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ABSTRACT

Designed to help trainers of military maintenance technicians evaluate the cost-effectiveness of using maintenance simulators as opposed to using actual equipment trainers, this report documents the value of using the synthetic training devices to duplicate the performance characteristics of operational equipment under both normal and many malfunction conditions. The report also outlines an evaluation of 12 studies conducted since 1967 which show that student achievement in courses that used maintenance simulators was either the same or better than those in courses using actual equipment trainers. While it is noted that the acquisition cost of maintenance simulators was typically less than that of actual equipment trainers, the report cautions that this finding must be qualified by the fact that effectiveness is based primarily on school achievement rather than on-the-job performance, and cost figures are based primarily on acquisition rather than on life cycle costs.
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COST-EFFECTIVENESS OF MAINTENANCE SIMULATORS FOR MILITARY TRAINING

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August 1981



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ABSTRACT

The cost-effectiveness of maintenance simulators, compared to actual equipment trainers, is evaluated for training military maintenance technicians. Maintenance simulators are as effective as actual equipment trainers when measured by student achievement at school; there is no difference in the job performance of students trained either way, according to supervisors' ratings, in only one study. The acquisition cost of maintenance simulators is typically less than that of actual equipment trainers. The cost to develop and fabricate one unit of a simulator was less than 60 percent of the cost of its counterpart actual equipment trainer in 7 of 11 cases investigated. The cost of fabricating an additional unit of the simulator was less than 20 percent of the cost of its counterpart actual equipment trainer in 9 of these 11 cases. Acquisition and use of a maintenance simulator over a 15-year period would cost 38 percent as much as an actual equipment trainer, according to the only life-cycle cost comparison that has been reported. Since maintenance simulators and actual equipment trainers are equally effective and since maintenance simulators cost less, it is concluded that maintenance simulators are cost-effective compared to actual equipment trainers. This finding is qualified because it is based on a limited number of comparisons, because effectiveness is based primarily on school achievement rather than on the job performance, and because it is based primarily on acquisition rather than on life-cycle costs.

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SUMMARY

A. PURPOSE

This paper evaluates the cost-effectiveness of maintenance simulators, compared to actual equipment trainers, for training military personnel to maintain military equipment.*

B. BACKGROUND

Maintenance simulators are synthetic training devices that appear to duplicate the performance characteristics of operational equipment under normal and many malfunction conditions. Actual equipment trainers are operational equipments that are provided with power, inputs, and controls needed to make them operate in a classroom. Maintenance simulators incorporate some type of computer support to provide a large variety of malfunctions for instructional purposes, are designed to withstand abuse in a classroom, do not expose students to dangerous conditions, and can measure student performance for the information of both students and instructors. They are generally less expensive to procure than actual equipment trainers. Actual equipment trainers provide students an opportunity to train on the actual equipment they will be expected to maintain after

*In 1976, the Defense Science Board recommended cost-effectiveness evaluations of military training. This study is one of several undertaken in response to that recommendation. The study was performed for the Office of the Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology), under the technical cognizance of the Military Assistant for Training and Personnel Technology.

they leave school. Limitations of such trainers are that, being designed for operational rather than instructional purposes, they may break down and be difficult to maintain in a classroom setting. They provide only limited opportunities for demonstrating malfunctions because instructors must install "faulty" components, which always takes some time and may be inconvenient. Actual equipment trainers do not include facilities for measuring student performance; this would require a complex and costly process of redesign.

C. EFFECTIVENESS

The effectiveness of maintenance simulators has been evaluated in 12 studies conducted since 1967. These involved maintenance training for equipment used in sonar, avionics, radar, propellers, flight control, navigation, aircraft power plant, communication, and ship automatic boiler control systems. Student achievement in 12 courses that used maintenance simulators was the same as or better than that in comparable courses that used actual equipment trainers; in one case, student achievement with a maintenance simulator was less. In one case where on-the-job performance was evaluated, supervisors' ratings showed that there was no difference between students trained with a simulator or an actual equipment trainer. Students trained with maintenance simulators completed their courses in less time than did those who used actual equipment trainers. In three cases where such data were collected, time savings were 22, 50, and 50 percent, respectively. Most students who use maintenance simulators have favorable attitudes toward their use; instructors are split about equally in having favorable, neutral, or negative attitudes toward the use of these simulators.

