with all components located in corresponding positions. Mechanical, electrical, and other controls respond to trainee manipulation with the counter forces or "feel" of the aircraft. Flight and other controls, the actions of which vary with operating conditions, respond like the aircraft. The indicators in the trainer respond realistically to control settings and reflect the status of the various systems being simulated.

The instructor station provides a means of monitoring, controlling, and assessing trainee performance, by the instructor, for each of the skill areas described in Table A-1. The station includes duplicate instruments, override controls, and provides for the introduction of malfunctions or emergencies in the student cockpit.

The estimated unit costs of developing a cockpit procedures trainer (CPT) for each of the aircraft under consideration in this report are indicated in Table A-2. Estimates are provided separately for the trainer and for the documentation typically procured with such equipment. The costs indicated for the trainer include a complete, full-scale representation of the simulated aircraft's cockpit to include all panels, instruments, controls, seats and other components; a computer programmed to provide full aircraft and engine simulation of non-flight dependent procedural tasks (including approximately 30 abnormal or emergency conditions); and a simplified control loading system. No MCA funding requirements exist specifically for these devices since they usually will be housed in facilities constructed for the simulators they support.

PART-TASK TRAINERS

Part-task training is defined as, practice on any aspect, phase or dimension of a task, procedure or work cycle which is independent of the rest of the work content inputs or work content outputs. Total task training can occur in the operational situation or in a complete simulator.

TABLE A-2

1974 COST OF CPT PROCUREMENT
(Thousands of Dollars)

Aircraft	Trainer	Documents	Total
UTTAS	240	75	315
AAH	260	80	340
HLH	350	90	440
ASH	220	60	280
CH-47	340	80	420
AH-1Q	240	70	310

Much of the research in part-task training and whole task training has been related to flight training. Considerable research is needed in determining requirements for training devices to teach maintenance skills for different types of aircraft. Maintenance training devices such as electrical systems, trainer hydraulic systems trainers are fabricated and procured in much the same fashion as they were in WW II. Programmed instruction techniques have not been developed to where they are acceptable at most of the service schools for maintenance training. It is the exception rather than the rule to attempt the development of a new concept for maintenance training. In general, maintenance trainers are procured on the basis of prime system contractor recommendations with little or no regard to job analysis or the system's approach to training.

There are new concepts in learning diagnostic procedures for maintenance training. A general purpose maintenance trainer with a mini-computer has recently been tested at the transportation school. The evaluation of this trainer which was used in the OV-1 Airframe Repair Course 67H20 concluded that those students who were trained with the simulator obtained higher scores than those who were trained using conventional methods (Ref. USA TRANS School Research Memorandum 3-75).

Maintenance trainers for the AH1G cost \$3.6M in FY 68. It is a reasonable assumption that trainers for the UTTAS and AAH will nearly double if they are procured in the same fashion as the AH1G. It appears that for a relatively modest investment of R&D funds, the potential exists to save several millions of dollars in the procurement of maintenance trainers.

TABLE A-3

CURRENT MAINTENANCE TRAINERS
COST SUMMARY

System	Number of Different Devices	Total Cost
OV-1	9	1,103,163
UH-1A/B/D/1d	11	2,042,828
AH-1G	7	3,604,325
CH-47	10	2,476,690
OH-6A	6	456,504
OH-58A	7	933,344
CH-54A/B	11	2,395,016

APPENDIX B

COMPUTATIONAL TECHNOLOGY OVERVIEW

INTRODUCTION

Simulation for training has several very important aspects that differentiate it from design simulation and/or simulation for operations research. In simulation for design or operations research it is possible to concentrate on a very special or particular aspect of the total simulation problem and perform simulation in non-real-time, i.e., one second of wing flutter may be calculated in several hours or vice versa several hours of space flight may be simulated in seconds. The purpose of the simulation is to obtain many and accurate answers under varying conditions. In simulation for training, with the trainee in the loop, the calculations generally cover the complete flight regime or the total simulation problem including errors, malfunctions, emergencies, and so forth rather than any narrow aspect, and the solution must be completed in real time, i.e., twenty seconds of flight must be completed in no more and no less than twenty seconds, also the answers need be only accurate enough to provide adequate simulation for training.

This real-time restriction imposes severe conditions on training simulation. Aircraft simulators particularly, and many others as well require extensive computation to accurately simulate the training situation. As had been indicated earlier, numerical methods are employed to solve the continuous equations of motion. In order to solve them in real-time and to provide adequate simulation, the solution rate must be fast enough to provide mathematical accuracy and also provide for smooth output indications on instruments and controls. Complex or extensive numerical methods, which provide very accurate answers, may be inappropriate because of these restrictions of calculation time. Therefore a choice must be made of a numerical method which can be calculated rapidly yet which will provide adequate accuracy. Another complication of the solution rate restriction is that the utmost efficiency of programming and machine instruction utilization must be effected to complete the calculations in one cycle time. This often precludes using sophisticated languages which are less efficient and calculated in several hours or vice versa several hours of space flight may be simulated in seconds. The purpose of the simulation is to obtain many and accurate answers under varying conditions. In simulation for training, with the trainee in the loop, the calculations generally cover the complete flight regime or the total simulation problem including errors, malfunctions, emergencies, and so forth rather than any narrow aspect, and the solution must be completed in real time, i.e. twenty seconds of flight must be completed in no more and no less than twenty seconds, also the answers need be only accurate enough to provide adequate simulation for training.

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The remainder of this report will provide more complete descriptions of the problems associated with digital computers in simulation for training. The report will describe the computer requirements in simulation, a brief explanation of computer system architecture, the computer hardware and software, and some of the problems of standardization.

COMPUTER REQUIREMENTS IN SIMULATION

1. Range of Simulation Problems. System simulation has long been used as a tool for engineering analysis and design. Electronic analog computers, for example, can simulate the behavior of many systems described mathematically by sets of differential equations. These include electrical, hydraulic, chemical and physical systems of interest in engineering and technology. With the introduction of the digital computer, the range of problems amenable to analysis through simulation has been greatly extended. Systems whose mathematical description is beyond the capability of the analog computer may be simulated using digital techniques. Digital simulation of many types of systems has been accomplished to assist in the design and evaluation of such systems.

System simulation is by no means limited to the design of systems. Indeed, such activities as marketing, the scheduling of work in manufacturing plants, the management of a business, the elective process and war gaming (e.g., the Army's new combined Arms Tactical Training System, CATTs) for which no precise mathematical formulation is known, can be simulated by using statistical and empirical models on a digital computer. Such simulations are performed to determine the probable effect of a proposed course of action or to develop a plan or strategy most likely to achieve desired objectives. For example, the optimum location for new retail stores can be estimated by simulation of local and regional consumer patterns.

A significant simulation application is that used to train personnel in the performance of hazardous and stress-inducing activities using digital computer activated training devices. Such training simulators make it possible, without risk to life or property, for trainees to become proficient in skills upon which their survival and well-being may some day depend. In this category are aircraft trainers of all types, submarine trainers and space-mission trainers used by both military and civilian activities. Such trainers enable both the military and major civilian airlines, for example, to familiarize their pilots with the routine and emergency operation of new aircraft even before the new planes are put into service.

The growing use of the digital computer and the entire field of digital computer technology for system simulation for training has led to the development of specialized techniques, especially of computer programming, that are not common to other simulation or processing methods. Real-time simulation, especially, poses problems of timing, numerical techniques and program organization that are not encountered in general scientific or business computing. In real-time simulation the computing of simulated system responses must be accomplished as rapidly as the actual system would itself respond. For example operational flight trainers, which must realistically reproduce the performance of a modern aircraft in response to a trainee who is manipulating the controls are typical of modern real-time computer controlled simulators.

2. Mathematical Models. Since the major capability of the digital computer in a simulator is to evaluate arithmetic and logical expressions, the problem to be solved must be translated into a form that can be solved by arithmetic and logical operations. A military vehicle or a physical situation to be simulated must be reduced to a set of mathematical relations between the operator inputs to the system and the desired response. The complexity of these relations ranges from turning on an indicator when a switch is thrown to representing the motion of an aircraft as a function of both pilot inputs and environmental conditions.

Development of a mathematical model requires analysis of the function of each switch, knob or lever operated by the trainee. The designer must decide which of the controls in the actual system must be simulated and the degree of simulation required for each. For vehicle simulation, the time-dependent equations describing the vehicle motion must be derived. This requires dynamic test data for the vehicle for the entire range of operation to be simulated.

The complexity of the mathematical model used in vehicle simulation depends upon the completeness and fidelity of simulation needed for the particular training application. In weapon systems simulation where vehicle motion is not under control of the trainee, essentially steady-state motion with realistic transitions to changes in speed, course and altitude may be sufficient. On the other hand, simulation of an aircraft for pilot training requires a set of equations that relate the throttle, stick, and rudder control inputs to aircraft motion for each different flight regime and configuration that will be used in the training exercises.

3. **Solution Techniques.** The solution of equations in a real-time simulation imposes requirements that are different from those present in the non-real-time scientific computation. In real-time simulation, the computer must respond to non-predictable external inputs and must solve these equations fast enough and often enough that the man recognizes them as occurring in real time. Numerical methods used to solve the differential equations representing vehicle motion require step-by-step solution of the equations at fixed time intervals. It is not possible to vary the time interval to retain a given accuracy as is possible in non-real-time solutions. The designer must preselect an interval that will give the desired accuracy for all conditions. This does not mean that all equations in a simulation be solved at the same rate. However, it does require that the equations be classified by solution sets and that each class of equations be solved at its appropriate rate. For example, the solution of aircraft motion might be performed 20 times per second, whereas the engine response might be handled only 10 times per second. In a simulator that includes a visual display, solution rates as high as 30 times per second have been found necessary.

4. **External Interfaces.** The external interfaces required to connect a digital computer to a simulator system can be divided into three types: (1) the normal input-output (I/O) interface used to perform data transfers between the computer and the usual peripheral devices (e.g., card reader and line printer); (2) a special I/O interface to allow transfer of discrete (e.g., switch closure information) and analog (e.g., control stick position) signals between the simulator and the computer; and (3) a direct access to the computer's main memory by special peripheral devices that require a high data rate. Figure B-1 shows a block diagram of a computer with all these types of interfaces.

In the modern digital computer, all three types of interfaces work on a cycle-stealing basis. That is, a transfer via the I/O interface, once initiated, proceeds at a rate fixed by the external device without any further intervention by the digital computer. Thus, transfers require computer time only for initiation and for the time delay encountered by conflicting requirements between computer and I/O devices for access to storage.

5. **System Architecture.** The system architecture for a simulator encompasses the configuration of the digital computer itself, the arrangement of I/O interfaces to communicate with devices external to its computer itself, and structuring of a simulator system to include sharing of the computation load between computers or using one computer to drive several simulators.

GENERAL-PURPOSE DIGITAL COMPUTERS

The general-purpose digital computer can be divided into four major parts: (1) arithmetic element, (2) control logic, (3) storage, and (4) I/O interface. A block diagram of a typical digital computer is shown in Figure B-2. The arithmetic element is the computational unit - it performs the required

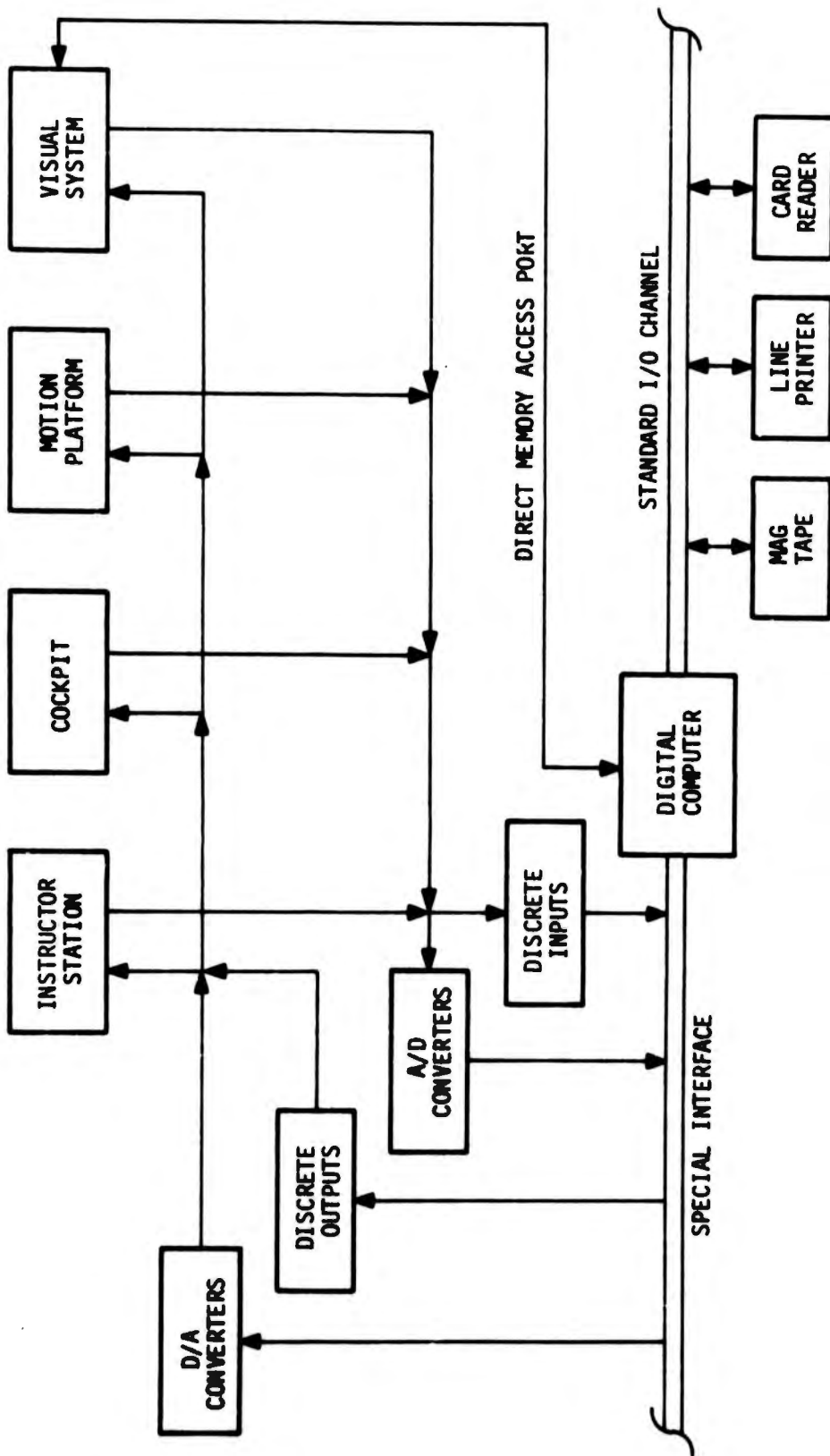


FIGURE B-1. SIMULATOR BLOCK DIAGRAM

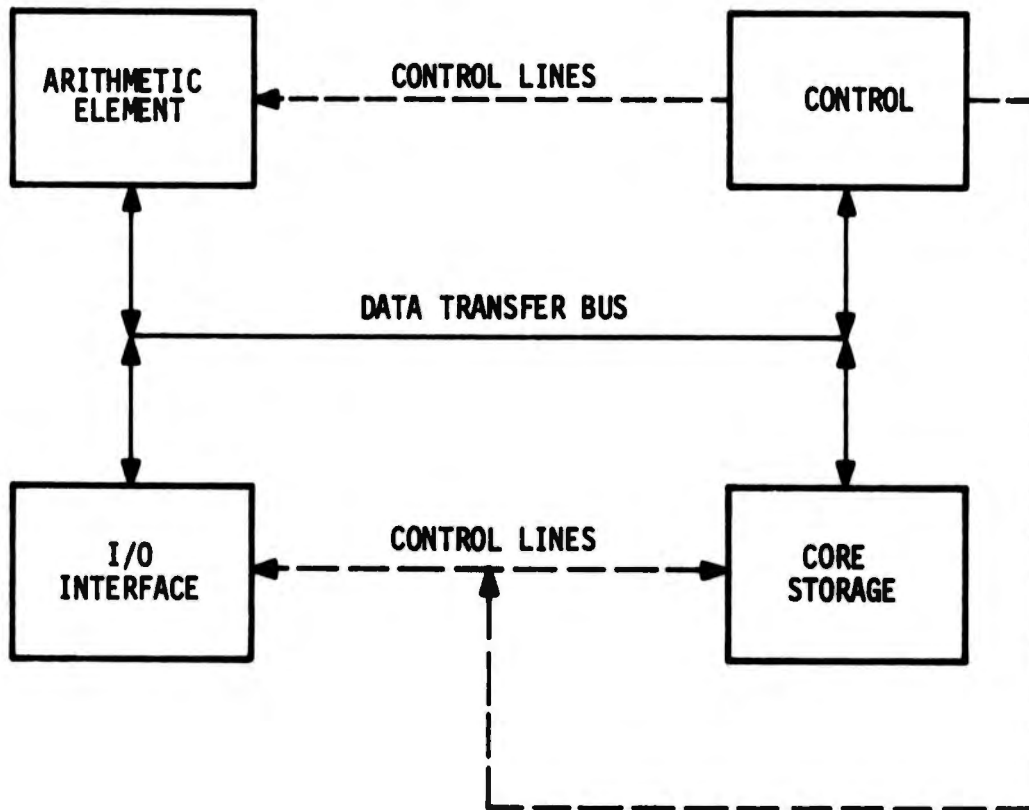


FIGURE B-2. COMPUTER BLOCK DIAGRAM

operations and holds the result. The storage is used to hold both data used in performing computations and the list of instructions the computer is to perform. The Control Unit provides the signals needed to retrieve instructions from storage and cause them to be executed. The interface allows communication between the computer's storage and external devices.

Instructions in the digital computer can be divided into three major classes: (1) computation (including storage and retrieval of data); (2) initiation and monitoring of I/O operations; and (3) changes in control sequence. The ability of a digital computer to store the instructions to be performed and to alter the sequence and choose which sets of instructions are performed is the key to the computer's flexibility. It is this decision process that makes it possible for the computer to solve complex problems.

1. Computer Parameters. The important parameters in choosing a computer to solve a real-time simulation problem are related to the ability to solve its problem within the allowed time period and to communicate with the rest of the simulator. A major parameter is storage size - the storage must be large enough to hold the instructions needed for the simulation, the data necessary, and any working space needed during the problem solution. The parameters associated with storage are word length, access time, and number of words.

The major parameters associated with the arithmetic unit are word length, instruction repertoire, and instruction execution time. These determine how fast the computer can solve a given problem. The word length required in a simulator is typically 16 bits (equivalent to 4 or 5 digit accuracy). Some operations require more accuracy, but these can be handled by using double precision computation (using two computer words to represent a value). The penalty paid for this is additional time needed to compute a double precision value. In those cases where use of a 16-bit word makes a large number of double-precision operative necessary, it may be better to use a 32 bit machine.

The instruction repertoire has a major effect upon the time required to solve a problem. For example, multiply and divide instructions are not essential to the problem solution, because either can be programmed by using add, subtract, and compare instructions. However, these instructions are essential in most real-time simulators, because the time required for programmed multiply and divide a prohibitive. Real-time simulation puts a premium upon an instruction repertoire that performs the arithmetic and logical operations required by hardware.

The instruction execution time for a computer is determined by its internal hardware - circuit capability and memory cycle time. A figure of merit is the "average" instruction execution time. This must be based upon an appropriate mixture of instruction types (e.g., 40 percent add/subtract, 20 percent multiply, 40 percent logic) selected to represent the problem to be solved. Since the mixture can be chosen to reflect the need for

double-precision operations, it gives a valid means of comparing machines having different word lengths as well as different instruction repertoires and execution times.

The I/O capability of a computer can be measured by the number of I/O channels available and the maximum data transfer rate over each channel. The designer must select a computer that provides a data transfer rate high enough for its particular application. In addition, the designer must insure that the required transfer rate can be met while executing the computer program at the required rate. Since the instruction execution time and the I/O channel transfer rates do not account for waits caused by conflicting requirements for access to the same storage, the designer must weigh the effect of the interaction.

2. **Microprogramming.** Microprogramming is a technique by which a computer is programmed in terms of steps more basic than the usual instruction level. For example, a normal add instruction requires several steps such as: retrieve operand from storage, add operand to contents of arithmetic register, access next instruction, etc. Microprogramming allows the programmer to generate a particular instruction repertoire tailored to the problem to be solved.

Microprogramming adds a dimension to programming between that of normal hardware and software. It is implemented by "firmware" in the form of a replaceable control module inserted in the computer hardware. Thus, the alteration of the microprogram is more complex than changing the instructions in a program, but it is less complex than redesigning the hardware. Microprogramming provides a capability particularly useful in real-time simulation for tailoring the computer to the application.

3. **Processor Configurations.** The basic system configuration for a computer in a simulator was described earlier (see Figure B-1). It consists of a digital computer with interfaces to both standard computer peripherals and special equipment needed for real-time simulation. The system illustrated uses one computer to solve one simulation problem.

4. **Multiprogramming and multiprocessing.** When more than one problem is to be solved (e.g., two separate aircraft simulations) one computer can be used to solve the entire problem. However, the designer must take into consideration the additional conflicts in storage access created by such a use.

Another alternative in configuring a computer system is to use multiple computers to solve a single simulation problem. Such an arrangement is made attractive by the small, low-cost minicomputers available. In a multiprocessor system, the storage is usually arranged so that each computer has its own private storage and also shares a bank of common storage with the other computers. The common storage provides a convenient way for the computers to exchange information and allows the external interfaces to be connected to a common storage unit.

Multiprogramming and multiprocessing can be combined in a single simulator. For example, a system can be configured to use two computers to drive four separate cockpits for aircraft simulation. The designer must make the choice, remembering the major restrictions imposed: (1) multiprogramming increases the possible conflicts in access to storage, and (2) multiple processors add a burden in control and synchronization of the problem solution.

HARDWARE

1. Logic Circuits. Logic circuits perform the many two-state functions required to implement the logical organization of a digital computer. As the development of the transistor progressed, so have the switch-type circuits which have been termed logic circuits. Basically, the elementary logic circuit is a high speed solid state switch. Its operation manifests itself in one of two conditions, either fully off or fully on (for saturating switches). These two mutually exclusive states can be used to represent either a "0" or "1" in the implementation of computer logic.

Early developments provided packages of transistors which were externally connected to discrete components (i.e., resistors, diodes, capacitors) to define the several logic circuit types. The next step in logic circuit development was to create the equivalent discrete component function as an integral part of the device and these were termed microcircuits.

Processing (or computer) requirements dictated the development of logic circuits whose switching speeds increased dramatically. For example, microcircuits of the older DTL (Diode Transistor Logic) configuration had the ability to change states (fully on to fully off or vice versa) in about 1 microsecond or less. When the TTL (Transistor-Transistor Logic) configuration was developed in microcircuit form, it provided two orders of magnitude improvement in switching speed (approximately 10 to 50 nanoseconds). Microcircuits in the ECL (Emitter-Coupled Logic) configuration can switch at speeds of less than 5 nanoseconds.

The rapid advances in computer hardware technology (particularly in microcircuit technology) permitted several independent microcircuits to be grown on a single silicon wafer or chip. In the standard 16 pin DIP package (Dual In-Line Package) it is customary to provide various combinations of logic circuits (e.g., 4 - two input gates, or 2 - four input gates, or two J-K type flip-flops, or 6-single input inverters and the like). This added a new dimension to the physical packaging problem in that it required fewer external interconnections for power and ground. The next obvious step was to "grow" large numbers of logic circuits on a single silicon chip and to define various fundamental logic functions for a single chip by providing the interconnections directly on the chip. Such logic functions as sums of products and product of sums, decoding matrices, storage registers, etc. are typical of this type. These arrays are termed Medium Scale Integration (MSI). A computer designed around MSI still requires external interconnections to form the overall arithmetic logic, control logic, and in some instances the various registers and data paths.

Probably the most significant advancement in microcircuit technology in the past three years has been that of Large Scale Integration (LSI). With this technique the logic of an entire processor, or of a complete arithmetic-logic unit, etc., is provided on a single chip.

The advent of MSI and LSI has radically changed the design approaches of digital computers. A dramatic decrease in physical size is now feasible. The cost of such units in quantities has been significantly decreased to a point where it now becomes cost-effective to implement in logic hardware special arithmetic and logic functions which formerly were accomplished in software. The entire field of portable and hand-held commercial electronic calculators is a direct fall-out of the development of LSI.

There is a definite design trend in the computer industry toward application of LSI. The so-called microprocessor is implemented with LSI and in some instances MSI is also utilized where special functional requirements are needed.

Use of MSI and LSI is revolutionizing computer designs, since they provide a solution to one of the most significant design problems and technical risks of the past - that of high speed switching noise. The problems of transients and cross-coupling on and between interconnecting leads is eliminated or reduced to manageable proportions since a majority of the external interconnecting wiring is eliminated with LSI. The reliability of computers will be increased and their maintainability improved since an entire function can be defined as the basic replaceable element.

2. Microprogramming. A significant trend in computer technology and design in recent years has been the replacement of the conventional wired logic control section of a digital computer with "stored logic" or microprogrammed control, stored in a very high-speed, non-destructive read-only storage or memory (ROM). A main reason for this shift in computer design and implementation technique is the superior cost effectiveness of microprogramming over conventional logic control (e.g., a control unit implemented with hard-wired logic elements). Microprogramming has made it economically feasible, for example, to build the same comprehensive instruction repertoire into an entire family of new computers, even the smaller ones. This results in having a family of computers that are architecturally and software compatible; yet their internal hardware (gates, flip-flops, etc.), logical organization and system architecture are radically different.

The flexibility of microprogrammed control permits architectural extensions and modifications that will make a given computer system perform certain data processing, computing and control functions with maximum efficiency.

A digital computer in its simplest terms can be described as an elaborate array of logic elements forming networks and called data paths. These data paths consist of such items as adders, shifters, indicators, registers, parity circuits, priority circuits, decoders, Boolean functions

and the like. The interconnections of the data paths contain many control gates that permit the information to flow between these functional units. All these data paths are static in nature and can be activated by logic control signals originating in the computer control section. It is the sequencing, timing and synchronizing of the timing and control signals (pulses) as modified by the control section which directly controls the computer. In the conventional general purpose digital computer, these functions (as microsteps) are implemented in wired logic hardware for each instruction. The sequence of the micro-operations can be defined in terms of computer states, that is, the suboperations on each data and control path that are carried out during each machine cycle during each instruction execution.

In a microprogrammed computer, the various machine states or control of the various states to execute the desired function is vested in binary "data" stored in a ROM (read only memory) and not in hard-wired gates, flip-flops, inverters, etc. The prescribed sequence of such stored "states" controls the machine states and thereby synthesizes the various instructions to be executed.

Primary advantages of microprogramming are the simplicity of computer hardware (less components) and the inherent ability to synthesize almost any instruction and thus emulate another computer.

The ROM storage unit of a microprogrammed computer can be implemented in several ways. Most frequently, the information stored has been permanently fixed in a ROM, and a change requires that a new ROM must be made. The use of Random Access Memory (RAM) permits the change of micro-code by rewriting the contents of the RAM.

3. Storage Techniques. Storage technology and techniques for modern high speed digital computers encompasses a wide spectrum of types and devices. Types of high speed storage (memory) include magnetic cores, metal oxide semiconductor (MOS), and solid state devices. Although the MOS and solid state memories provide higher speeds, both are volatile (i.e., the stored information is lost when power is turned off). The magnetic core provides non-destructive storage. Information stored is not lost when power is turned off. Because it is non-volatile and also more reliable, magnetic core storage is preferred over solid-state storage in training simulators.

Bulk (or mass) storage devices for computers consist of punched tape, magnetic tape, fixed head magnetic disc's and moving head disc-pack systems. In a number of applications several of these devices also serve the function of input-output media.

For training device applications where program storage requirements do not exceed 20,000 instructions, punched tape is completely adequate in providing program read-in capability in a reasonable time. Magnetic tape is preferred for trainers with more than 20,000 instructions, because of its faster transfer rate.

Disc storage is available in fixed-head or moving-head units. The moving head disc provides greater storage density and a lower cost per bit than fixed-head discs. The price paid is slower access to data, lower reliability, and higher maintenance for the moving-head units. For these reasons, use of moving-head discs is often limited to storage of data bases so large that use of fixed-head discs is impractical.

Storage capacities of fixed head discs units range up to 5 or 6 megabytes (million bytes), whereas moving head disc pack units can store up to 45 megabytes on a single unit.

Magnetic tape is an excellent medium for library type storage for I/O functions. Federal Information Processing Standards presently cover plug-compatible tape units with a bit packing density of 800 ppi, NRZI (non-return to zero inverted) with minimum tape speeds of 45 inches per second. A single 2400 foot 10 inch reel of tape can store 23,000,000 USASCII characters.

4. Peripheral Devices. In a computer system peripheral devices provide the input-output capability. The present day peripheral devices in common usage are; the paper tape reader, the paper tape punch, the magnetic tape unit, the high speed line printer, the low-speed teletype device which has not only a low speed printing capability but also a manual keyboard.

Depending upon the particular system requirements a CRT display system and other devices such as plotters, etc. are also special I/O peripherals. Frequently, the digital information outputted from the computer must be converted to analog form or to a form for driving a synchro unit. The digital-to-analog, analog-to-digital, digital-to-synchro and synchro-to-digital converters are also special peripheral equipment.

There are two addition peripheral devices which are becoming available. They are a tape cassette and the flexible disc (called the floppy disc). Because of the relative newness of these two devices, there is a lack of performance and interfacing standards when compared to other peripheral units. The cassette tape is a low speed high density recording-playback medium which more than likely will replace punched tape in many applications. The floppy disc has the physical appearance of a smooth phonograph record. The information is stored in minute magnetic groups on the surface of the disc. The floppy disc has a reasonable storage capacity but the access time is long since the disc rotational speed is not as high as that of a fixed head disc or a moving head disc pack. Physical and electrical tolerances must be wider and this also contributes to the lower data storage capacity.

Both the magnetic tape cassette and the floppy disc require some testing, evaluation and standardization of characteristics before they should receive universal application to trainers and simulators as I/O (peripheral) devices.

SOFTWARE

The programming of a computer to perform its role in a simulator system is usually more complex and more costly than configuring the system and purchasing the computer. In procuring a simulator, great emphasis must be placed upon defining the problem and the software support required to solve the initial problem and to allow future modifications to the program.

1. Software Definition. Software design begins with a definition of the problem and the operating environment. The functions to be performed by the computer must be specified in a mathematical model. The inputs available and the outputs required must be specific in terms of sampling rate, scaling, and form in which the data is available.

The size of the program needed in a simulator makes it necessary to divide the total program into sections, with each part specified in terms of its own inputs and outputs. These parts are usually represented by flow charts indicating the major steps in performing the computation needed to solve the problem.

Once the program has been flow charted, the steps indicated in the flow charts must be translated into the individual machine instructions to be executed by the computer. Test and checkout of the software is done in several steps: (1) individual modules, (2) groups of program modules, (3) the entire program with simulated inputs, and (4) the entire program operating with the actual hardware. The complexity of the program testing needed is indicated by the software costs involved. In many cases, more than 50 percent of the total software cost is incurred during integration of the software into the actual simulator.

2. Programming Languages. Programming languages have been developed to allow the programmer to specify the instructions to be executed by the computer in a more convenient form than the instructions recognized by the computer hardware. If the programmer had to specify each step in the program in terms of binary operation code and operand address used by the machine, it would be impractical to solve many of the problems now solved by digital computers.

a. Assembly Language. The first step in the development of programming languages was the introduction of the assembly language. This allows the programmer to use mnemonic codes to represent the instruction and alphanumeric symbols to represent the operand address. The symbolic address is particularly useful, because any program change that inserts an instruction in a sequence alters the address of each subsequent instruction. Without symbolic addressing, a trivial program change can make a massive alteration of the programming code necessary.

The assembler relieves the programmer of much of the clerical work associated with coding, but it still requires a knowledge of the machine language of the computer being programmed. The need for a knowledge of the machine code is inconvenient, but an even greater problem is that assembly

language precludes use of program written for one computer on some other computer.

b. High-Level Languages. The machine dependence of assembly languages have led to a variety of programming languages that are machine independent. These are characterized by design for a specific application. Each different language has a notation closer to the problem to be solved than to the repertoire of a computer executing the program. It allows portability between computers as long as the programmer follows the syntax of the standard language and there are no discrepancies in data configurations in the various machines. Another factor affecting portability for real-time programming is the execution time for a program. Since execution time is not a part of the language definition, there is no way to guarantee that execution times on various computers will even be the same order of magnitude.

In spite of these shortcomings, high-level languages have a place in simulation. These ease in learning the language, coding and understanding, debugging, and maintaining and documenting programs make high-level languages useful in coding programs for real-time simulation. The restrictions in high-level languages presently available make it necessary to use assembly language in conjunction with a high-level language to create an efficient real-time program. The result is a computer program for the target computer - one that is not useable on a computer of another type. However, it is generally less expensive than one written entirely in assembly language.

3. Operating Systems. Execution of a complex computer problem requires a program structure that is controlled by an executive program. In non-real-time systems, this executive handles the scheduling of different jobs and performs utility services such as initiating and controlling input and output operations. Real-time simulators require the same functions, though to a lesser extent. The availability of utility programs is a major consideration in hardware selection, since it has an impact on programming cost and schedule.

In particular, use of peripherals that allow interaction with the real-time program and the display of selected data about the student performance (e.g., keyboard entry devices with CRT displays) requires support software. Unless such utility software is available, the addition of peripheral devices to a computer system is both expensive and time consuming.

4. Documentation. Adequacy and standardization of software documentation has long been a problem area. Traditionally programmers do not adequately document their work in forms which can be readily understood even by other programmers.

A significant step toward defining, standardizing, and requiring adequate digital computer program documentation is specification of the way that a contractor must organize, manage, and execute the work. Current trainer procurements are requiring the contractor to design software in

well-defined steps from basic system analysis through programming and coding and finally to systems integration and acceptance. Requiring documentation, with customer approval at each step, provides a complete software picture for design review and customer control of the software design process.

STANDARDIZATION

1. Hardware. There have been many attempts to standardize computer hardware. The military departments (notably the Navy) have to a certain extent standardized computers (main frames, memory, etc.) and some peripheral devices. The most recent examples are the AN/UYK-7 and the AN/UYK-20 computers built by Univac for the Naval Tactical Data System (NTDS).

Commercial standardization has been limited predominantly to the so-called plug-compatible peripheral devices such as magnetic tape units, disc drives, line printers, ASR and KSR 33 and 35's, communication line modem interfaces, and the like. Some companies offer memory modules which are also plug-compatible with various main frame (CPU) models. Obviously, standardization of main frame characteristics would not be acceptable commercially because of competitive factors. A basic problem even with the military standardization efforts is the fact that the development and the tendency to extend operational use to benefit from standardization increases the life time cycle to a point where obsolescence becomes a problem. In addition there are many training simulator requirements that the military-standard computer cannot meet - particularly in real-time processing capabilities.

The microprogramming approach derived from commercial computer technology developments offer a means of achieving standardization. Microprogramming allows different computers to be programmed in the same way to produce the same result. The near-term objectives of current research in this area are to reduce the number and types of computers in the training device inventory and reduce life cycle and logistic costs by commonality of spares, documentation, maintenance and operator training.

2. Software. Standardization of computer languages in the computer industry has been limited to a few compilers such as FORTRAN. Standardization of assembly level languages (and machine codes) has been limited to a particular manufacturer's family of similar computers (e.g. Xerox Data Systems Sigma Series, IBM 360-370 series, etc.). There has been no attempt to standardize machine codes for this would be tantamount to standardizing computer main frame hardware.

The American National Standards Institute has undertaken to standardize information interchange alphanumeric codes (the familiar USASCII codes) in order that peripheral code formats and communications terminal equipment codes interfaced with computers would be standard. Even so, the entire computer industry has not fully accepted the USASCII standard.

Each computer manufacturer has his own operating system design which will handle his computer languages and programs. Although software operating systems are similar in functional organization and capabilities, their

specific implementation is peculiar to a given line of computers. There is no transportability between computers of different manufacturers.

Even though the higher level languages, e.g., FORTRAN, COBOL and ALGOL have been standardized in their syntax, the exact implementation is different not only in terms of the computer hardware required for their operation, but the implementation is also different depending upon who designed the compilers and did the detailed coding. For such reasons, transportability of programs coded in those languages from machine type to machine type is almost impossible to achieve without some modifications. The run time of programs compiled from these high level languages is quite a variable because their exact coding is a variable. Therefore, it is not possible in many instances to program software for real-time execution on one machine and expect to achieve the same run time by compiling it for a different machine. It is for these reasons that standardization of computer languages for either commercial or simulator applications has not been entirely successful.

SPECIAL-PURPOSE COMPUTERS

Special-purpose computers are used in simulators to solve problems where the solution rate exceeds the capability of general-purpose computers. Applications such as voice generation, speech recognition, and radar and visual simulation require such special hardware.

1. Voice Systems. Some training systems require voice communication with the trainee that is simple enough to be done by a computer. For example, in training a pilot to make a ground-controlled approach (GCA) for landing, the function of its ground controller can be replaced by a computer-controlled voice generator. In training a ground controller to give instructions to an approaching aircraft, a voice recognition system can be used with a computer to simulate the aircraft response to the trainees instructions.

The above applications of voice generation and recognition are within the state-of-the-art because the GCA controller uses simple phrases from a standard vocabulary. Application of voice devices to less restrictive training application requires further research into some basic properties of speech and general pattern recognition.