D. COST

Maintenance simulators appear to cost less to acquire than do actual equipment trainers. The cost to design, develop, and fabricate one unit of a simulator is less than 60 percent of the unit cost of its counterpart actual equipment trainer in 7 cases out of a sample of 11; in the remaining four cases the simulators cost more than the actual equipment trainers. Once developed, the cost of fabricating an additional unit of a simulator is less than 20 percent of the unit cost of its counterpart actual equipment trainer in 9 of those 11 cases; in only one case did the simulator cost more to fabricate than the actual equipment trainer.

In the one available case of a life-cycle cost-effectiveness evaluation, the Air Force 6883 Test Stand Three-dimensional Simulator was as effective as the actual equipment trainer, both at school and on the job. The total costs for the same student load over a 15-year period were estimated to be \$1.5 million for the simulator and \$3.9 million for the actual equipment trainer; that is, the simulator would cost 38 percent as much to buy and use as would the actual equipment trainer.

CONCLUSIONS

Conclusion 1. Maintenance simulators are as effective as actual equipment trainers for training military personnel, as measured by students' achievement at school and, in one case, on the job. The use of maintenance simulators saves some of the time needed by students to complete courses, but data on this point is limited. Students favor the use of maintenance simulators; instructors are favorable, neutral, or negative toward the use of simulators in about equal numbers.

Conclusion 2. The acquisition cost of maintenance simulators are typically less than that of actual equipment trainers. The cost to develop and fabricate one unit of a simulator was less than 60 percent of the cost of actual equipment trainers in 7 of 11 cases examined; the cost to fabricate an additional unit of a simulator was less than the 20 percent of cost of actual equipment trainers in 9 of the 11 cases. The one available life-cycle cost estimate shows that purchase and use of a simulator would cost 38 percent as much over a 15-year period as it would to buy and use an actual equipment trainer.

Conclusion 3. Maintenance simulators are as effective as actual equipment trainers for training maintenance personnel. In addition, they cost less to acquire. Therefore, maintenance simulators are cost-effective when compared with actual equipment trainers.

Conclusion 4. In general, the data on the cost and effectiveness of maintenance simulators have not been collected systematically. Therefore, there is no basis at present for making trade-offs between the effectiveness and cost of different types of maintenance simulators on such issues as two-dimensional

versus three-dimensional design, the complexity of maintenance simulators (in such terms as number of malfunctions and instructional procedures), the extent to which simulators should provide a mixture of training in general maintenance procedures and/or for maintaining specific equipments, and the optimum combination of maintenance simulators and actual equipment trainers for training technicians at school.

There have been insufficient studies on the amount of student time saved with the use of maintenance simulators. There have been no studies on whether the use of maintenance simulators influences the amount of student attrition at school. There have been no studies to collect objective measures of performance of maintenance technicians on the job after training, either with simulators or actual equipment trainers.

Conclusion 5. Maintenance simulators now under development have not yet taken advantage of recent technological advances such as videodiscs, automated voice input and output, and miniaturization sufficient to make them readily portable. Reductions in size would make it possible, as well as more convenient, to use maintenance simulators for refresher training near job sites and for performance evaluation and/or certification of maintenance personnel on an objective basis in operational environments. Extreme reductions in size would make it possible to use maintenance simulators as job aids in performing maintenance on operational equipment, thus assuring a close link, not yet available, between facilities used for training at school and for performance on the job.

RECOMMENDATIONS

Recommendation 1. Collect data to enlarge what is now known about the effectiveness of maintenance simulators and actual equipment trainers at school. Data are needed on specific knowledge and skills acquired by students at school, the time needed to complete courses, attrition rates, and instructor attitudes toward the use of simulators and actual equipment trainers.