2. Sensor Simulation. Realistic portrayal of radar, infra-red (IR), and low-light-level television (LLTV) displays available in aircraft is a major problem in simulating weapons delivery vehicles. Such simulation requires: (1) a data base describing the characteristics of the gaming area for the training problem, (2) a data retrieval method for insuring that the part of the data needed for the computation is immediately available, (3) a computation system to transform the raw data into the form needed to drive a suitable display, and (4) the display unit. The block diagram for a sensor simulation system is shown in Figure B-3.

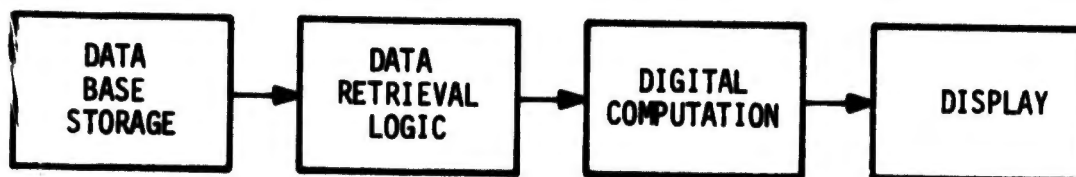


FIGURE B-3. SENSOR SIMULATOR SYSTEM BLOCK DIAGRAM

The primary requirements in implementing a sensor simulation system are: (1) a mathematical model of the physical phenomena, and (2) a data base containing the information needed to apply the mathematical model. As in most simulator applications, the mathematical model and data base used are chosen with consideration of the degree of realism required for a particular training application and the system cost.

Because radar has been available longer than IR or LLLTV and is simpler to model, radar simulation technology is much farther advanced than IR or LLLTV. Radar simulators are part of several training systems; whereas, IR and LLLTV simulation is still in research and development.

a. Radar Simulation. The mathematical model for radar simulation is well-known. The radar return from an object in terms of its radar reflectance properties can be calculated. Systems using tri-color or black-and-white photographic transparencies to represent land mass (data on terrain elevation and reflectivity at points on the earth's surface) have been in use for more than a decade. In these systems, information read from the transparency is processed by analog computation to provide the signals to drive a simulated radar display. These systems have been generally satisfactory for radar training at high altitudes.

Simulators using transparencies do not provide the radar training capabilities required for newer weapons systems. A particular problem is the simulation of radar effects at low altitudes. Major defects are inadequate presentation of cultural features, unrealistic simulation of terrain-following radar, and difficulty in updating the data base.

Digital radar land mass simulation (DRLMS) techniques offer a way to correct these deficiencies. Digital methods allow input data to be stored with various degrees of resolution and in an easily updated form. Specific low-altitude effects can be inserted in the data and tailored to match the true picture. The DRLMS systems already developed have demonstrated an improvement over simulators using transparencies, and it is expected that all future RLMS will be digital. However, there are still technical problems in developing a DRLMS that universally duplicates all radar system capabilities. Major problems are low-altitude effects that are dependent upon characteristics of man-made objects and adequate data to satisfy the capability of storage for flight-resolution radar.

b. Infra-Red (IR) Simulation. IR simulation is more difficult than radar simulation to achieve, because the information content in an IR picture is greater. Targets not apparent on a radar display produce specific "signatures" in IR. Since local temperature and the moisture content of an object have a pronounced effect on its IR emission, IR simulation is dependent upon weather and time-of-day.

Further research in IR simulation is needed to develop techniques suitable for training. Work to be done includes mathematical modeling and derivation of a data base. Since IR has greater information content and higher resolution capability, the computation techniques used in radar must be improved before they can be applied to IR.

c. Low-Light-Level Television Simulation. LLLTV simulation may be even more complicated than IR simulation. In addition to being more dependent on aspect angle and environment than IR, it relies on an illumination source dependent upon reflections in the surrounding environment.

3. Visual Simulation. Visual simulation is one of the most difficult problems in the design of trainers. The sensor system described above are limited in both field-of-view available and information content compared to that which a human operator can perceive. The visual problem requires a substantially larger data base and means of retrieving and processing more information than is necessary for the sensors using electronics. For the purpose of describing computation requirements, it is convenient to divide visual simulation systems into those using computer-generated imagery (CGI) and those using other methods of providing information about the visual scene.

a. Computer Generated Imagery. CGI systems present a more complex data processing problem than sensor simulators, because of the greater amount of data to be handled. The mathematical model is well known - individual elements in a visual scene can be described in terms of planar surfaces specified by location of vertices and color of surface. If the size of individual elements is made small enough, a picture representing an actual view of a scene can be generated. However, generation of such a sequence of pictures within the time constraint imposed by simulation for training is beyond the state-of-the-art.

The CGI systems used in present-day simulators provide much less detail than a real scene. This gives a cartoon-like presentation, adequate for some training situations but not satisfactory for others. A typical result of the lack of picture detail is that the velocity and position cues that would be available in a real picture are not present. As a result, the trainee must rely on other information (e.g., aircraft instruments) and therefore operates a simulator differently from the way he would operate the real vehicle.

b. Other Methods of Visual Simulation. Other methods of visual simulation (e.g., model boards, holography) can provide more detail than CGI. These methods are described in Appendix D. The computation problem

associated with these systems is essentially that of providing position, heading, and velocity information to a separate device. Where characteristics of the device are known, additional computations may be required to compensate some short comings in the visual device. However, this does not add a significant computation load for a general-purpose computer. In general, visual simulation other than CGI is not constrained by limits in the computer state-of-the-art.

4. Synchronization of Stimuli. A simulator supplies stimuli to the student by various means. In a flight simulator, the pilot may have aircraft instruments, motion curs, visual scene, radar, etc. Each of these stimuli is incorrect to some extent, but each one is within an accuracy deemed adequate for training. However, unless special care is taken, the various systems may give conflicting cues. For example, a visual simulator and a radar simulation may each be adequate when used alone. Since the two use different input data, the scenes portrayed by the two systems may give conflicting information.

APPENDIX C

RESEARCH AND DEVELOPMENT OVERVIEW

INTRODUCTION

This appendix presents summaries of relevant flight training simulation research and development efforts in progress or proposed by DoD and NASA.

The general direction of on-going DoD programs is to make use of advanced simulation technology to support new weapon systems by the use of engineering simulation, and to provide the capabilities for training in simulators. The services have been aggressive in utilizing computer technology for sensor simulation, visual displays, motion systems, and as instructor aids. In addition to the programs related to weapon systems, the services are building advanced simulators to develop and evaluate the newest technology.

The Air Force is conducting research and development in support of simulator procurements in two major areas. The first is R&D into improved methods of simulation and the second is aimed at improving the fundamental understanding of the training process as influenced by simulator capabilities and instructional strategies. Exploratory and advanced development programs for training equipment are conducted by the USAF Human Resources Laboratory (AFHRL). AFHRL/AS at Wright Patterson AFB is responsible for simulation equipment research while AFHRL/FT at Williams AFB is responsible for flight training research.

Navy programs emphasize the development of real image visual display systems and deal with a complete range of Navy pilot training tasks including aircraft carrier takeoff and landing, field takeoff and landing, formation flying and weapons delivery. On-going development programs vary from refinement of conventional visual simulation subsystems such as camera-model board probes, zoom lenses and wide-angle projection lenses to new concepts such as laser holographic displays, crossed-scan TV rasters, insetted high resolution TV rasters, and panoramic TV projectors.

The Navy's advanced development program places emphasis upon developing synthetic targets for use with operational radar, sonar, and electronic warfare equipment, the development of a tactical simulation technology for the conduct of wide-scale fleet exercises, the providing of experimental model investigations of visual presentations suitable for flight training and the development of a methodology for a generalized maintenance trainer.

The Navy's engineering development program places emphasis on supporting identified requirements for large training systems. The program includes generalized maintenance prototypes, training prototypes, operational training equipment in radar, electronic warfare and sonar, and damage control. The efforts represent a maturing of technology to the point of engineering development.

The Army's programs are oriented to producing cost-effective training simulators for such missions as air-to-ground weapons delivery, air-to-air gunnery, nap-of-the-earth flight, and low level navigation. Key programs are aimed at developing technology in such areas as wide field of view with high resolution in color, and data storage to describe large geographical areas in great detail and in color. The major effort is directed at component research which will lead to high fidelity flight simulator training systems with motion platforms, computerized instruction, and keyed to nap-of-the-earth flight, both day and night.

The general direction of NASA's on-going simulator programs has been to use advanced simulators for aeronautical research activities. The effort directed to development of simulation technology per se has been small. Some analytical and basic experimental programs to develop the techniques for modeling the response of the pilots have been supported, which could ultimately have an application to simulator design. These latter activities have a broad range of application, however, and as currently focused and supported, cannot be expected to contribute directly to simulator design for many years.

With respect to simulation technology, emphasis is being placed within NASA on the development and use of advanced simulators for aeronautical research (viz., Flight Simulator for Advanced Aircraft and the Differential Maneuvering Simulator), and the development of improved visual scene generation and display concepts.

Overviews of the research and development programs for each of the three Department of Defense departments and NASA are presented in the following sections.

U.S. AIR FORCE FLIGHT SIMULATION RESEARCH

The major effort of the Air Force R&D program is in three advanced development programs of which two are in the final phases of hardware integration and acceptance. These are the Advanced Simulator for Undergraduate Pilot Training (ASUPT) which is now in operation, the F-4E Weapon Systems Trainer Number 18, and the Simulator for Air-to-Air Combat (SAAC).

1. ASUPT Program. The ASUPT Program is designed to develop a data base for procurement of the next generation flight simulators for undergraduate pilot training. The program objectives may be stated broadly as optimization of simulator associated software/hardware systems, and advanced instructional methodology. For example, the program will study motion requirements and drive methodologies, visual scene requirements for various flight tasks (viz., aerobatics, landing), design and usage of instructor stations (i.e., conventional instrumented stations and advanced computer CRT display stations), and will derive advanced instructional technologies for optimizing the simulator training curricula. The ASUPT system will simulate the maneuvers significant to undergraduate pilot training, many of which could not be simulated in the past, (viz., post

stall spin, aerobatics, formation flying). The data base developed from this program is expected to impact the entire flight and simulator training curriculum.

The ASUPT is a highly sophisticated two-cockpit simulator for the T-37B training aircraft. Motion simulation is provided for each cockpit by a six-degree-of-freedom synergistic motion system supplemented by a "G-seat" gravity force simulator integrated into the pilots seat. A seven-window CRT mosaic encloses the cockpit providing a visual field of view of +120 degrees horizontal by +100 degrees and -40 degrees vertical. The visual scene is computer generated with 2000 edges for one cockpit or shared by the two cockpits. The instructor area design includes conventional stations with repeater instruments, controls, and indicators for each cockpit plus an advanced all CRT station without the customary controls and indicators.

The ASUPT facility is planned to be used for a program of basic research in training and simulation to be conducted on four levels: 1) the study of the basic components of simulation; 2) the examination of the interactions of those components; 3) the experimental investigation of candidate simulator devices and the determination of the extent that they can be substituted for aircraft training; and lastly, 4) the development of pilot training programs which make maximum effective use of the training equipment.

a. Level I. These studies form the foundation of the research and will include examination of each major independent variable of simulation. The objective of Level I is to gather knowledge on the basis components of simulation. For research purposes, these components have been divided into two major classes: hardware design and training methods. Hardware components consist of the motion, visual, aural, and computer systems which make up the physical parts of the simulator. Training methods such as automatic demonstration, variations in task difficulty and sequencing, enhancement of feedback, and malfunction insertion are the intangible aspects of simulation which govern its use. Each of these areas will be studied separately in this first level and then in combination in a later level.

b. Hardware Research. The general approach to hardware research will be a two-step process. The first part will be directed at establishing the kinds of component configurations to be examined, and the second part will consist of the systematic investigation of those component configurations in training. The present USAF commitment to six-degree-of-freedom motion systems suggests an advantageous first use of ASUPT to assess alternative primary motion cueing systems - three, five, and six degrees of freedom - with and without the newly developed g-seat and with and without visual. Such a systematically developed data base would either support continued procurement of these large six degrees of freedom devices or identify the substantial cost reductions achievable with simpler mechanizations.

c. Training Methods Research. Here research will be concerned with evaluating the application of individual training methods to the

simulator; for example, automatic demonstrations, variations in task difficulty, task sequencing, student feedback, instructor feedback, and malfunction insertion. These training methods will be examined individually to determine the qualities of each which contribute to or interfere with training.

d. Level II. These studies will examine the interactive effects of the components of simulation. More specifically, how motion, vision, mathematical modeling, etc., interact to impact device training effectiveness will be examined. Another purpose of this stage will be to study the way in which training methods where feedback and computer aided instruction interact to influence training effectiveness. The specific interactions chosen for examination will be determined based upon data obtained during the first phase of the program, considerations of the combination, and the length of time required to collect the needed data.

e. Level III. These studies will involve investigation of candidate simulator configurations and their interaction with training methods. These candidate configurations will consist of the combinations of hardware components found in Level II research to have the highest probability of being cost effective in the UPT program. One of the primary concerns of this stage of the research program will be the relationship between simulator configuration and training value as a function of time in the simulator. Interacting with this relationship is the training method employed during the time the student is in the simulator. Hence, the "simulator" configurations studies at this time will be examined in a three way interaction of device configuration, training method, and time. The results of this stage of the effort will provide information as to the most likely cost effective simulator or family of devices for implementation in UPT. This also will involve the study of substitutability which is the first step in determining the most productive utilization of that hardware within the operational training environment. The results of this stage will provide information on the effectiveness of simulation within the major phases of T-37 pilot training.

f. Level IV. Level IV training syllabus development has as its purpose, study of the complex interrelationships between amount, content, and sequence of simulator/aircraft training. The procedure to be employed will require the examination of the utilization of the previously identified simulator system within the entire primary jet training phase of the UPT program and follow-on studies to monitor the progress of simulator trained students through advanced jet training and combat crew training. The output of these syllabus development studies will be recommendations for the effective utilization of the complete simulator hardware system defined during the preceding four stages of research.

The capabilities of the ASUPT facility will permit the full detailed program to be conducted at AFHRL/FT.

2. F-4E WST Number 18. The F-4E Weapon System Trainer No. 18 is a research simulator designed to study simulator configurations in the ground

attack mode and incorporating the development of a new high resolution visual system. The simulator consists of an F-4E cockpit mounted on a six degree of freedom synergistic motion system with a six channel high resolution visual system providing a field-of-view of 108 degrees (+54 degrees) horizontally by 48 degrees (-25 to +23 degrees) vertically. The visual scene is provided through a camera-model board system using a 1500:1 scale model and a 120 degree field-of-view Scheimpflug-corrected probe. An automated adaptive training capability is included in the simulator software. The research effort will start with an assessment of the simulator (and especially the visual system) acceptability for training pilots in takeoff and landing and air-to-ground weapons delivery. A second study will evaluate simulator effectiveness in reducing aircraft time required in transition training for airwork and traffic patterns. Evaluation of the effectiveness of the use of adaptive training in the development of training syllabi will be a continuing effort.

3. Simulator for Air-to-Air Combat (SAAC). The SAAC is designed to provide the total cue environment for air combat maneuvering training. A number of advanced visual simulation concepts have been included. The visual display consists of eight surfaces of a dodecahedron solid. Each surface is an optical/video display device. The background terrain and sky information is time-shared with the target image, making it possible to make the target a high resolution image. The terrain image provides velocity, attitude and altitude cues.

The SAAC has two cockpits simulating F-4E aircraft. Each cockpit is mounted on a six degree-of-freedom synergistic motion system. Sustained acceleration effects are provided by g-seats and g-suits in each cockpit. Scoring and evaluation systems are incorporated in the software to permit determination of pilot air-to-air combat competence.

The research program utilizing the SAAC will begin with a systematic assessment of its utility in developing basic fighter and air combat skills. A second phase will investigate the maintenance of skills of non-flying pilots. Additional programs involve the evaluation of other fighter aircraft and tactical weapons used in air-to-air combat.

The technology is capable of expanding beyond one on one combat training into the highly important tactics in multiple aircraft situations. Trainers developed from the SAAC technology base will move beyond were substitution of simulators for aircraft for training. It will enable students to integrate advanced concepts such as energy maneuverability into flight practice with benefits in both student performance and development of new tactics.

4. Large Amplitude Multi-Mode Aerospace Research Simulator (LAMARS). The LAMARS is being developed as an engineering tool for coordinated studies encompassing pilot/vehicle analysis and ground-based simulation as applied to flight dynamics research. The LAMARS provides a combination of visual cues and motion cues to the pilot which will evoke proper pilot response for a large number of controlled and variable mission conditions

and pilotage tasks. The motion system consists of a 30-foot long horizontal beam, which is gimballed and driven by hydraulic actuators at the rear end of the beam to provide +10 feet of vertical motion and +10 feet of lateral motion to the cockpit and to the simulator pilot. An additional structure, the cockpit gimbal system, is mounted on the forward end of the beam, and provides three-directional rotation (+25 degrees in pitch, yaw and roll motion) to the cockpit and pilot. The visual display system consists of a 20-foot diameter, spherical shaped screen - also mounted on the cockpit gimbal system - which moves with the cockpit, and two projectors similarly mounted. One projector, mounted above and behind the pilot, projects the image of a target, which can be either another aircraft (used in air-to-air combat mission simulation) or a ground-based target or terrain image (used in air-to-ground mission simulation). The target aircraft image is generated by an aircraft model viewed by a television camera or by CGI. The terrain image is generated by a large model board viewed by a television camera through an optical probe. The other projector, mounted above and slightly behind the target projector, is known as the sky-earth projector, and projects a clear blue sky with occasional clouds, featureless brown earth, and well-defined horizon on the inner wall of the spherical display screen.

U.S. NAVY FLIGHT SIMULATION RESEARCH

The Navy's exploratory development programs related to flight simulation may be logically categorized into five major task areas. These are:

- Optical Technologies
- Electronic Techniques
- Projected Visual Simulation
- General Simulation Modeling
- Human Factors in the Design and Use of Naval Training Systems

Research into optical technology is aimed at advancing technology in the field of optics and associated disciplines with the goal of obtaining better visual simulation in Navy training devices. A major objective is the development of wide angle visual systems with high resolution target imagery for use in operational flight trainers. Other objectives include the development of a system consisting of multiple television cameras and television projectors for the purpose of displaying a 360 degree panoramic scene, and the development of a film image generation system that would have multiple applications in aviation training.

Holography, laser and infrared applications are among a number of developments pursued by the Navy. Additional effort is aimed at providing a 360 degree hologram for use in a number of training applications. Another effort involves the development and application of holographic information storage techniques for training devices. An objective of the research in holography is the development of a heads-up data display using holographically

produced Frenel zone plate elements. These elements permit multiple input channels to combine data received from more than one source.

Among the many laser applications studied by the Navy is the development of a universal trainer that will simulate sighting and firing of standard weaponry under combat conditions. These will include automatic rifle, machine gun, grenade launcher, and light anti-tank weapon. The device will be used for advanced gunner and refresher training. A major effort is the development of an eye-safe laser for training pilots in air-to-ground gunnery.

A major program involving infrared is the development of a method of simulation of airborne forward looking infrared (FLIR) systems for training of operators.

Electronics research is aimed at solving simulation problems with modern electronic techniques. A major effort is the investigation of techniques for generating and controlling an area-of-interest (AOI) display into a large background scene. An on-going research effort involves determination of the technical parameters and approaches for simulation of remotely piloted vehicles.

The primary intent of the visual simulation program is to develop means for providing necessary visual cues from the outside-the-vehicle operational environment to the trainee. An objective is to develop a method which will permit precise numerical and mathematical definition of the scene content within a specified field of view based on color, orientation, shading, and range of cue objects. Research is also being performed on advanced training devices such as the air cushion vehicle and other new conventional types of vehicles. Objectives of this research are to develop visual simulation and vehicle motion simulation subsystem to represent the visual and terrain environment as presented to operators of such vehicles.

Research efforts in the general simulation modeling program are directed to the development of computational techniques. An objective of this program is to develop a high level visual display descriptor language and a translator or compiler that will accept this language as an input and produce output on media compatible with state-of-the-art displays. A major effort is the investigation of performance capabilities, system interface characteristics, data error rates, storage capacity, hardware reliability, and maintainability of new mass data storage elements and technology for application to the design of more cost-effective computer systems for training devices. Also under study is the identification of technical and economical benefits to be derived from microprogrammed emulation techniques. Such techniques as computer generated displays, computer controlled voice output, voice input to the computer, and physiological input to computers are being investigated for potential means to provide more efficient and effective communication between instructor, trainee, and the training device.

Human factors research is directed at accelerating individual and team skill acquisition by improving training device design and use patterns.

The effort includes exploring methods for training in decision-making skills for threat evaluation and weapons selection and employment, and ensuring that individuals are skilled in their own jobs when they enter team training. A major effort is the development of a data base for, and generalized approach to the design, of avionics maintenance trainers. Another effort is studying the interaction between visual and motion cues in simulation and the effect on training device design. An objective is to develop procedures and models that will permit systematic planning of new aircraft instructional programs.

The Navy's Aviation Wide-Angle Visual advanced development program is designed to demonstrate the feasibility, capability, and training effectiveness of a wide-angle real-image visual system with a high resolution target image and all types of currently available television image generation techniques. Secondly, this program will provide a flexible cockpit motion visual system which will provide an experimental basis for the development of future Navy advanced flight simulators.

The Intermediate Hands-On Maintenance Trainer for Avionic Systems advanced development program is designed to improve application of personnel to productive maintenance, improve trainer configuration management, and increase self-paced instructional capabilities.

The Navy's Device 2F90 Visual System is intended to be used in investigating variations in the elements of a visual display, such as scenic content, color versus monochrome and extent of field of view. This program is designed to determine the extent to which substitution of simulator time for aircraft time can be increased with addition of the visual display and to provide a data base for the development of a production model visual system that will be integrated into the Navy's undergraduate pilot training program.

In the area of engineering simulation, the Navy is conducting an ongoing air-to-air combat simulation effort using television projection of computer-generated target and terrain, a small deck landing simulation program in support of the Light Airborne Multi-Purpose System (LAMPS), and a spin simulation program using the human centrifuge.

U.S. ARMY FLIGHT SIMULATION RESEARCH

At present, the Army's major efforts are the development of advanced subsystems of the SFTS. These efforts include developing a weapon systems simulator with a front and left side visual system to accommodate TOW missiles and 20 mm guns at nine foot skid height and sixteen foot eye height in a nap-of-the-earth environment, developing a cargo simulator with a visual system capable of VFR and/or IFR operations for an aircrew of three, and a simulator with a full visual system capable of training pilot and observer in techniques of employment and specialized target acquisition equipment.

In addition to the concentration on developing advanced hardware, the Army is giving consideration to research in such areas as training program development and design, utilization of training devices, maintenance support concepts for flight simulators, and other areas with the objective of implementing modern training technology. A number of these programs are described in the following paragraphs:

1. **Development of Training Techniques.** This research includes a broad and exhaustive compilation of training techniques intended for pilot training with simulators. Sources include the literature, training research laboratories, and the educational technology field. Following careful analysis, a few candidate training techniques with good expected cost-effectiveness will be compared experimentally using aircraft, simulators, and specially trained instructors.

2. **Content of Simulator Training Programs.** Methods will be developed to determine the types of training objectives that can be taught most efficiently using a simulator with given characteristics. Inferences will be made about the simulator design factors which allow or preclude training on certain tasks. The research will include a review of the literature and on-going training programs, the use of analytic techniques, and empirical evaluation.

3. **Visual Fidelity Requirements.** This research is intended to determine the degree of visual simulation fidelity required for various aviation operational tasks. Variables such as resolution contrast, color, scene content, and field of view will be examined. An assessment of the state of the art in visual simulation technology will be undertaken, and areas requiring improvement will be identified. The cost-effectiveness of alternative visual simulation methods will be evaluated.

4. **Development of Automated Performance Measurement Techniques for Use in Pilot Training Simulators.** Device 2B24 is a sophisticated instrument flight simulator with automated training and performance measurement features. These capabilities have never been used operationally, however, and may never be used unless their effectiveness is established. Simulators for the CH-47 (Device 2B31) and AH-1Q (Device 2B33) are being manufactured with similar automated features and will require validation.

The proposed research includes an assessment of the state-of-the-art in automated performance measurement, selection of several automated measures and development of techniques for their generation, determination of methods of automation using the 2B24, 2B31, and 2B33, and the actual implementation of selected measures with complete programming documentation. Finally, the predictive validity and reliability of the automated measures will be assessed using pilot performance in aircraft.

5. **Baseline Proficiency of Aircrews.** The Army Research Institute (ARI) has identified ten components of aircrew performance: Aircraft control, navigation and orientation, target acquisition and surveillance, mission planning, crew coordination, communications, systems operation, contingency performance, safety, and tactical employment. The research proposed would initiate a continuing program of performance measurement in each of these

component areas to provide "quality control" data for the Army. To accomplish this, efficient sampling procedures must be developed, optimum measurement methods and schedules are needed, and provisions for data collection and analysis must be provided. Although flight testing will be required in various operational environments, it may be possible to substitute simulator tests, analyses of operational records, and measurement data obtained in non-test flights.

6. Proficiency Loss. This research is intended to supplement the baseline proficiency measurement project (see above) by providing information on decrements and decrement rates as a function of time without flight practice, proficiency recovery rates as a function of renewed practice and training, and optimum refresher training strategies. Flight simulators would seem to provide a practical and safe means of acquiring much of the required data.

7. Performance Assessment Methodology. The proposed research would provide for: the identification of key performance variables to be measured for each of the ten aircrew performance component areas; evaluations of the cost-effectiveness of alternative measurement methods (automated, data extraction from flight records, etc.) for the key performance variables; selection of optimum sets of variables for different applications. The performance variables and measurement methods developed will be evaluated in operational tests of validity and reliability.

8. Nap-of-the-Earth Flight Training. This research includes an analysis of tasks to define the performance requirements of NOE flight. From this a comprehensive statement of training objectives will be obtained. At this point a determination will be made of the effectiveness of present training programs so that training objectives which are not being met can be identified. Assessment of a wide range of training methods and technology will follow, with due consideration given to resources and related constraints. Objective evaluation of the training effectiveness of promising methods will be accompanied by a determination of the most cost-effective duration, sequence, and scheduling of training.

9. Development of Automated Training Techniques. Device 2B24, the Army's UH-1H simulator, incorporates automated training features which have not been fully utilized as yet. The proposed research would develop techniques for using these features effectively, and provide a data base for the design and utilization of automated training features for new simulators. Questions concerning the instructor's role and the characteristics of the overall training program will be formulated and addressed through experimentation.

10. Aircraft Systems Maintenance Trainers Studies. These studies are intended to evaluate the design-for-training considerations which have been applied to aircraft systems maintenance trainers, and to provide data for the development of such considerations for use with future trainers.

11. Automated Instructional Requirements. This research will explore the instructor-machine trade off to maximize training effectiveness and develop the potential of existing simulators. The research emphasizes the cost effective automation of instructor tasks and the development of design concepts amenable to engineering implementation. The program will emphasize trade-offs between the overall training program and machine implemented training.

12. Utilization of Synthetic Flight Trainers. The studies will include comparisons of present and potential simulator utilization, and the development of detailed plans for the optimum integration of simulators into overall training programs. Data will be collected concerning all aspects of aviation flight training requirements, present methods and programs, equipment, facilities, simulators, and other training devices. The geographic distribution of aviators, their availability, and individual training requirements will be considered. Relationships concerning optimum simulator distribution and utilization will be developed.

13. Investigation of the Causes of Pilot Error Accidents through the Use of Simulation. The Army Agency for Aviation Safety (USAAAVS), Fort Rucker, has found that 80 percent of all aircraft accidents involved pilot error. Factor analytic studies have shown that there were nine factors associated with these accidents. Further research into these factors in order to evaluate their impact on aviator selection, the training program, and the design of aircraft systems is under consideration. Using the data already available from USAAAVS and related accident data obtained from field units, a determination will be made of the feasibility of alterations to selection, training, and hardware systems which should lead to accident reduction. Experiments validating these findings will be conducted in such simulators as the 2B24 device because of their inherent safety and the ease with which experimental conditions can be controlled.

14. Flight Simulation in Medical Research. Variables such as the emotional state, injury induced states, and pharmacological agents used affect pilot performance. Training related variables, such as time on task, work load, and mission profile, as well as hardware related factors such as cockpit environment and anthropometric considerations also affect performance. Such variables are being studied at the present time and simulators are being installed to facilitate the research.

15. Maintenance and Support Concepts. Following a review of all regulations, concepts, and practices for device maintenance within DoD and FAA purview, information concerning the present organizational structure and capabilities for performing device maintenance will be collected. Comparisons of these data with collateral determinations of maintenance and support requirements, e.g., skills, knowledges, and qualifications of maintenance, engineering, and logistics personnel, will lead to recommendations concerning alternative approaches to obtaining total support.

NASA FLIGHT SIMULATION RESEARCH

NASA's programs fall into two categories, facility upgrading and simulation requirement research. The facility upgrading is motivated by the need for aircraft research and development simulators of high quality. These engineering simulation programs, many of which are for proposed military aircraft, require the acquisition of state-of-the-art visual systems or new devices in order to upgrade existing systems. Simulation requirement research involves formal scientific studies of simulator cue-producing requirements. Such work includes both analytically derived hypotheses from basic physiological and psychological characteristics, and testing of these hypotheses by statistical studies of pilots in simulators. To the greatest extent possible, NASA uses engineering simulators for these efforts.

1. Facility Upgrading Projects. NASA has three on-going projects in this category. These are the S-19 fixed base cockpit development, the UH-1H-V/STOLAND in-flight simulator development, and the nap-of-the-earth (NOE) terrain model. The S-19 consists of a UH-1H cockpit mounted on a fixed base. The cockpit is connected to a visual display system having a collimated TV image. The UH-1H-V/STOLAND consists of a UH-1H cockpit that has a Sperry V/STOLAND control/display system. These two developments are closely tied to U.S. Army participation and are oriented toward studies of stability and control, and display parameters during nap-of-the-earth flight. In conjunction with these two projects, NASA is developing a detailed terrain model so that visual displays can depict scenes at or below tree-top height.

In addition to the three on-going facility upgrading projects, NASA is anticipating such new starts as the following:

a. Vertical Motion Simulator (VMS). This simulator will consist of a fully outfitted multi-man cockpit mounted on a six degree of freedom motion platform with large vertical and lateral motion capabilities. The cockpit, with rotational and longitudinal actuators, is mounted on a vertically moving platform which is supported by a structure moving laterally on rails. Anticipated motion performance characteristics of the simulator are as follows:

Mode	Displacement	Velocity	Acceleration
Vertical	+30 feet	20 feet per sec	1.02G(33 ft/sec ²)
Lateral	+20 feet	10 feet per sec	0.75G(24 ft/sec ²)
Longitudinal	+ 4 feet	2 feet per sec	+0.5G(16 ft/sec ²)
Roll	+22 degrees	+15 degrees per sec	+50.0°/sec ²
Pitch	+26 degrees, -24 degrees	+15 degrees per sec	+50.0°/sec ²
Yaw	+29 degrees	+15 degrees per sec	+50.0°/sec ²

b. V/STOL Integrated Cockpit Research Facility. It is planned to procure a six-degree-of-freedom simulator that will be fitted with a two-man V/STOL type cockpit and a synthetic visual display. Objectives are the study of pilot's perception and processing of complex visual, motion and auditory stimuli, and the evaluation and engineering development of computer graphic displays, color systems, high contrast CRT's and multi-planar displays.

c. Wide Angle Area of Interest Visual Display. This effort will involve the procurement and development of a system that will provide a wide field of view. The approach taken involves providing a detailed scene, of the usual 48 x 35 size, which can be centered on the "area of interest" and moved within a target field of view. The portion of the field of view not taken up with the area of interest is provided with some synthetic imagery.

2. Simulation Requirement Research. NASA has ten on-going projects in this category. The efforts include research to provide information about characteristics of the human subject relevant to aircrew performance efficiency, and research on the impact of training device performance on aircrew performance efficiency. Briefs on these projects are presented in the following paragraphs.

a. Pilot Perception of Aircraft Motion Cues. While a great deal is known about human sensitivity to motion cues, and this information has been quite useful in the design of washout procedures for aircraft motion simulators, information is needed concerning the effects of motion on the perception of visual movement, and the rate and course of adaptation to motion cues at levels of acceleration similar to those encountered in aircraft. Research into these questions will be undertaken using the Ames Man-Carrying Rotation Device during FY 75.

b. Pilot Perception of Complex and Interactive Visual Cues. The empirical question addressed by this research concerns whether the simulator pilot perceives and acts upon meaningful complexes of cues in the same way he would in actual flight. By introducing errors, e.g., vertical and horizontal displacements into a simulated open-loop landing situation, and observing pilot decisions to "land" or "go around," a scaling of pilot error sensitivity is obtained. Presumably, it should also be possible to assess pilot response bias, i.e., willingness to chance a landing, by manipulating the pay off matrix. Similar characterizations of pilot parameters could be obtained in real flights for comparison.

c. Investigation of Spurious Motion Cues. Simulator motion systems may introduce spurious motions, thus providing the simulator pilot with misinformation if they are perceived. This research is intended to identify these spurious motions and develop techniques to remove or compensate for them.

d. Dedicated Computer Concept. Modern flight simulators have large computing requirements imposed by the real time demands of various subsystems,

e.g., visual, motion, etc. To handle these requirements, a single computer must have high performance (speed) and a large memory. However, it is possible that dedicated minicomputers driving the subsystems in parallel could relieve the central computer of much of this load. The research described is an investigation of this approach and requires the acquisition and integration of appropriate hardware, interfacing, and software.

e. Studies of Distance Perception. A determination is being made of whether the perception of distance from an observer to a familiar object is fundamentally different for an object viewed on a non-collimated CRT display, a collimated CRT display, or in a real visual scene. Comparisons of perceived and actual distances are used to infer whether or not distance perception is mediated by the same cues in all cases. Angular relationships will be investigated in a similar fashion.

f. Electronic Fog Requirements. Research is being conducted in collaboration with the Scripps Institute of Oceanography into the perceptual and decision making processes involved in simulated aircraft landing scenes in which both ceiling and runway visual range are varied using computer generated fog, windshield moisture and rain, and reflections due to approach patterns over water.

g. Remote Piloted Vehicle Ground Station Simulation. Using a simulator for the Piper PA-30 aircraft and two visual display systems arranged in various configurations, this research has identified initial display concepts which give very consistent landing performance in the simulator. Implementation in the Firebee II landing studies program is being considered. Completion of an operational RPRV station will allow comparison of simulated and real RPRV pilot performance.

h. Measurement of Cognitive Skills. Real time data will be acquired from a Singer GAT-1 general aviation simulator using a PDP-12 computer. While basic aircraft attitude, power and flight path data will be monitored, emphasis will be placed on pilot monitoring of the aircraft system status information with which he interacts during the course of general aviation missions. Pilot interaction will be measured by frequency of contact, and by message content analysis. These data will then be used to draw conclusions about pilot cognitive skills. Validation studies will be completed using aircraft.

i. Measurement of Pilot Internal State by Voice Stress. Since the consequences of errors committed in flight are more severe than those associated with errors during simulator performance, the motivational stress states operating under these two conditions may differ and may mediate changes in the ways sensory information is processed. This research, in collaboration with the University of California at Los Angeles, is an exploratory study of the feasibility of applying digital pattern recognition in the frequency domain of speech samples to detect stress differences in the same speaker.

j. Simulation Data Management System. The simulation of modern flight vehicles requires that the simulation project engineer record, examine, and collate large amounts of data from the simulated aircraft. This research would develop a computer-based, conversational mode Simulation Data Management System with graphic display output to assist the project engineer to perform this function efficiently.

k. Aircrew Performance and Aviation Safety (General Aviation Training). Intended for general aviation student pilots, this inexpensive radio communications skills simulator will consist of standard communications scenarios incorporating various forms of signal degradation, and be accompanied by a tracking task to force attentional time shaving. An error classification system has been devised which will provide a basis for performance assessment.

APPENDIX D

OVERVIEW OF SIMULATOR VISUAL TECHNOLOGY

INTRODUCTION

The purpose of this appendix is to identify the Army's flight simulator visual system requirements, to outline the state of the art in aviation visual simulation and to point out areas where the state of the art falls short of meeting the Army's visual simulation requirements. The Army's visual system development goals are outlined and the associated hardware and training risk are assessed.

VISUAL SYSTEM REQUIREMENTS

Operational flight trainers currently provide cost effective training for instrument flight, but the majority of Army flight takes place in a visual environment. Visual systems are necessary for any significant increase in the number of tasks that can be taught in flight simulators. Table D-1 outlines the visual flight tasks for each of the Army's current developmental aircraft.

Each flight task has a different set of visual system requirements. For example, the field of view required for target acquisition is considerably larger than that required for confined area operation. Maximum recommended vision envelopes for each flight task of an attack helicopter are plotted in Figure D-1. These were derived from an analytical study recently conducted by the U.S. Army Aviation Systems Command. Similar plots for observation, utility, and cargo helicopters are provided in Figures D-2 through D-4. The minimum acceptable field of view for training each flight task is probably less than that recommended in the plots, but the plots are representative of maximum field of view requirements for Army flight simulator visual systems including those for the developmental helicopters. The actual visual system capabilities will depend upon flight task analyses and visual technology limitations at the time of each flight simulator procurement.

CURRENT STATE-OF-THE-ART

1. Introduction. Every visual system possesses two fundamental subsystems, an image-generation and processing subsystem, and a visual display subsystem. A general breakdown of these subsystems is provided with current capabilities and limitations of each element. The capabilities and limitations of current visual systems are presented first for subsystem elements and secondly for overall systems. Each generic type of existing and developmental wide angle visual system is described and a table of performance characteristics for each system type is provided. Seven basic categories of wide angle visual systems are identified. A systems description is provided and performance parameters are listed for each system.