Recommendation 2. Collect objective data on the performance of technicians on the job after training with simulators or actual equipment trainers. Determine the transfer of training of maintenance skills from school to the job, when either maintenance simulators or actual equipment trainers are used in training courses. Such data should be collected in a way that will permit a determination of the relative effectiveness of maintenance simulators with varying characteristics such as, types of design, degrees of complexity, physical appearance, and in generic and specific maintenance training courses.

Recommendation 3. Collect cost data in sufficient detail to permit the development of cost-estimating relationships for maintenance simulators. The cost elements should account for all portions of the total costs incurred to procure and use maintenance simulators and actual equipment. A suggested structure for the collection of procurement cost data is contained in this paper.

Recommendation 4. Design and conduct studies of training with maintenance simulators and actual equipment trainers, that will yield trade-offs between the level of effectiveness and total cost as functions of the characteristics of training

equipment, the ways it is used, and the types of training involved.

Recommendation 5. Develop a procedure to categorize the functional characteristics of maintenance simulators and actual equipment trainers in ways that will relate to their effectiveness for training.

Recommendation 6. Develop objective measures of the job performance of maintenance personnel in operational settings to provide valid measures with which to evaluate the effectiveness of simulators and actual equipment trainers.

I. INTRODUCTION

A. PURPOSE

The purpose of this paper is to evaluate the cost-effectiveness of maintenance training simulators, compared to actual equipment trainers, for use in training military personnel to maintain operational equipment. Both types of equipment have been used at technical training schools to train personnel to perform corrective and preventive maintenance at organizational and intermediate levels.

Actual equipment trainers have long been used in technical training schools for two significant reasons: (1) they can be acquired simply by ordering additional units of operational equipment already being procured for use in weapon and support systems; and (2) they provide realistic training on the equipment to be maintained after the student leaves school. Operational equipment is often modified for training purposes by, for example, placing it on a stand and adding power supplies, input signals, and controls needed to make it operate in a classroom. There has been a trend, in recent years, to use maintenance training simulators rather than actual equipment for training purposes. Maintenance simulators are said to have advantages for use in training such as lower cost, ability to demonstrate a wider variety of malfunctions, and more freedom from breakdown in the classroom. These advantages will be considered later in this paper.

The purpose of maintenance training is, obviously, to train personnel to maintain complex equipment; this requires both technical knowledge and manual job skills. Maintenance

training familiarizes the student with the layout of the equipment, sources of power, use of tools and test equipment, safety requirements, control settings, instrument readings, operating procedures, and the like. Maintenance personnel must be able to diagnose malfunctions; identify, replace, or repair faulty components; verify that all components perform within prescribed tolerances; and perform tests to insure that the entire equipment has been returned to working order. This type of training can be provided by a variety of means such as conventional classroom instruction, studying technical manuals, learning fault-finding procedures by self-study, computer-assisted or computer-managed instruction and, of course, the use of various types of training devices. The issue addressed in this paper is whether maintenance simulators are more cost-effective than actual equipment trainers for training military maintenance personnel.

Even if maintenance simulators are more cost-effective at school for training personnel, it is obvious that training is supposed to prepare technicians to maintain operational equipment in the field and not just to perform well at school. Thus, the major substantive issue is to compare how personnel trained with maintenance simulators or actual equipment trainers actually maintain operational equipment in the field. Whether this question can be answered on the basis of currently available information is considered later.

B. TYPES AND LOCATIONS OF MAINTENANCE ACTIVITIES

There are two main types of maintenance activities:

1. Corrective maintenance applies to equipment that has failed or is known to be operating improperly. In the typical case, a malfunction is noted and reported by operational personnel who use the equipment and repaired by the maintenance personnel. Corrective maintenance involves troubleshooting, diagnosing the

reason for a malfunction, identifying the component (or components) that has failed, repairing and/or replacing the faulty component (or larger module of which it may be a part) and, finally, testing and calibrating to assure that the malfunction no longer exists.

2. Preventive maintenance applies to equipment that has not failed and appears to be operating properly. It involves periodic inspection, cleaning, testing, and calibrating of equipment; this may include the replacement of functioning parts in accord with schedules established to reduce the possibility of future breakdowns.