TABLE D-1

FLIGHT VISUAL TASKS FOR ARMY DEVELOPMENTAL AIRCRAFT

Visual Flight Tests	Development Aircraft		
	Aerial Scout Helicopter (ASH)	Advanced Attack Helicopter (AAH)	Utility Tactical Transport Aircraft System (UTTAS)
Stagefield Takeoff and Landing	X	X	X
Confined Area and Pinnacle Operations	X	X	X
Hover	X	X	X
Reconnaissance	X		
Contour Flight	X	X	X
Nap-of-the-Earth Flight	X	X	
Target Acquisition	X	X	
Weapons Delivery		X	
Cargo and Personnel Transport			X
Navigation	X	X	X
Formation	X	X	X
Autorotation	X	X	X

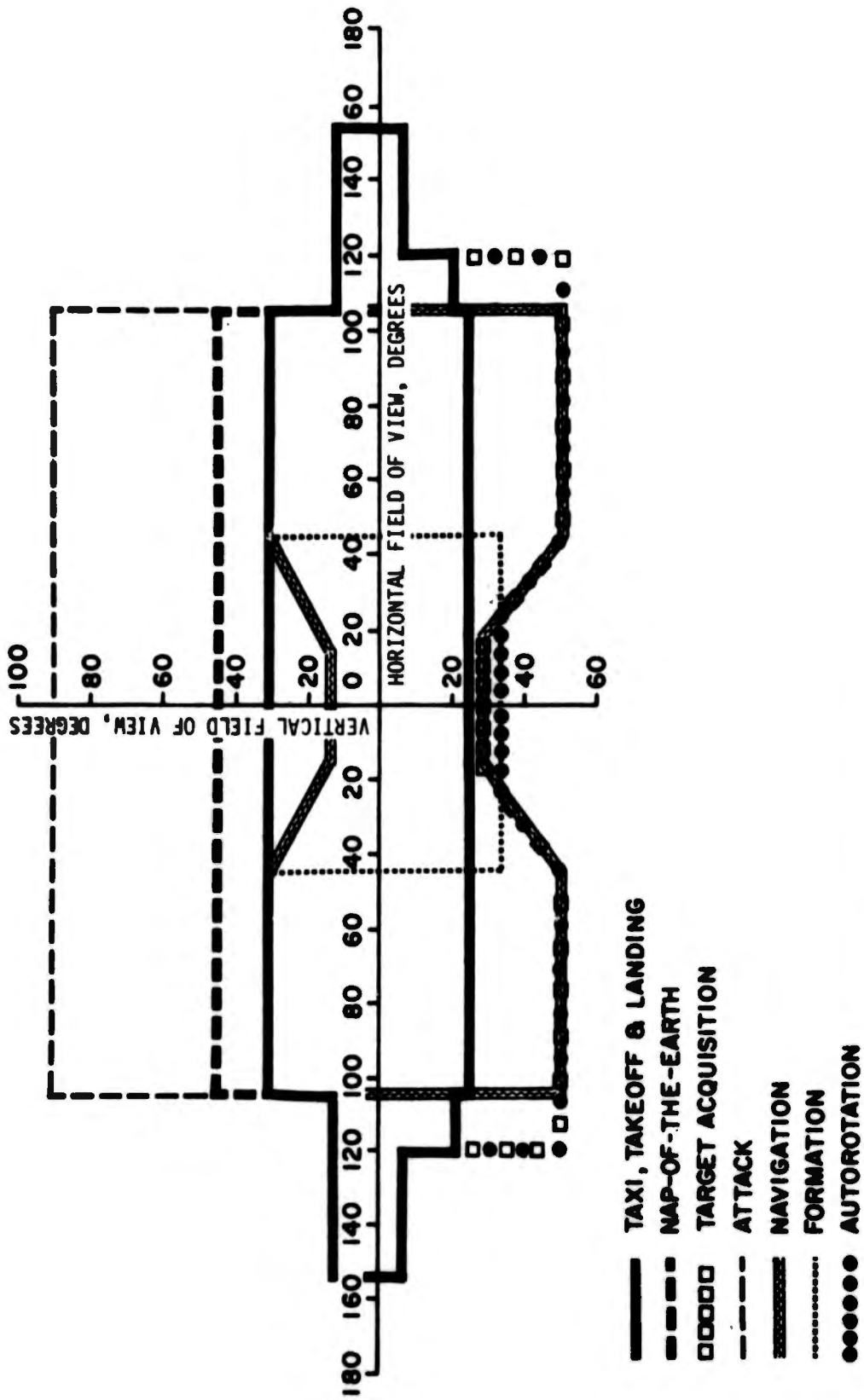
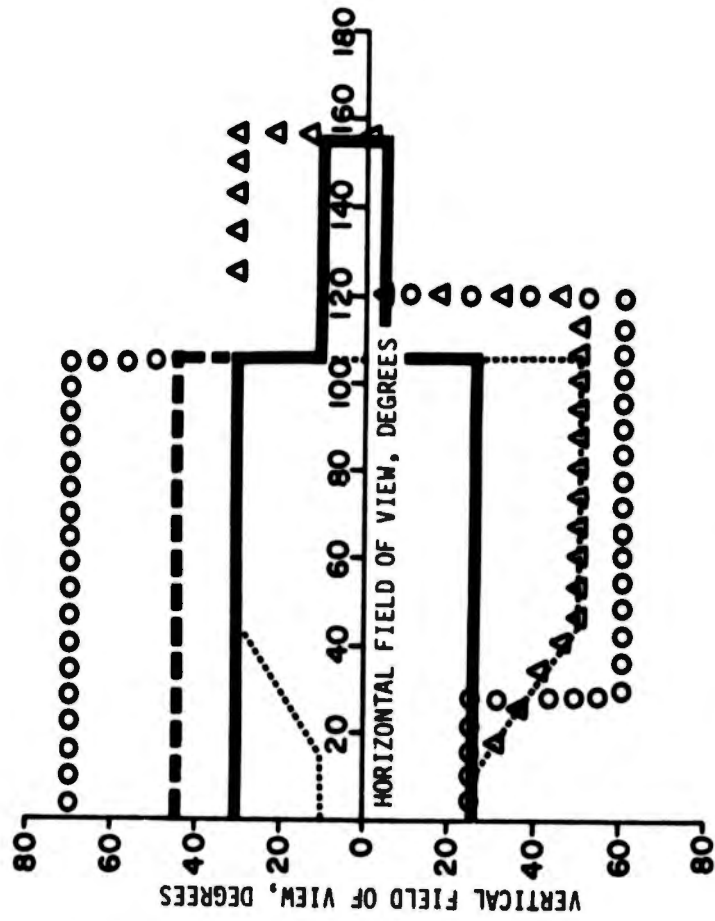


FIGURE D-1. MAXIMUM RECOMMENDED VISION ENVELOPE REQUIREMENTS FOR ATTACK HELICOPTER



- TAXI, TAKEOFF & LANDING
- RECONNAISSANCE
- NAP-OF-THE-EARTH
- · - · NAVIGATION
- - - - FORMATION
- △△△△ AUTOROTATION

FIGURE D-2. MAXIMUM RECOMMENDED VISION ENVELOPE REQUIREMENTS FOR OBSERVATION HELICOPTER

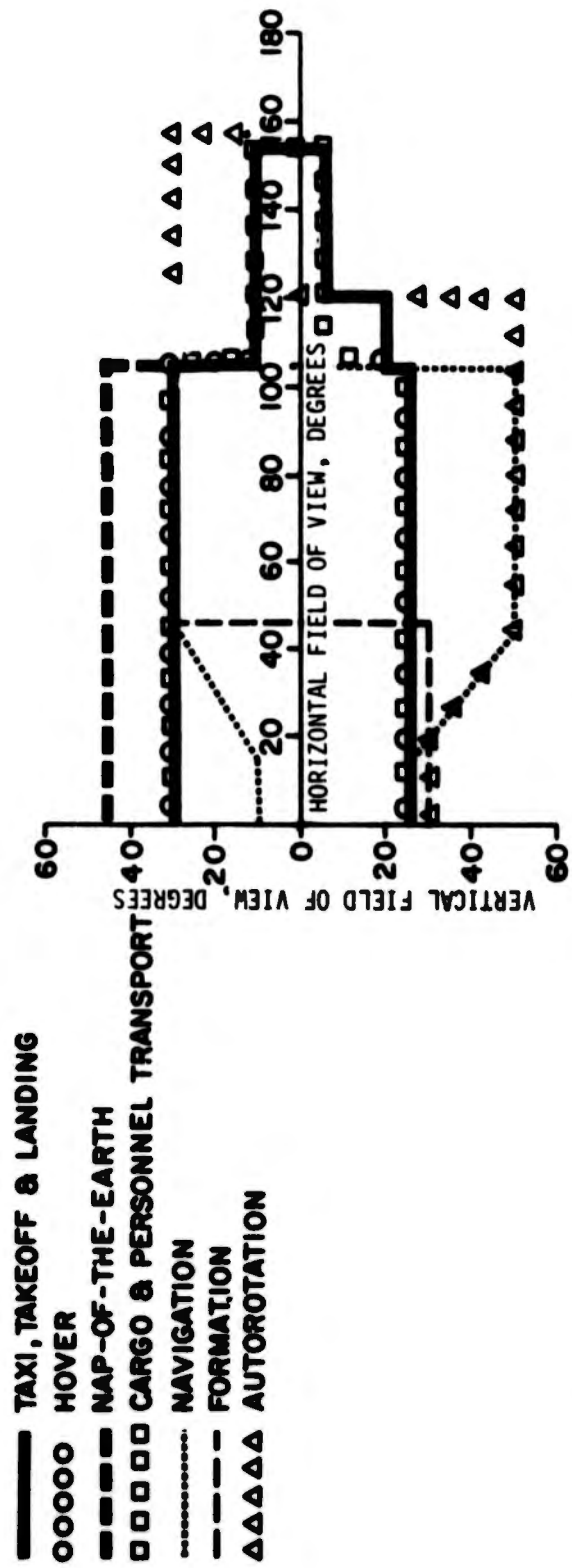
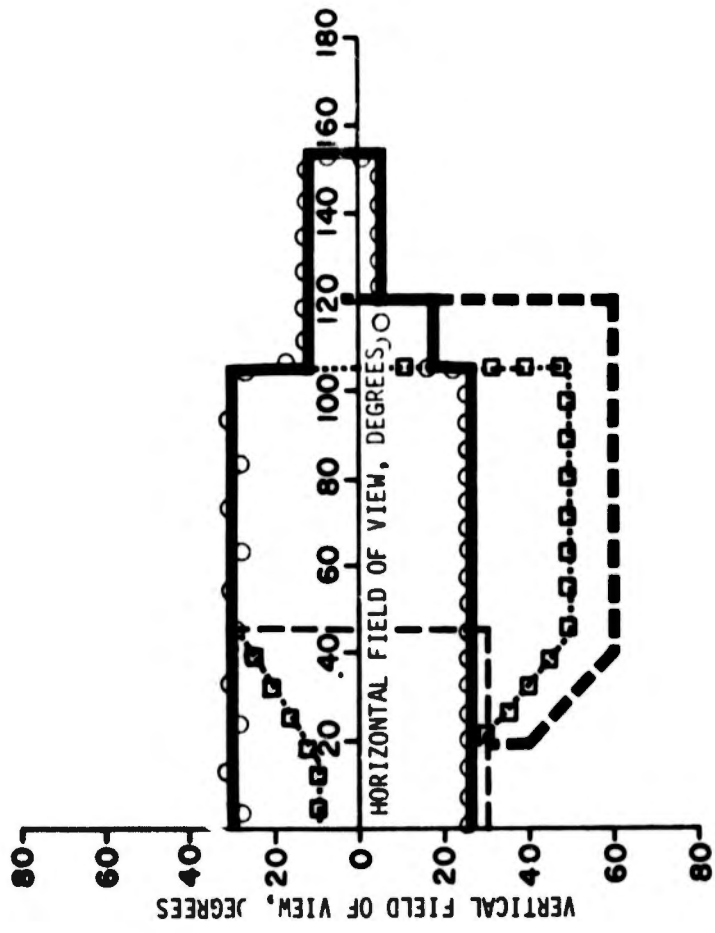


FIGURE D-3. MAXIMUM RECOMMENDED VISION ENVELOPE REQUIREMENTS FOR UTILITY HELICOPTER



- TAXI, TAKEOFF & LANDING
- HOVER
- - - - CARGO DELIVERY
- · - · NAVIGATION
- - - - FORMATION
- — — — AUTOROTATION

FIGURE D-4. MAXIMUM RECOMMENDED VISION ENVELOPE REQUIREMENTS FOR CARGO HELICOPTER

2. Image Generation Subsystems. Image generation subsystems are categorized by the media in which the simulated visual environment is stored. Current image generation subsystems fall into three basic categories: i.e., camera-model subsystems, computer-generated imagery (CGI) subsystems, and film subsystems. Each type of image generation subsystem is described in the following paragraphs and the capabilities of each type of subsystem are listed in Tables D-2, D-3 and D-4.

In a conventional camera-model subsystem, a television camera views a model board through an optical probe. The camera, optical probe and/or the model board are driven by servo mechanisms such that the desired portion of the model board is imaged by the optical probe onto the sensor surface of the television camera tube. The television camera converts the desired optical image into a video signal that is fed to a television display system. The capabilities of current camera-model subsystems are listed in Table D-2.

In a CGI subsystem, the coordinates of line or edge intersections that make up a three-dimensional visual environment are stored in a digital computer. The computer is programmed to select from the total stored visual environment that portion which would be visible from a given viewing position within the total visual environment. The computer processes this selected three-dimensional information for display as a two-dimensional scene in proper perspective within the field of view of the television display system. CGI displays can consist of colored point lights, straight lines, colored surfaces, or any combination of these. The capabilities of current CGI subsystems are given in Table D-3.

In a film image generation subsystem, the visual scenery may be stored in a motion picture film or a film transparency. The motion pictures usually are made with a camera mounted on a helicopter which traverses the path to be simulated. The transparencies usually are made photographically; color may be added with dyes or water colors.

Motion picture visual systems fall into three basic categories, i.e., conventional, annular and variable anamorphic systems. In a conventional motion picture system, a reel of conventional motion picture film of real-world scenery is projected onto a viewing screen. In an annular motion picture system, a spherical or hyperboloidal mirror is used with a vertically oriented lens to image a 360-degree scene into an annular film format. In the annular image, the horizon appears as a circle with sky and terrain on opposite sides of the horizon circle. The 360-degree scene is projected onto a spherical viewing screen by a vertically oriented projector with a spherical or hyperboloidal mirror.

Variable anamorphic film subsystems fall into two categories, i.e., variable anamorphic optical subsystems and variable anamorphic electronic scan subsystems. In a variable anamorphic optical subsystem, servo-driven prisms rotate, translate and distort the image of a conventional motion picture film to simulate deviations from the filming flight path. In an electronic scan system, a cathode-ray-tube flying spot scanner and a photo-detector transform the motion picture into a video signal for

TABLE D-2

CAMERA-MODEL IMAGE GENERATION SUBSYSTEMS

Components	Capabilities
<p>Television Cameras</p> <p>Video Chains</p> <p>Terrain Models</p> <p>Optical Probes</p> <p>Gantries</p>	<p>Up to 1365 scan lines per frame, 30 frames per second, 800 television lines per picture height resolution, color</p> <p>4- to 50-MHz video bandwidth</p> <p>144:1 to 10,000:1 scales, up to 24 feet in height and 64 feet in length</p> <p>Fixed focal length for terrain model boards, up to 140-degree field of view; Scheimpflug correction for focus; roll, pitch, and yaw servos</p> <p>Variable focal length for target models, up to 40:1 zoom capability</p> <p>Velocities up to 12 inches per second, accelerations up to 8 inches per second, servo dynamic ranges up to 2000:1, Z (attitude) travel 2 to 4 feet</p>

TABLE D-3

COMPUTER-GENERATED IMAGERY SUBSYSTEMS

Components	Capabilities
<p>General-Purpose Computer</p> <p>Special-Purpose Computer</p>	<p>Active data base for edges within the display field of view, level of scene detail selection, up to 131,072 words, 32 bits per word, 600-nanosecond memory cycle time with dual processor</p> <p>Coordinate transformation, windowing, and three-dimensional perspective for two-dimensional display; hidden surface removal; signal processing for television format, up to 3300 edges, color, up to 7 channels</p>

TABLE D-4

FILM IMAGE GENERATION SUBSYSTEMS

Components	Capabilities
Motion Picture Systems:	
<p>Conventional</p>	<p>8-, 35- and 70-millimeter color motion picture film, 24 frames per second, programmed visual scene does not respond to flight control inputs</p>
<p>Annular</p>	<p>5-inch color motion picture film with annular format; with variable-frame-rate and gimbal-mounted projector, semi-programmed visual scene responds to flight control inputs for changes in simulated aircraft speed and attitude</p>
<p>Variable Anamorphic</p>	<p>70-millimeter color motion picture film with variable anamorphic optics or 35-millimeter color motion picture film with variable anamorphic electronic scan, variable frame rates for changes in simulated aircraft speed, optical elements or electronic film scan provides semi-programmed visual scene with trainee controlled changes in simulated aircraft attitude and small deviations about the filmed flight path</p>
Film Transparency Systems:	
<p>Spherical or Cylindrical</p>	<p>Blue sky with clouds and mountainous horizon for attitude and heading cues or terrain pattern for attitude and heading cues, no translation cues, sky and terrain provided by separate transparencies</p>
<p>Planar</p>	<p>Colored terrain and cultural scenes; roll, pitch, yaw and all translational cues; 4-foot diameter discs up to 6-foot square transparencies; 50:1 up to 5000:1 scales; maneuvering area limited by size and scale of transparency</p>

presentation on a television display. Deviations from the filmed flight path are simulated by electronic shift and distortion of the electronic scan pattern. In each type of subsystem, changes in air speed are simulated by changing the projector frame rate.

In a film transparency system, a point light source, such as an arc lamp, projects the scenery of a film transparency directly onto a viewing screen. Spherical, cylindrical, and planar transparencies are available. A spherical or cylindrical transparency is mounted at or near the center of a spherical viewing screen with the illuminating point light source near the center of the spherical or cylindrical transparency. A planar transparency is mounted between the point light source and a flat or spherical projection screen. A flat projection screen usually is rear illuminated and mounted vertically to provide a forward field of view. A spherical projection screen may be illuminated from above with a point light source and a horizontal transparency to provide a 360-degree terrain scene. Changes in vehicle heading, attitude and position are simulated by rotating and translating the transparency with respect to the viewing screen and point light. The capabilities of film image generation systems are outlined in Table D-4.