To be effective, both types of maintenance require not only proper training but also proper tools, test equipment, relevant and up-to-date technical documentation, and efficient diagnostic procedures; the equipment itself must be designed to permit convenient access, test, repair, and replacement of parts; and there must also be a proper supply of spare parts and an adequate number of maintenance personnel, including supervisors, to handle the workload.

Maintenance activities are also associated with the places where they occur. There are three types, as described below:

1. Organizational maintenance is performed on equipment on the flight line or in the field by maintenance personnel assigned to the unit that operates the equipment. It consists generally of inspecting, servicing, lubricating, adjusting, and replacing faulty assemblies and subassemblies (line-replaceable units or LRUs).
2. Intermediate maintenance is performed in maintenance shops by personnel assigned to a base or support organization. It generally consists of calibration, repair or replacement of damaged or unserviceable parts, the emergency manufacture of nonavailable parts, and providing technical assistance to the using organization.

3. Depot maintenance is performed at a central, industrial-type facility and consists of large-scale repair, modification, and refurbishment.

C. MAGNITUDE OF THE PROBLEM

The Department of Defense, as of 1976, possessed weapon systems and equipment which cost about \$125 billion to acquire (see Table 1). About \$49 billion was requested for procurement in FY 1982 (Brown 1981, p. 312). The purpose of maintenance is to keep these weapons and their support equipment in a state of operational readiness to meet mission requirements and to do this in a timely and economic manner. Maintenance is a critical aspect of defense planning and operations and costs \$18-20 billion each year, including the costs of spare parts, supplies, and modifications (Turke 1977, p. 5).

TABLE 1. ACQUISITION COST OF WEAPON SYSTEMS AND EQUIPMENT IN USE OR ASSIGNED, JULY 1, 1976 (TURKE, 1977)

	Acquisition Cost	
	Billions of Dollars	Percent
<u>Military Department</u>		
Army	19.2	15
Navy	61.7	49
Air Force	<u>45.3</u>	<u>36</u>
	126.2	100
<u>Weapons Group</u>		
Aircraft	54.1	43
Ships	38.8	31
Missiles	8.7	7
Vehicles	9.0	7
Other	<u>15.6</u>	<u>12</u>
	126.2	100

According to the General Accounting Office, the Army spends 25 percent (\$7.0 billion in FY 1978) of its annual budget on maintenance; over 200,000 mechanics and equipment operators in the Army have specific unit-level maintenance responsibilities (GAO 1978, p. 1). In the Air Force, maintenance requires about 28 percent of the work force (military and civilian) and costs between \$5 and \$7 billion annually (Townsend 1980). Labor for repairs is estimated to account for 39 percent of the cost of recurring logistical support (Fiorello 1975). Training is only one of many factors that influence effective maintenance, e.g., design of equipment to assure high, inherent reliability; design of equipment to permit unambiguous identification of failed components; easy access for test and replacement of components; the availability of spare parts and test equipment; up-to-date technical documentation, tools, job aids, and the like.* Specialized skill training at military schools costs about \$2.9 billion or 33 percent of the cost of individual training each year [Department of Defense, Military Manpower Training Report (MMTR) for FY 1981, p. 6]; the portion attributed solely to maintenance training is not known.

High turnover among enlisted personnel increases the difficulty of maintaining military equipment. According to planning estimates for FY 1981, about 337,000 personnel were to be recruited; 313,000 (93 percent) of these were expected to complete recruit training; only 64,000 (37 percent) would reenlist for a second term [MMTR FY 1981, p. III-3; estimate on reenlistment from all volunteer force data base, ASD (MRA&L), 20 Mar 1980].

*See Integrated Technical Documentation and Training (ITDT) (1978) and Navy Technical Information Presentation Program (NTIPP) (1977) for a review of current efforts to improve technical documentation required for maintenance; see Rowan (1973) and Post and Price (1973) for recent reviews of studies which compare performance of maintenance technicians using innovative performance aids or conventional documentation.

About 393,000 enlisted personnel were expected to complete initial skill training courses (after 8 percent attrition) and 165,000 to complete skill progression training (after 5 percent attrition) (MMTR FY 1981, p. V-4, V-7). The costs of on-the-job training which follows school training are essentially unknown (they are included among the costs for Operation and Maintenance, which are \$62.4 billion in FY 1982 (Brown 1981, p. 312).