3. Visual Display Subsystems. Visual display subsystems are categorized by the type of imagery displayed, i.e., real imagery or virtual imagery. A real image is viewed directly on a cathode ray tube (CRT) or projection screen while a virtual image is viewed through an optical window. In a virtual image display, the optical window magnifies a real image to make the simulated scenery appear at the real world distance from the observer. The components and capabilities of commonly used real image and virtual image display subsystems are listed in Tables D-5 and D-6 respectively.

4. Narrow Angle Visual System Capabilities. Film image generation systems with optical display techniques provide the best resolution and scene quality of all present visual systems. Motion picture projectors with variable anamorphic optics currently provide color displays with a resolution of 3 to 4 minutes of arc and a luminance up to 20 foot-Lamberts. However, variable anamorphic film based systems are limited in application because the film is inherently semi-programmed and the variable anamorphic optics introduce distortions in the scene that are particularly objectionable when vertical objects are displayed. Any simulated flight path that falls outside of the limited flight envelope, recorded on the film, will result in loss of the visual scene.

Visual systems with computer-generated imagery provide the most flexible imagery for simulating non-programmed flight paths and for simulating FLIR, RADAR and LLLTV displays. However, the imagery for a real-world day scene has a symbolic character and lacks realistic detail and texture for day scene simulation. The image quality is limited primarily by the display, and the image content is limited by the computer storage and processing capacity. Computer-generated imagery systems are being developed to provide day scenes in color with 3 to 5 minutes-of-arc resolution over a 40-degree display field of view. Computer-generated imagery systems that provide night scenes with colored point lights are available with 3 minutes of arc resolution over a 36-degree field of view.

TABLE D-5

REAL IMAGE DISPLAY SUBSYSTEMS

Components	Capabilities
Television Projectors:	
Cathode Ray Tube (CRT) Projectors	Up to 1225 scan lines per frame, 30 frames per second, up to 1000 television lines per picture height resolution, color display with up to 2200 lumens light flux output
Light Valve Projectors	<p>Monochrome - Up to 1203 scan lines per frame, 30 frames per second, up to 1000 television lines per picture height horizontal resolution and 700 television lines per picture height vertical resolution at 945 scan lines per frame, 4000 lumens light flux output</p> <p>Simultaneous Color - Up to 525 scan lines per frame, 30 frames per second, 600 television lines per picture height vertical resolution, 3600 lumens of light flux output</p> <p>Field Sequential Color - Up to 735 scan lines per frame, 150 fields per second, 600 television lines per picture height vertical resolution, 900 lumens of light flux output</p>
Motion Picture Projectors:	
Conventional	Projection angles up to 160 degrees horizontal by 60 degrees vertical
Annular	Projection Angles up to 360 degrees horizontal by 92 degrees vertical
Variable Anamorphic	Projection angles up to 58 degrees horizontal by 28 degrees vertical
Screens	<p>Flat - Front or rear projected, wide angle coverage with side-by-side arrangement, gain depends on field of view, and on maximum viewing and projection angles to the screen normal</p> <p>Spherical - Up to 360 degrees horizontal coverage, gain depends on number and separation of viewers and on separation of projectors from viewers</p>

TABLE D-6

VIRTUAL IMAGE DISPLAY SUBSYSTEMS

Components	Capabilities
Mirror-Beamsplitter Optics	Illuminated by cathode ray tube, typically up to 48 degrees horizontal by 33 degrees vertical field of view, 18-percent light transmission efficiency, can be arranged in row-column matrix for wide angle coverage
Pancake Window Optics	Illuminated by high-brightness cathode ray tube or television projector, up to 80-degree diagonal field of view, one percent light transmission efficiency, can be arranged in a dodecahedron mosaic pattern for wide angle coverage

Television display systems with camera-model image generation provides for non-programmed flight; but the flight path must be within the area limits of the model board and the dynamics of the optical probe gantry. Display image quality is a function of the optical probe, the television camera pickup tube, all the elements of the video processing chain, the television projector or display tube, and the display optics. The model board provides both the three-dimensional dynamic cues such as motion parallax and interposition, and the surface texture cues which are useful for judging relative velocity and closure rates. Television display systems with camera-model image generation have provided color displays with 11 minutes-of-arc resolution and up to 20 foot-Lamberts luminance with a 60-degree horizontal by 40-degree vertical field of view.

5. Wide Angle Visual System Capabilities. Wide-angle visual systems with continuous horizontal fields of view greater than 180 degrees are limited currently to film image projection techniques. The point light source system uses a two-dimensional film transparency to provide a color display with typically 1 foot-Lambert luminance and 10 minutes of arc over a 200-degree horizontal by 60-degree vertical field of view.

Film transparency systems, with an annular image format, can provide a color 360-degree horizontal by 42-degree vertical field of view with 3 to 4 minutes of arc resolution and approximately 3 foot-Lamberts luminance.

Spherical transparency systems commonly are used in conjunction with narrow angle television projectors which are servo positioned in the wide angle field of view to simulate a target for gunnery or weapons delivery. This type of system can provide a target image whose resolution of approximately 6 minutes of arc at close range improves with range to approximately 1 minute of arc at maximum range. The luminance of the target image is typically 1 to 3 foot-Lamberts.

Wide angle television systems have been developed with a combination of two or more narrow angle display segments arranged to extend the field of view. A wide angle computer-generated imagery system with three 60-degree by 60-degree display segments has been developed as an attachment to a fixed-wing operational flight simulator. A visual system for fixed wing aerial combat simulation has been developed using aircraft target models with television pickup cameras, a computer-generated synthetic background scene, and a mosaic of seven optical display windows. Each display window is illuminated by a cathode ray tube with a monochrome television display. A similar optical mosaic of eight windows has been developed using computer-generated imagery. The optical mosaic display systems can provide a field of view up to 300 degrees horizontal by 220 degrees vertical.

Most of the aviation wide angle visual systems that are operational now or that will be operational by December 1975, fall into seven basic categories. These categories, or system types, are identified in Table D-7 as systems A through G. Performance parameters are listed for what is considered to be the best overall system of each system type. A brief description of each of the seven basic wide-angle visual systems is provided below:

a. System A. This system is comprised of a spherical screen on which two aircraft target images are projected. A window with mirror-beam-splitter virtual image optics is mounted in front of the cockpit. This window utilizes a CRT and two target projectors to provide a vertical image display of the background scene and the target images within the forward 60-degree field of view. A total of six target projectors are used, two on each side of the cockpit and two for the forward virtual image window. The target images are derived from two television cameras which view gimbal mounted three-dimensional aircraft models. Each target image is switched from one projector to another as the target image traverses from one side of the screen to the other or into or out of the forward 60-degree virtual image window.

The background scene is projected onto the screen by a sky-earth projector comprised of two internally lighted transparent hemispheres. The sky-earth projector is gimbal mounted behind the cockpit near the center of the spherical screen. The sky contains scattered clouds and the ground has a terrain pattern. The hemispheres are tilted and rotated to create the illusion of aircraft attitude and heading changes in response to flight control inputs. The point light source is moved within the terrain hemisphere to create the illusion of ground growth with altitude changes. No translational cues are provided in the background scene. The background scene for the forward virtual image window is derived from a television camera which views a background scene on a gimbal-mounted sphere.

Currently, a system of this type is being used as a research tool in the design of new aircraft and aircraft systems. The forward 60-degree virtual image window is used in the design and development of operational heads-up display systems. This visual system provides visual simulation for two-on-one air-to-air combat. However, the system is limited in application since

TABLE D-7

WIDE ANGLE VISUAL SYSTEM PERFORMANCE PARAMETERS

Performance Parameters	Wide Angle Visual Systems						
	A	B	C	D	E	F	G
Background Display							
Number of Channels	2	1	6	7	8	3	1
Resolution, Center (Arc Min/O LP)	Unknown	10-15	11	14	17	20	4 to 15
Resolution, Edges (Arc Min/O LP)	Unknown	10-15	11	14	17	20	4 to 15
Field-of-View, Total (Deg)	360H x 150V	266H x 137V	108H x 48V	240H x 160V	300H x 142V	180H x 60V	200H x 60V
Field-of-View, Per Channel (Deg)	60 CRT Insert	Not Applicable	36H x 24V	75	72	60H x 60V	200H x 60V
Luminance (Ft-L)	.1	.5 to 1.0	8	6	2	3	1 to 5
Contrast		15:1	20:1	10:1	10:1	20:1	15:1
Color	PS-Yes, CM-Yes	Yes	Yes	No	No	Yes	Yes
Refresh Rate (No./Sec)	Continuous & 60	Continuous	60	60	60	30	Continuous
Lag (Sec)			0.05	.1	.1	0.1	Varies w/Alt
Position Accuracy (Deg)		0.3	1	Less than 1	1	Varies w/Alt	Varies w/Alt
Geometric Distortion (Percent)		Less than 1	Less than 2	Less than 1	Less than 2	Varies w/Alt	Varies w/Alt
Target Display							
Resolution, Max FOV (Arc Min/O LP)	1.7	6	-	-	4.5	-	-
Field-of-View, Max (Deg)	10	15 and 60	-	-	40	-	-
Luminance (Ft-L)	.4	1.5 to 3	-	-	8	-	-
Contrast		15:1	-	-	20:1	-	-
Color	Yes, CG, CH	No	-	-	No	-	-
Refresh Rate (No./Sec)	30	30	-	-	60	-	-
Lag (Sec)		0.1	-	-	0.1	-	-
Position Accuracy (Deg)		Less than 5	-	-	Less than 1	-	-
Geometric Distortion (Percent)			-	-	Less than 2	-	-
Aircraft Flight Performance Envelopes							
Altitude Range, Min/Max (Ft)	0/100,000	50/10,000	10/32,768	0/35,000	0/65,000	0 to 500,000	5 to 25,000
Maneuvering Area (NM x NM)	1400	600	4 x 11	50 ² or 1250 ²	50 x 50	200 x 200	4 x 4 (X Scale)
Velocity (Knots)	10	6	550	Unlimited	800	Unlimited	K X Scale
Acceleration (G's)	Unlimited	+9C	Unlimited	Unlimited	-5 to +10	Unlimited	K X Scale
Pitch Excursions (Deg)	300	+12U	60	Unlimited	Unlimited	Unlimited	+20
Pitch Velocity (Deg/Sec)	Unlimited	+180	80	Unlimited	100	Unlimited	+229
Pitch Acceleration (Deg/Sec ²)	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	+20
Roll Excursion (Deg)	300	+240	360	Unlimited	300	Unlimited	+40
Roll Velocity (Deg/Sec)	Unlimited	+960	150	Unlimited	150	Unlimited	+224
Roll Acceleration (Deg/Sec ²)	Unlimited	+120	60	Unlimited	60	Unlimited	Unlimited
Heading Excursion (Deg)	300	+180	80	Unlimited	100	Unlimited	+57.3
Heading Velocity (Deg/Sec)	Unlimited						+86
Heading Acceleration (Deg/Sec ²)	Unlimited						
Computer Rates							
Motion Equations (Cycles/Sec)	20 to 100	20 to 40	20	7.5	20	20	100/50/25
Command Signals (Cycles/Sec)		Approx 30	20	15	20	20	25
Display Size, Width x Length x Ht (Ft)	20 x 20 x 20	16 x 16 x 16	11 x 8 x 8	16 x 16 x 13	14 x 17 x 13	21 x 16 x 7	25 x 25 x 20
Display Weight (Lbs)	6000	Approx 1000	3000	13,000	9500	5000	Unknown

it lacks a capability for taxiing, takeoff and landing, and translation over terrain.

b. System B. This system is comprised of a spherical screen on which a background scene and a target image are projected. A sky-earth projector, comprised of two internally lighted transparent hemispheres, is gimbal-mounted above and behind the cockpit to project a sky and terrain scene. The sky and terrain are without distinctive features except for clouds and a jagged horizon representing distant mountain peaks. The hemispheres are rotated in roll, pitch and yaw to create the illusion of aircraft attitude and heading changes in response to flight control inputs.

A narrow angle CRT projector is gimbal-mounted between the background projector and the cockpit to superimpose a target aircraft image on the background scene. The target image is generated by a television camera which views a three-dimensional aircraft model. The model is encapsulated in a transparent ball which is servo driven to present the aircraft model in proper perspective to the camera.

This system can provide a high resolution target image and a continuous background display with no image breakup due to window interfaces, but it is limited in application. It does not provide adequate visual simulation for taxiing, takeoff and landing, or translation over the terrain. Heavy reliance must be placed on cockpit instruments particularly when the horizon is not in view because the terrain scene lacks any distinctive features. Currently, a system of this type is being used as an engineering development tool in the design of new aircraft.

c. System C. This system is comprised of a matrix of high resolution color television monitors and mirror-beamsplitter virtual image optics. The wide angle image is derived from a high resolution color television camera and a three-dimensional model board. The camera is gantry mounted and is equipped with a wide angle optical probe.

This system provides visual simulation for taxiing, takeoff and landing and circling approaches; but it lacks the capability to provide high resolution target imagery for tank target acquisition. Currently, a system of this type is being installed as an experimental visual system for research in pilot training.

d. System D. This system is comprised of multiple pentagon shaped display channels which are mosaiced together to form a partial dodecahedron shell surrounding cockpit. Each display channel has a CRT with pancake window virtual image optics. Since the pancake window optics are only one percent efficient, large high-brightness monochrome CRT's are used. Color CRT's with the required brightness are beyond the state of the art.

A visual environment for taxiing, field takeoff and landing, aerobatics and formation flying is provided by a computer generated imagery system. Currently, a two-cockpit system of this type is being installed for use as an experimental visual system for research in undergraduate pilot training.

This system is limited in application since it lacks the capability to present high resolution target imagery for tank target acquisition.

e. System E. This system is comprised of multiple pentagon shaped display channels which are mosaiced together to form a partial dodecahedron shell surrounding the cockpit in a manner similar to System D. Each display channel has a CRT with pancake window virtual image optics. Unlike System D, each CRT has a shrunken raster capability to provide high resolution target imagery.

The target imagery is generated by a television camera which views a gimbal mounted aircraft model. The background scene of terrain and sky is computer generated. The background and aircraft images are displayed in time sequence. The background scene is displayed on each full-size raster while the target image is superimposed on the background with a shrunken raster. The shrunken raster provides high resolution in the target image.

The display electronics of each window require very high performance subsystems. These include wide bandwidth video amplifiers and linear horizontal and vertical deflection systems. The deflection systems must be linear and accurately matched to maintain image continuity as the aircraft image moves across window interfaces and to maintain proper image perspective as the aircraft raster is changed in size to simulate a change in target range. High-brightness CRT's are used because of the one-percent efficiency of the pancake windows.

Currently, a two-cockpit system of this type is being installed for use as an experimental visual system for research in air combat tactics and in air-to-air combat training. This system is limited in application since simulation of takeoff and landing is not provided.

f. System F. This system is comprised of a single row of flat rear projection screens mounted side-by-side around the cockpit. Each screen is illuminated by a color light valve television projector. A computer-generated imagery system feeds colored surface imagery to each of the television projectors.

A visual environment is provided for taxiing, takeoff and landing, formation flying and weapons delivery. Currently, an experimental system of this type is being evaluated to determine its potential for undergraduate pilot training. This system is limited in application since it lacks sufficient resolution for air-to-air combat simulation.

g. System G. This system is comprised of a spherical screen and a point light source with a gimbal-mounted planar transparency. The gimbal system translates and rotates the transparency with respect to the point light source to portray motion of the simulated vehicle. The scale of the scene can be changed in steps by changing the transparency. Some down time is required to change transparencies.

The point light source provides a continuous wide angle display with a translational background which is desirable for simulation of taxiing, takeoff and landing. However, the point light source has the disadvantages of relatively poor resolution at close ranges, low brightness, and a very limited geographical area. The geographical area is particularly limited where low scale factors are used to provide the needed resolution for take-off, landing and low altitude flight.

PRESENT TECHNOLOGICAL LIMITATIONS

1. Narrow Angle Visual System Limitations. Currently, narrow-angle visual systems are limited in field of view to about 60 degrees horizontal with a resolution of from 4 to 15 minutes of arc. The better resolution of 4 minutes of arc can be obtained from motion picture film at the expense of scene flexibility. However, the scene content of a motion picture visual system is inherently programmed or semi-programmed. A conventional motion picture is an example of a programmed scene. No provisions are made for the scene to change in response to any trainee or instructor control inputs; the scene only can be watched. A motion picture system with variable anamorphic scene distortion is an example of a semi-programmed scene. Provisions are made for the visual scene to change realistically in response to trainee inputs through the simulator flight controls. However, the simulated flight path is limited to a narrow corridor about the original path of the photographing aircraft. If the simulated flight path moves outside of a narrow flight envelope, the scene will be lost.

Non-programmed visual systems are available with television or computer-generated imagery. These systems respond to trainee inputs such that the simulated flight paths are unrestricted within the geographical and altitude limits of the image generation system. The resolution and image quality of these systems generally are poorer than that of motion picture systems, but the freedom of flight and flexibility of the television and computer generated imagery systems are preferred for most flight missions.

2. Wide Angle Visual System Limitations. Currently, wide angle visual systems with mosaiced television displays are limited in field of view to about 240 degrees horizontal with a resolution of 14 minutes of arc throughout the total field of view. Horizontal fields of view up to 360 degrees are available with a transparency and point light source. A gimbal mounted projector may be used to superimpose a small target image on the 360-degree background scene. In such systems, the wide-angle background scene is limited in resolution to about 15 minutes of arc while the narrow-angle target image is limited to about 2 minutes of arc.

A summary of present and near-term wide angle visual system limitations is provided in Table D-8. Upper and lower performance limits are shown for each system parameter. The system or systems that exhibit each upper and lower parametric limit are identified by letter codes. Performance parameters for each system type are listed in Table D-7, and a description of each system type is provided in Section 3 of this appendix.

3. Design Limitations. It would be desirable to design a system with all of the favorable parametric limits of Table D-8, the more favorable value being the upper or lower limit depending upon the parameter. Unfortunately, this is not possible because many of the parameters involve tradeoffs with other related parameters. Table D-9 indicates some of the parameters that interact in visual systems. In general, improvement of one parameter will result in the degradation of a related parameter.

For example, a wide field of view is usually accomplished at the expense of image resolution and brightness. Figures D-5 and D-6 illustrate some of the constraints encountered in the tradeoff of resolution and brightness for a greater field of view. The family of curves in Figure D-5 indicate that the limiting resolution of a television display system is degraded as the display field of view is increased. The family of curves in Figure D-6 indicate that the brightness of a projected image on a spherical display screen decreases as the display field of view is increased.

The resolution of a target image can be improved by decreasing the projection angle of a zoom projector lens. This effect is illustrated in the family of curves in Figure D-7. Two desirable features of a projector zoom lens are apparent in this family of curves. First, the variable image magnification offers a means to simulate changes in target range, and secondly, the compression of the target information improves the resolution of the small target image where high resolution is needed most. The zoom projector technique will be used in a Navy wide angle visual system that is scheduled for delivery in fiscal year 1977. This visual system will provide a small target image resolution that approaches the limit of the human eye (approximately one minute of arc).

VISUAL SYSTEM DEVELOPMENT GOALS

1. Near-Term Goals. Near-term goals for the next two to three years are to use and refine existing visual system technology to meet the Army's present pilot training requirements. Current efforts are directed toward the development of two prototype visual systems, one for the CH-47 (Device 2B31) and one for the AH-1Q (Device 2B33). These visual systems are scheduled for delivery in fiscal year 1976 as part of the CH-47 and AH-1Q prototype flight simulators. Both of the visual systems will employ camera-model board technology with state-of-the-art optics and electronics. Special image generation techniques are being developed for the 2B33 to simulate weapons trajectories and impact signatures.

The Army's 2B31 and 2B33 visual display systems will provide high resolution color imagery that exceeds the overall performance of any existing visual system. The projected resolution of the 2B33 visual system is compared with that of an existing visual system and that of the real world in Table D-10. The data for the existing visual system is based on the capability of a typical visual system in use by the airlines. The ranges in the table for real world capabilities are based on the assumptions that a tank can be detected as an object when it subtends an angle from 1.5 to

TABLE D-8

RANGE OF WIDE ANGLE VISUAL SYSTEM PERFORMANCE PARAMETERS

Performance Parameters	Lower Limit		Upper Limit	
	Data	System Type*	Data	System Type*
Background Display				
Number of Channels	1	B	8	E
Resolution, Center (Arc Min/OLP)	4	G	20	F
Resolution, Edge (Arc Min/OLP)	4	G	20	F
Field-of-View, Total (Deg)	108 x 48	C	300 X 142	E
Field-of-View, Per Channel (Deg)	36 x 24	C	360	A
Luminance (Ft-L)	.1	A	8	C
Contrast	10:1	D,E	20:1	C,F
Color	Monochrome	D,E	Full Color	C,F,G
Refresh Rate (No./Sec)	30	D,F	Continuous	B
Lag (Sec)	.05	C	.1	D,E,F,
Position Accuracy (Deg)	.3	B	Varies w/Alt	G
Geometric Distortion (Percent)	Less than 1	B,D,E	Varies w/Alt	G
Target Display				
Resolution, Max FOV (Arc Min/OLP)	1.7	A	6	B
Field-of-View, Max (Deg)	10	A	60	B
Luminance (Ft-L)	0.4	A	8	E
Contrast	15:1	B	20:1	E
Color	Monochrome	B,E	Full Color	A
Refresh Rate (No./Sec)	30	A,B	60	E
Lag (Sec)	0.1	B,E	0.1	B,E
Position Accuracy (Deg)	1	E	Less than 1	E
Geometric Distortion (Percent)	Less than 1	A	Less than 5	B
Aircraft Flight Performance Envelope				
Altitude Range, Min/Max (Ft)	50/10,000	B	0/500,000	F
Maneuvering Area (NM X NM)	4x4 (X Scale)	G	1250 X 1250	D
Velocity (Knots)	550	C	1400	A
Acceleration (G's)	0.09	G	Unlimited	D,F
Pitch Excursions (Deg)	+20	G	Unlimited	A,C,D,E,F
Pitch Velocity (Deg/Sec ²)	+40	G	Unlimited	D,F
Pitch Acceleration (Deg/Sec ²)	80	C	Unlimited	D,F
Roll Excursion (Deg)	+20	G	Unlimited	A,B,C,D,E,F
Roll Velocity (Deg/Sec)	+40	G	Unlimited	D,F
Roll Acceleration (Deg/Sec ²)	150	C	Unlimited	D,F
Heading Excursion (Deg)	Unlimited	All	Unlimited	All
Heading Velocity (Deg/Sec)	57.3	G	Unlimited	D,F
Heading Acceleration (Deg/Sec ²)	80	C	Unlimited	D,F
Computer Rates				
Motion Equations (Cycles/Sec)	7.5	D	100	A,G
Command Signals (Cycles/Sec)	15	D	30	B
Display Size, Width X Length X Ht (Ft)	11 x 8 x 8	C	25 x 25 x 20	G
Display Weight (Lbs)	1000	B	13,000	D

*Sec Table D-7.

TABLE D-9

VISUAL SYSTEM PARAMETER INTERACTION

Performance Parameters	Number of Channels	Field-of-View per Channel	Luminance	Contrast	Color	Refresh Rate	Image Generation Source	Type of Display
Number of Channels		X						X
Field-of-View per Channel	X							X
Resolution		X	X	X	X		X	
Luminance		X		X	X	X		X
Contrast			X		X	X		
Color			X	X			X	
Refresh Rate			X	X			X	
Lag			X			X	X	X
Position Accuracy						X	X	X
Geometric Distortion		X					X	X
Maneuvering Area							X	
Display Size	X	X						X
Display Weight	X							X

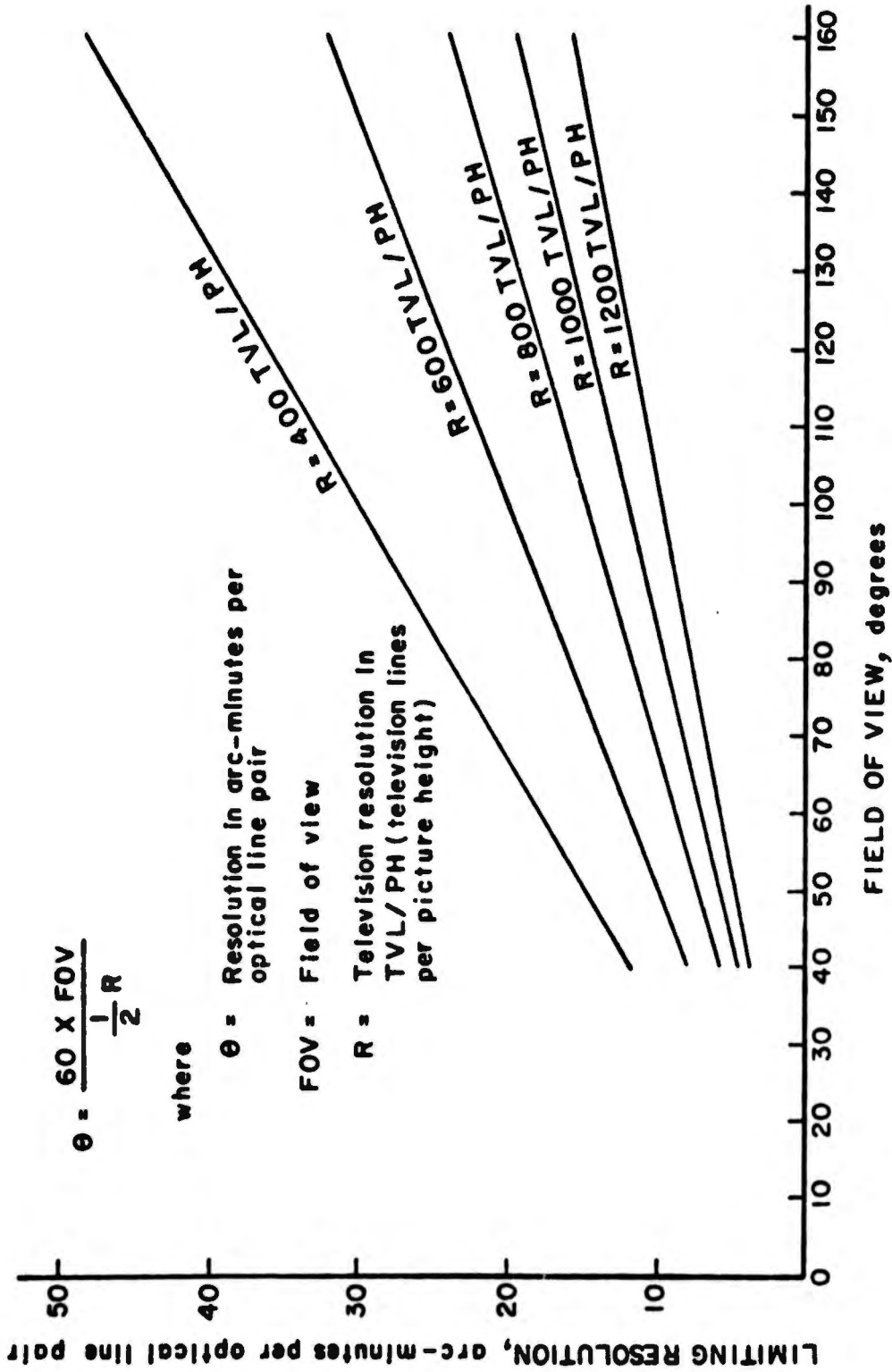


FIGURE D-5. LIMITING RESOLUTION VERSUS FIELD OF VIEW

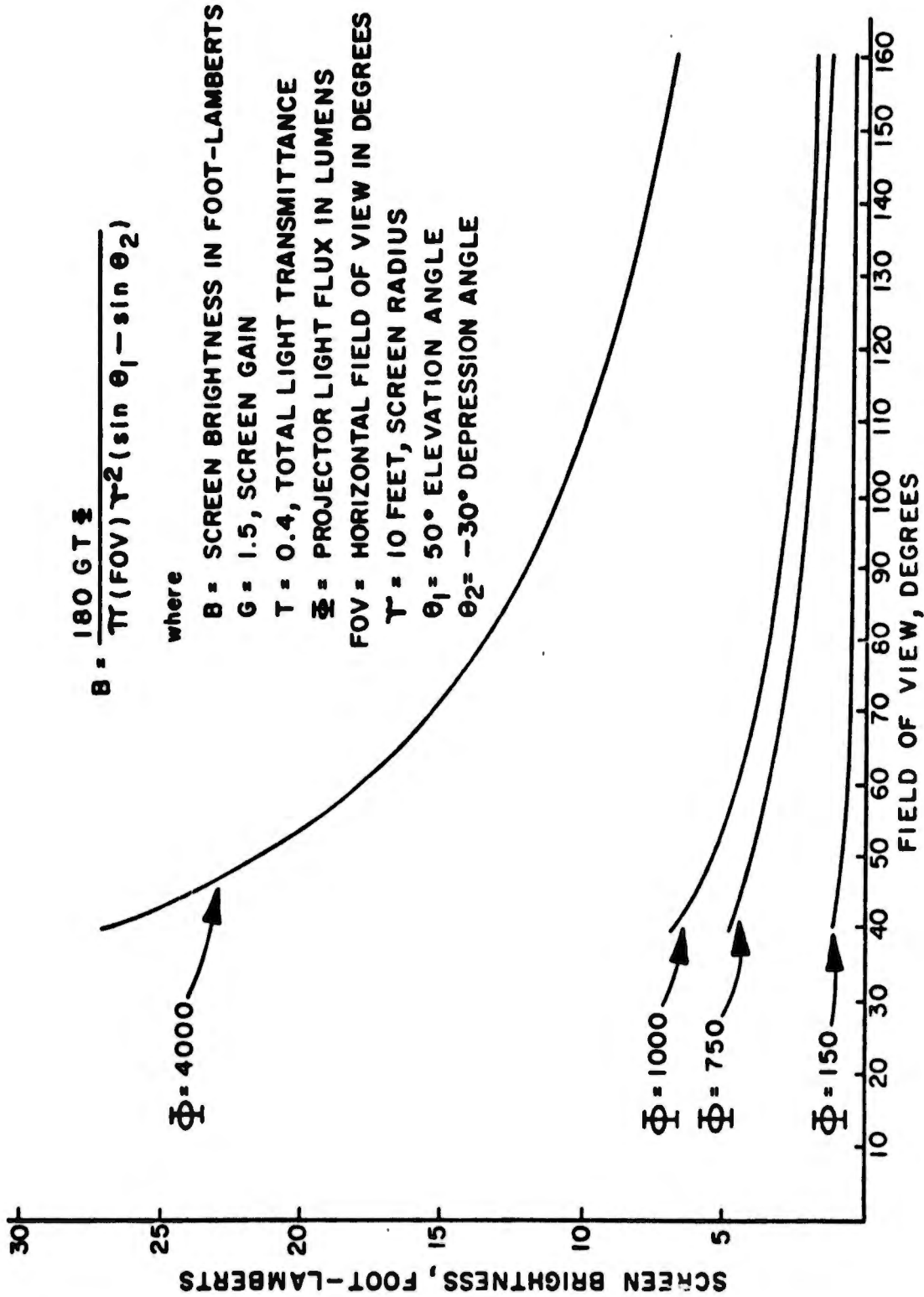


FIGURE D-6. SPHERICAL SCREEN BRIGHTNESS VERSUS FIELD OF VIEW

$$\theta = \frac{240}{R} \tan^{-1} \frac{W}{2D}$$

where

θ = Resolution in arc-minutes per optical line pair

R = Television resolution in TVL/PH (television lines per picture height)

W = Target maximum width

D = Target range

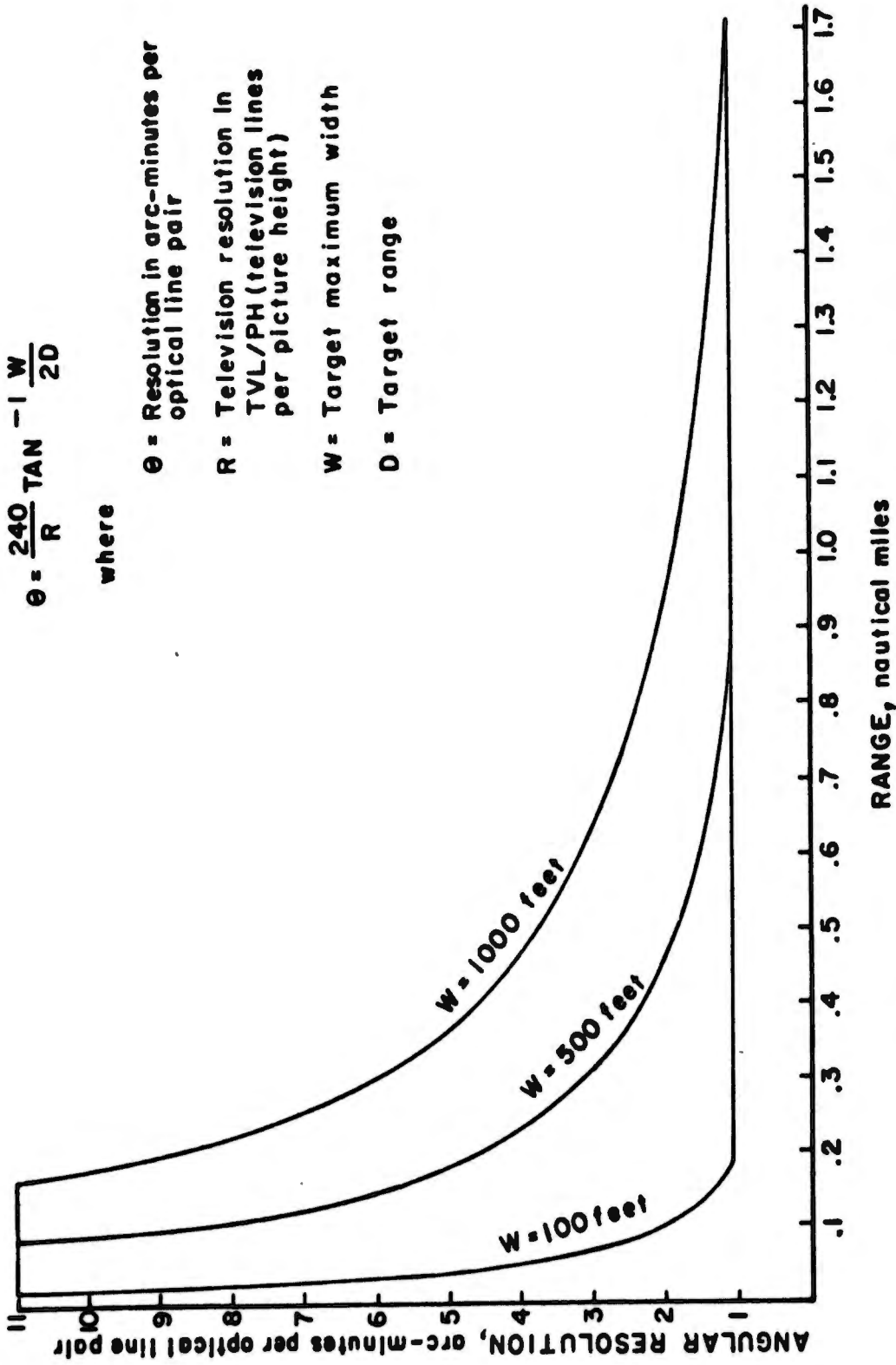


FIGURE D-7. ANGULAR RESOLUTION VERSUS TARGET RANGE FOR 10:1 ZOOM PROJECTOR LENS

3 minutes of arc; that it can be recognized as a tank when it subtends an angle from 5 to 10 minutes of arc; and that it can be identified as friend or foe when it subtends an angle from 20 to 40 minutes of arc.

While the resolution capability of the 2B31 and 2B33 visual systems will be significantly better than that of existing visual systems, further development is required to approach the desired real world capabilities. However, minimum resolution requirements should be determined for each visual task to avoid unnecessary development and procurement costs for resolution that may not be needed.

TABLE D-10
CAPABILITIES OF EXISTING, DEVELOPMENTAL,
AND DESIRED VISUAL SYSTEMS

Visual System Status	Visual System Resolution (Minutes of Arc)	Display Field of View (degrees)	Tank Detection Range (meters)	Tank Recognition Range (meters)	Tank Identification Range (meters)
Existing	14	38 x 50	1500-3000	500-1000	100-300
Developmental	9	36 x 48	2000-4000	700-1200	150-450
Desired (Real World unaided eye)	1	120 x 270	4300-8700	1300-2600	300-600

2. Mid-Term Goals. Efforts over the next three to five years will be directed toward general upgrading of near term capabilities and determining the most effective mix of visual system techniques. Mid-term goals include the development of wide angle visual systems for the Army's developmental helicopters. Particular emphasis will be placed upon the generation of data needed to develop a tactical visual display system with a nap-of-the-earth (NOE) training capability. In pursuit of this goal, the Army Research Institute for the Behavioral and Social Sciences (ARI) has an on-going program of research in the NOE training area. During fiscal years 1976 and 1977, ARI plans to procure a wide angle NOE visual system as a research facility. The ARI research effort plus developments from other government and industrial research should result in a technically feasible approach to a cost effective NOE visual system.

3. Long-Term Potentials. The potential for the next five to ten years is to provide full field of view simulation with high resolution imagery over a wide area. It is anticipated that computer-generated imagery (CGI) may have the potential to accomplish this objective for most, if not all, of the Army's pilot training tasks. However, the acceptability of a CGI visual system would depend upon the acceptability of the symbolic imagery of a CGI visual scene. Model boards with wide angle laser scanning systems

have the potential to provide high resolution realistic imagery over a wide angle (up to 360 degrees horizontal). The concept for a wide angle laser scan visual system has been developed by industry.