The three Services spent over \$5 million in FY 1979 for research and development on maintenance simulators; this amount is projected to decrease to about \$1.6 million by FY 1983 (Table 2). About \$3.7 million (68 percent) of the FY 1979 funds (category 6.4 funds) were for the development and procurement of prototype equipment; about 49 percent of all funds for FY 1980-1983 would also be allocated to prototype equipment. Maintenance simulators either under contract or planned for development, as of February 1981, are listed in Table 3.

Over a 7-year period (FY 1975-1981), the Naval Training Equipment Center alone procured training equipment at a cost of \$649 million; planned procurements as of March 1980 were for an additional \$305 million. Maintenance trainers will account for \$3.2 million or 0.3 percent of these procurements; equipment with a unit cost less than \$100,000 is not included in these figures (private correspondence, NTEC N-7, 8 March 1980).

The Air Force Air Training Command estimates that the current inventory of all maintenance training devices cost \$500 million, of which \$350 million is for aircraft maintenance alone (Aeronautical Systems Division, 1978). There are thought now to be about 3600 different types of maintenance training devices in the inventory to support aircraft systems. The procurement of maintenance simulators for the F-16 aircraft is estimated to cost about \$32 million (this includes some units to be delivered to NATO countries).

TABLE 2. FUNDS FOR R&D ON MAINTENANCE SIMULATORS BY MILITARY SERVICES
 FY 1978 - 1983
 Funds (thousands of dollars)

Service/PE	FY 78 and Prior	FY 79	FY 80	FY 81	FY 82	FY 83
Army						
6.2	47	600	800 ^a	650 ^a	600 ^a	900 ^a
6.4	2000	2000	2000	--	--	--
(Total)	(2047)	(2600)	(2800)	(650)	(600)	(900)
Navy						
6.3	2723	362	516 ^b	1210 ^b	1125 ^b	--
6.4	1703	1665	233 ^c	275 ^c	302 ^c	211
(Total)	(4426)	(2027)	(749)	(1485)	(1427)	(211)
Air Force						
6.3	600	800	640 ^d	800 ^d	700 ^d	500 ^d
(Total)	(600)	(800)	(640)	(800)	(700)	(500)
TOTAL	7073	5427	4189	2935	2727	1611

^aPE 62727A-230 B0: AMTESS II, Software, BITE/AMTE. PM TRADE FY 1981 Apportionment Review, 10 June 1980.

^bPE 63733N W 1202-PN IMTS; W 1201-PN IHOMS; W 1207-PN ATE. NTEC R&D Program, February 1980.

^cPE 64703N W 0784-PN SAMT. NTEC R&D Program, February 1980.

^dPE 63751F 2361, 6883, Flat panel simulator. FY 1981 AFHRL Apportionment Review Data Book, 27 June 1980.

Source: Joint Technical Coordinating Group - Sub-group for Maintenance Simulators, December 1978 (Draft), with modifications noted above.

TABLE 3. MAINTENANCE TRAINING SIMULATORS UNDER CONTRACT FOR PRODUCTION OR DEVELOPMENT OR PLANNED FOR DEVELOPMENT (as of February 1981)