ASSESSMENT OF RISKS

The definitions of Table D-11 will be used in the assessment of technological and training risks. Hardware risk is a function of the current state-of-the-art while training risk is a function of the system application. The distinction between technological and training risks is important because a visual technique may have a low hardware development risk with a high training risk or vice versa. An example of a visual system with low hardware risk and high training risk would be one that could be built to a set of hardware specifications with little or no difficulty but after completion it may provide little or no positive training for a given application. A visual system may have a low training risk for one application, but a moderate or high risk for a different application. Obviously, it is desirable for a visual system to have both low hardware risk and low training risk.

Possible applications of image generation sources to Army pilot training tasks are indicated in Table D-12. Hardware and training risks for each application are identified individually by letter code. The risk codes are defined in Table D-11. Wide angle visual display systems that could be applied to Army pilot training tasks are indicated in Table D-13. Again, hardware and training risks are indicated by the letter codes defined in Table D-11. In each case, the system applications and risk assessments are based on engineering judgment. A thorough analysis of specific pilot training requirements should be conducted before any image generation sources or visual display systems are applied to an aircraft-specific visual system procurement. It is apparent from Tables D-12 and D-13 that existing image generation sources and visual display systems must be improved or new techniques developed before all of the Army's visual flight training tasks can be accomplished with a single simulator.

TABLE D-11

DEFINITION OF RISK CODES

Risk Code	TEC (Technological)	TRG (Training)
L (Low Risk)	Technology in general use	Proven effective by similar technique
M (Moderate Risk)	Engineering development required	Unproven but analysis endorses
H (High Risk)	Research and development required	Unproven without significant analysis

TABLE D-12

IMAGE GENERATION SOURCES APPLIED TO ARMY FLIGHT TRAINING TASKS

Visual Flight Tasks	Image Generation Sources							
	Risk Assessment (See Table D-11)	Terrain Model Board/ Television Camera	Target or Helicopter Model/ Television Camera	Computer Generated Imagery (CGI)	Motion Picture Film	Film Transparencies	Computer Animated Photography Special Effects (Fog, Base, etc.) Generation System	
Stagefield Takeoff and Landing (day and night)	TEC	L		L	L	L	M	M
	TRG	M		H	M	H	H	M
Confined Area and Pinnacle Operations	TEC	M		M			M	M
	TRG	M		H			H	M
Reconnaissance	TEC	M	M		L		M	M
	TRG	H	H		H		H	M
Nap-of-the-Earth	TEC	M					M	M
	TRG	M					H	M
Target Acquisition	TEC	M	M	M	L		M	M
	TRG	M	M	H	H		H	M
Weapons Delivery	TEC	L	M			L		M
	TRG	M	M			H		M
Hover - Transport	TEC	M		M				
	TRG	M		M				
Navigation	TEC	M			L		M	
	TRG	H			H		H	
Formation	TEC		M	M		L		
	TRG		M	M		L		
Autorotation	TEC	M					M	
	TRG	M					H	

TABLE D-13

VISUAL DISPLAY SYSTEMS APPLIED TO ARMY FLIGHT TRAINING TASKS

Visual Flight Tasks	Wide Angle Visual Display Systems							
	Risk Assessment (See Table D-11)	A. Point Light Source Sky-Earth Projector, CRT Projectors with Shrunken Raster and Gimballed Optics, Spherical Screen with a CRT Virtual Image Window	B. Point Light Source Sky-Earth Projector, Gimbal Mounted CRT Projector with Shrunken Raster and Refractive Optics	C. Matrix of Color CRT's with Mirror/Beamsplitter Virtual Image Optics	D. Mosaic of Monochrome CRT's with Pancake Window Virtual Image Optics	E. Mosaic of Monochrome CRT's with Shrunken Raster and Pancake Window Virtual Image Optics	F. Single Row Matrix of Color Light Valve Projectors with Flat Rear Projection Screens	G. Point Light Source with Planar Transparency and Spherical Screen
Stagefield Takeoff and Landing (day and night)	TEC	L	L	M	M		L	L
	TRG	M	H	M	M		M	M
Confined Area and Pinnacle Operations	TEC			M	M		L	L
	TRG			H	H		H	H
Reconnaissance	TEC			M	M		L	L
	TRG			H	H		H	H
Map-of-the-Earth	TEC	L		M	M		L	
	TRG	H		H	H		H	
Target Acquisition	TEC	L		M				
	TRG	H		H				
Weapons Delivery	TEC	L	L	M		M		
	TRG	H	M	M		M		
Hover - Transport	TEC			M			L	
	TRG			M			H	
Navigation	TEC				M		L	
	TRG				H		H	
Formation	TEC		L		M	M	L	
	TRG		M		M	M	M	
Autorotation	TEC		L	M	M			L
	TRG		H	H	H			H

APPENDIX E

PROJECT MANAGER TRAINING DEVICES (PM TRADE) CHARTER

DESIGNATION OF PROJECT MANAGER

Colonel Leland A. Wilson was designated Department of the Army Project Manager for Training Devices effective 9 September 1974. The project manager reports to the Commanding General, U.S. Army Materiel Command (AMC). This is the initial charter for the Project Manager (PM), Training Devices (TRADE), and it will be reviewed annually on its anniversary date by the project manager to insure currency and adequacy.

MISSION

The Project Manager (PM) Training Devices (TRADE) is responsible for project management of Army Training Devices, except those training devices under the cognizance of AMC Major Subordinate Commanders and other Project/Product Managers, in accordance with DoD Directive 5000.1, AR 1000-1, AR 70-17, AR 71-7, AMCR 11-16, and other pertinent regulations. The PM TRADE exercises direct control over the U.S. Army Training Device Agency (ATDA), Orlando, Florida.

AUTHORITY AND RESPONSIBILITY

The project manager has been delegated the full line authority of the Commanding General, AMC, for the centralized management of the Training Devices project, and is responsible for:

1. Planning, directing, and controlling and allocation and utilization of all resources authorized for execution of the approved projects.
2. The definition, development, product assurance, initial procurement, production, distribution, and integrated logistic support to accomplish project objectives.
3. Achieving the technical performance objectives of the projects, as stated in the requirements documents, on schedule and at the lowest practicable cost. Cost parameters shall be established which consider the cost of acquisition and ownership; discrete cost elements (e.g., unit production cost, operating and support cost) shall be translated into "design to" requirements. Traceability of estimates and costing factors, including those for economic escalation, shall be maintained.
4. Practical trade-offs between training devices capabilities, costs and schedules within the bands of performance of the training device requirements. Trade-off decisions will give full consideration to the effect on training devices support effectiveness and integrated logistics support resource elements.

5. Assuring that planning is accomplished and that, except as otherwise directed, the execution of the projects conform to the plans, including implementation by the organizations responsible for the complementary functions of integrated logistic support, product assurance and operational testing, and activation or deployment of training devices and related equipment.

6. Assuring that all major decisions are supported by a comprehensive Decision Risk Analysis (DRA).

7. Providing full support and responsiveness to the management authority for any training devices under the cognizance of AMC Major Subordinate Commanders and other Project/Product Managers.

8. Appropriate utilization of the AMC corporate and commodity laboratories in the solution of project technical problems and insuring that project industrial contractors are fully aware of the technical resources and expertise available in these laboratories.

9. Exercises direct control over the U.S. Army Training Device Agency (ATDA) Orlando, Florida. The Commanding Officer, ATDA reports to the PM TRADE and is responsible for research, development, and engineering of training devices and selected training aids through the application of selected resources of the Naval Training Equipment Center (NTEC) to fulfill Army requirements in accordance with the joint Army-Navy agreement of 20 March 1950.

Paragraph VIII. B. identifies offices and organizations which are responsible for the execution of specifically assigned project tasks, and other participating organizations which support the project manager in accordance with DoD and DA directives and regulations.

ASSIGNED ARMY RDTE PROJECTS AND TASKS

The project manager is responsible for the Army RDTE projects listed in Table E-1.

ASSIGNED PROCUREMENT PROGRAM ELEMENTS

The project manager is responsible for the procurement program for non-system training devices and assigned selected training aids and system training devices, including product improvement, initial production facilities, and other customer procurement, as required.

OTHER ASSIGNED PROGRAMS AND TASKS

The project manager is responsible for:

1. Serving as the principal focal point below Headquarters, DA, for training devices acquisition and support.

TABLE E-1

ASSIGNED ARMY RDTE PROJECTS OR ITEMS

Title	Element Code	DA Project
Synthetic Flight Training System	6.32.09.A	1X263209DB39
Synthetic Flight Training System	6.42.04.A	1X264204D275
Nonsystems Training Devices [Includes priority tasks for the Combined Arms Tactical Training Simulator (CATTS) and the Multiple Integrated Laser Engagement System (MILES)]	6.47.15.A	1X764715D572
Army Support for Naval Training Equipment Center	6.47.15.A	1X764715D573

Other Training Devices RDTE Projects as may be assigned on a tasking basis by the applicable program manager.

2. Insuring optimum commonality, compatibility and interoperability within and between training device components.

3. Participating in and providing technical support as required in the establishment of intra-Army and inter-service engineering design standards and test specifications for training devices.

4. Providing or insuring provision of, technical assistance to Headquarters, DA, staff agencies and major Army commands in the execution of their responsibilities in the field of training devices and, in particular, participating with U.S. Army Training and Doctrine Command (TRADOC) and U.S. Army Forces Command (FORSCOM) in defining explicit requirements which are commensurate with available technology, permissible costs and schedules.

5. Insuring effective configuration management to include identification, control and status accounting of training device specifications and component interfaces.

6. Insuring that an effective product assurance program is established for the materiel life cycle, to include reliability, maintainability, quality assurance, test and assessment.

CONTRACTOR PERFORMANCE MEASUREMENT

The project manager is specifically responsible for establishing and maintaining a system for contractor performance measurement in the areas of cost, schedule, and technical performance. As part of his management of the project, he will:

1. Continually monitor and analyze the variances between the amount of work planned and that accomplished; and between the amount of work accomplished and the actual costs. Should the provisions of DoDI 7000.2 (Performance Measurement for Selected Acquisition) be or become applicable to the training devices program, data generated by this requirement and called for on the Contract Data Requirements List (DD Form 1423) will be used for contractor performance measurement. Otherwise he may establish some other techniques which will enable him to perform as effectively as practicable the required variance analysis. As a result of his analysis in contractor performance, the project manager will identify potential or incipient problem areas and will develop and define alternatives, and depending upon the authority threshold, he will take or recommend actions to overcome the problems with minimum adverse effect upon the program.

2. Insure his project meets the performance objectives stated in the requirements documents. He will maintain continued surveillance of technical characteristics to detect and correct sub-standard performance.

INTERFACE AND PARTICIPATING ORGANIZATIONS

1. Interface Organizations

- a. Office of the Secretary of Defense
- b. Defense Supply Agency
- c. Department of the Army
- d. Department of the Navy
- e. Department of the Air Force
- f. Other U.S. Military Commands, as applicable
- g. Foreign Governments, as required

2. Participating Organizations

- a. U.S. Marine Corps

The Marine Corps Liaison Officer, Naval Training Equipment Center, Orlando, Florida coordinates with the project manager and communicates directly with the Commandant of the Marine Corps (Director, Training and Education Division, Code MT), Headquarters, Marine Corps, concerning Marine Corps participation in Army projects. He assists the project manager in management for timely coordination of all Marine Corps - Army matters within the purview of the program. He is responsible to the Commandant of the Marine Corps, as his representative for representation in the project, subject to the authorities and responsibilities delineated herein. The Marine Corps Liaison Officer, Naval Training Equipment Center is delegated authority to speak for the Commandant of the Marine Corps in matters pertinent to the TRADE development, subject to the limitations prescribed herein. Reliance is placed on his ability to refer to the appropriate

designated authority those matters requiring decisions by higher echelons. His authority to act independently is limited by referral to the Commandant of the Marine Corps prior to taking actions which:

- 1) Require deviation from established Marine Corps policy.
- 2) Require Marine Corps funding of the project.
- 3) Change delivery schedules for Marine Corps procured material.

b. U.S. Army Training and Doctrine Command

Support the project manager as prescribed by Army regulations and DA directives, i.e., operator and maintenance training, training device requirements (TDR), input to qualitative/quantitative personnel requirements information, and basis of issue.

c. U.S. Army Forces Command

Support the project manager as prescribed by Army regulations and DA directives, i.e., unit training support requirements.

d. U.S. AMC Commodity Commands

Provide design, fabrication, production assurance, integrated logistics support of training devices and plan for and procure GFE equipment as required.

e. U.S. Army Test and Evaluation Command

Conducts developmental tests and special tests in accordance with current regulations.

f. U.S. Army Ballistic Research Laboratories

Work on a task basis for the project manager to provide data in support of training devices, i.e., (ballistic data).

g. U.S. Army Human Engineering Laboratories

Work on a task basis for the project manager to provide assessment of human factors associated with training devices.

h. Other U.S. AMC Corporate Laboratories

As tasked by the project manager, design and develop or contribute to the design and development of particular configuration items of training devices. Perform theoretical and empirical analyses as required.

i. U.S. Army Logistics Evaluation Agency

Participates in review of RDTE efforts for logistical implications and the adequacy of integrated logistic support planning.

j. U.S. Army Materiel Systems Analysis Agency

Conduct effectiveness studies and trade-off analyses as tasked by the project manager through Director of Plans and Analysis, AMCPA-S, Headquarters, AMC.

k. Defense Contract Administration Services

Contract administration

l. U.S. Army Operational Test and Evaluation Agency

Operational test and evaluation.

m. Fort Benning, Georgia

Provides administrative support in accordance with a separately negotiated intra-service support agreement.

n. U.S. Army Research Institute for Behavioral and Social Sciences

As tasked by the project manager through ODCSPERS assists in assuring training effectiveness of training devices at all stages of requirements generation, development, and evaluation.

COMMUNICATION CHANNELS

1. The project manager has a direct channel of communication to the Commanding General, AMC, the Chief of Staff, Army, and to the Secretary of the Army should any of the participating organizations fail to respond to project requirements in any of the several management areas.

2. Direct communication is authorized between all participants involved in implementation of the approved project to assure timely and effective direction and interchange of information between participants.

3. Prior to communicating with the Office of the Secretary of the Army, Office of the Chief of Staff, or interface agencies not part of DA, the project manager will apprise the Department of the Army System Coordinator (DASC) or the appropriate Army staff agency of the communication to insure coordination and assistance.

RESOURCE CONTROL

1. Army resources to accomplish the above responsibilities will be provided directly to the project manager by Headquarters, AMC. The project manager will, in turn, provide the necessary monetary resources to the ATDA or appropriate participating organizations for support provided in accordance with applicable regulations and policies. Other departmental resources pertinent to assigned missions will be provided directly to the project manager by Military Interdepartmental Purchase Request (MIPR).

2. The staff of the project manager is the source of personnel to perform management functions in the areas of personnel and training management, program management, procurement and production, system engineering, configuration management, product assurance and test, human factors engineering, producibility engineering and planning, cost estimating and analysis, and integrated logistics support management.

3. The project manager is responsible for cost control of his projects, and he is specifically responsible to insure that the procurement cost is minimized through cost control, change control, contractual enforcement, and contractor motivation. In the execution of this responsibility he will maintain continual surveillance of the variance between planned cost of the work performed and actual cost for that work to detect and ameliorate incipient cost growth, and he will insure that each contract change is analyzed for life cycle cost impact prior to execution.

4. To insure effective resource control, the project manager will provide system Life Cycle Cost Estimates during the early stages of development which will serve as baseline estimates for total system costs. The baseline estimates will be established as initiating points for cost tracks on each system program. Estimates of acquisition costs should be continually reassessed and reestimated as necessary. Operating costs in the baseline estimates will be reassessed only as required for appropriate decision points, or for managerial control, as the project manager or higher authority may determine.

LOCATION AND ADMINISTRATIVE SUPPORT

The Project Manager, Training Devices is located at Fort Benning, Georgia, with necessary facilities and administrative support being provided by that organization. Field Offices or liaison teams may be created by the project manager, as required, without change of charter. Necessary facilities and administrative support will be provided by the command/activity where established.

TRANSITION

1. The status of the training devices project precludes the development of a realistic phase out date, and transition plans have not been addressed.

2. Six months prior to the transition of an individual training devices project, a transition agreement will be negotiated with the applicable U.S. Army Materiel Command major subordinate command or activity to identify the manager who will assume responsibility for materiel management and support of the training device.

SPECIAL DELEGATION

The Commanding General, AMC, has delegated direct control of the U.S. ATDA, Orlando, Florida, to the Project Manager, TRADE.

APPROVED HOWARD H. CALLOWAY DATE 23 DEC 1974

APPENDIX F
INFORMATION SOURCES

The following organizations provided information for inclusion in this plan:

U.S. ARMY

Aeromedical Research Laboratory, Fort Rucker, AL
Agency for Aviation Safety, Fort Rucker, AL
Air Systems Division, HQ, Army Materiel Command, Alexandria, VA
Air Systems Division, HQ, Department of the Army, Washington, D.C.
Air Mobility R&D Laboratory, Ames Research Center, CA
Aviation Center, Fort Rucker, AL
Deputy Chief of Staff for Training, Training and Doctrine Command,
Fort Monroe, VA
Electronics Command, Fort Monmouth, NJ
Human Engineering Laboratory, Aberdeen, MD
Missile Command, Redstone Arsenal, Huntsville, AL
National Guard Bureau, Department of the Army, Washington, D.C.
Night Vision Laboratory, Fort Belvoir, VA
Project Management Office, AAH, Aviation Systems Command, St. Louis, MO
Project Management Office, ASH, Aviation Systems Command, St. Louis, MO
Project Management Office, UTTAS, Aviation Systems Command,
St. Louis, MO
Research Institute for the Behavioral and Social Sciences, Arlington, VA
Reserve, HQ, Department of the Army, Washington, D.C.

U.S. NAVY

Naval Training Equipment Center, Orlando, FL
Training Analysis and Evaluation Group, Orlando, FL

U.S. AIR FORCE

Human Resources Laboratory, Williams AFB, AZ
Human Resources Laboratory, Wright-Patterson AFB, OH
System Project Office for Simulators, Wright-Patterson AFB, OH

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

Ames Research Center, Moffett Field, CA

OTHER ORGANIZATIONS

American Airlines Flight Academy, Fort Worth, TX
Human Resources Research Organization, Fort Rucker, AL
Martin-Marietta Corporation, Orlando, FL
Northrup Corporation, Hawthorne, CA
Philco-Ford Corporation, Western Development Laboratory, Palo Alto, CA
Singer, Simulation Products Division, Binghamton, NY
Vought Systems Division, Link-Temco-Vought, Dallas, TX

APPENDIX G

SUMMARY - BASIS OF ISSUE FLIGHT SIMULATORS

(UNDER SEPARATE COVER)

APPENDIX H
SUMMARY OF FUNDING

(UNDER SEPARATE COVER)

APPENDIX I

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