System Simulated or Simulator Designation	Service ^a	Maintenance Echelon Trained ^b	Type of Simulator ^c	Device/Program Characteristics and Status
AMTESS (Army Maintenance Training and Evaluation Simulation System)	A	--	2-D/3-D	To provide initial training in diverse skill areas. Contract let in December of 1980 for delivery, in October of 1981 of two "breadboard" units for evaluation.
EEMT (Electrical/Electronic Maintenance Trainer)	N	--	2-D/3-D	Initial (Navy A-school) training for electronic and electronic warfare technician ratings. Contracts awarded in June and July of 1980 for delivery of twenty 2-dimensional and two 3-dimensional prototype units.
Fire Control/Search Radar Maintenance Trainer	N	--	--	Initial (Navy A-school) training for fire control technician rating. Front-end analysis completed. RFP planned for release in March with contract award for units anticipated by August 1981.
6E and 11H67 Series Trainers	N	--	2-D	Small flat panel devices for basic skill training (Navy A-school) in several skill areas. Contract awards to two firms encompass 20 simulations and 194 trainers. Deliveries on one contract are scheduled to be completed in February 1981. Deliveries on the second contract are scheduled to begin in the spring of 1981 and to be completed in December.
ROLAND Institutional Trainer	A	0 and 1	2-D/3-D	Training in electronic and hydraulic systems at organizational and direct support (DS) echelons. RFP released in December 1980, contract award planned for October 1981. Contract is to include five organizational trainers, two DS echelon trainers, and two mockups.
FIREFINDER	A	0 and 1	2-D	Provides operator and maintenance (organizational and intermediate echelons) training for mortar- and artillery-locating radars. Contract awarded August 1977 for 36 trainers for operator training of both radars and maintenance training of the mortar-locating radar; deliveries began in January 1980 and should be completed in early 1981. Maintenance trainer for artillery-locating radar will be developed/procured on a subsequent contract. (See Randle 1980).

(Continued)

TABLE 3. (Continued)

System Simulated or Simulator Designation	Service ^a	Maintenance Echelon Trained ^b	Type of Simulator ^c	Device/Program Characteristics and Status
REES (Reactive Electronic Equipment Simulator)	A	0	3-D	Provides operator and organizational maintenance training for the Army Tactical Communications System (ATACS). Contract awarded in September 1977 for one 4-station network. Delivery currently anticipated for mid to late Summer 1981.
FVS (Fighting Vehicle System) Maintenance Trainer	A	0 and I	2-D	Contract has been let for design and data. Contract for fabrication planned to be funded from FY 1982 budget and to include four different simulations and a hands-on trainer, all for turret maintenance.
M-1 Tank Maintenance Training System	A	0	2-D	In procurement; includes six simulations (covering five tank subsystems) and hands-on trainer. Delivery of prototypes is scheduled to begin in February 1981. Delivery of production versions is scheduled for July 1982 to February 1984.
M109/110 Turret Trainer	A	0	2-D	In procurement, deliveries to begin in July 1981. One simulation provides training in electrical and hydraulic maintenance for self-propelled artillery.
IRR (Integrated Radio Room)	N	0	3-D	Provides operator and maintenance training of Trident submarine communications system. One system (consisting of a simulated communications system and several part-task trainers) was placed under contract in September 1979 and is scheduled for delivery in March 1981. A second system may be procured.
Mk 92 FCS (Fire Control System)	N	0	2-D	Currently on letter contract (to be made definite in February or March 1981), with first deliveries scheduled for March 1982. Configuration is a modification of the TICCIIT system that integrates conventional flat panels in a 12-student-station TICCIIT complex. Contract will involve two complexes.
CIWS (Phalanx Close-in Weapon System)	N	0	2-D	Letter contract (signed in October 1980) to be made definite in February 1981 with deliveries scheduled to begin in November 1981. Contract provisions specify delivery of 39 sets of

(Continued)

TABLE 3. (Continued)

System Simulated or Simulator Designation	Service ^a	Maintenance Echelon Trained ^b	Type of Simulator ^c	Device/Program Characteristics and Status
DD 963 Waste Heat Boiler	N	0	--	<p>eight simulations, (panels portraying different subsystems) and one 3-dimensional model.</p> <p>Contracted in December 1980 for delivery of one set of three simulations in December 1981. Firm design will not be set until March or April 1981.</p>
SQQ-89 Sonar Maintenance Trainer (formerly the Generalized Sonar Maintenance Trainer)	N	--	--	<p>Large program consisting of operation and maintenance trainers for three sonar systems. Complete program planned to consist of both simulation and stimulated operational equipment. RFP for procurement of operator trainers scheduled to be issued in March 1981, with resulting contract to be funded from FY 1981 budget. Maintenance trainer front-end studies to be contracted from FY 1981 funds with procurement planned from FY 1983 budget.</p>
Hagen ABC (Automatic Boiler Control)	N	0	2-D/3-D	<p>Prior contracts resulted in procurement and evaluation of three units employed for research. Current funding is to modify the three simulators to the current configuration of the operational equipment for use in mainstream training.</p>
Woodward Governor	N	0	--	<p>Research program. Front-end analysis essentially completed. Current funding provides for design/development of audio-visual and courseware (other than EDP) materials. Design/development of hardware and EDP software/courseware to be initiated with future year's funding.</p>
A6-E TRAM ORS (Detection and Ranging System)	N	0	3-D	<p>Two trainers delivered under prior contracts. Current funding is limited to updating these devices to the current configuration of the operational equipment.</p>
EA-6B ICAP-1 TJS (Tactical Jamming System)	N	0	3-D	<p>Procurement contract awarded in December 1980 for two units. Deliveries are scheduled for January and March 1982. Current planning includes later modification of at least one unit to the ICAP-11 aircraft configuration.</p>

(Continued)

TABLE 3. (Continued)

System Simulated or Simulator Designation	Service ^d	Maintenance Echelon ^b Trained	Type of Simulator ^c	Device/Program Characteristics and Status
AT Trainer	N	0	3-D	Military in-house program initiated in December 1975. Delivery of partially configured trainers in June 1979 (1 device) and December 1980 (2 devices). Modification of delivered trainers to full design configuration is scheduled for completion in November 1981.
MA-3 Test Bench/CSD (Constant Speed Drive)	N	I	3-D	Research program. Single device delivered in August 1980. Current funding provides support for on-site training evaluations.
SH-3 Blade-fold Trainer	N	0		Front-end analysis scheduled for completion during Summer 1981. No decisions regarding the program are anticipated before that time.
F-18 Maintenance Trainers	N	--	--	Front-end study recommended a mix of simulations and operational equipment trainers. RFPs for five simulators were released in January 1981. Contract awards are expected to begin in April 1981. Procurements will be managed by McDonnell Douglas as sub-contracts to the basic weapon contract.
6883 Test Bench (Flat Panel Trainer)	AF	I	2-D	Research program. Single device delivered in August 1980. FY 1981 funding is to support an on-site training evaluation.
F-16 Maintenance Simulators	AF	0	2-D/3-D	Initial contract (September 1977) provided for delivery of six sets of 18 simulations. Deliveries of six sets of 12 modified (degraded) simulations were completed by September 1980. FY 1981 and later funding is to provide for retrofit of delivered articles to their initial design configuration and production/delivery of the remaining simulations.
E-3A (AWACS) Radar	AF	0	2-D	In development. Contract awarded in September 1980 for one simulator, containing 10 student stations. Delivery anticipated in May 1982.
E-3A (AWACS) Data Display/Control System	AF	0	--	Front-end analysis nearing completion. RFP scheduled for release in March 1981. Contract award anticipated at the end of FY 1981.

(Continued)

TABLE 3. (Continued)

System Simulated or Simulator Designation	Service ^a	Maintenance Echelon ^b Trained ^d	Type of Simulator ^c	Device/Program Characteristics and Status
EA-6B ICAP-II CNR (Communication/Navigation)	N	0	--	Front-end analysis and detailed specification scheduled for completion in April 1981. Funding for procurement anticipated from the FY 1982 budget.
E-3A (AWACS) Advanced Radar Maintenance Trainer	AF	0	--	For training to advanced skill level. Functional requirements study in initial stages. Contract award not anticipated before the end of FY 1982.
AN/TPS-43E Radar	AF	0	3-D	Military in-house project. Program initiated in early 1977. First device placed in use in late 1978. A second unit is currently being fabricated

^aA. Army, N: Navy, AF: Air Force^d

^b1. Intermediate-level maintenance, 0 Organizational-level maintenance.

^cTwo-dimensional, three-dimensional.

^dProposed for M 109/110 howitzer turret, M60 tank, M809 truck, radar illuminator.

^eAlso called the Simulated Avionics Maintenance Trainer.

One large industrial contractor has estimated that the Department of Defense will spend about \$620 million for maintenance trainers over the period 1977-1985; annual procurements are estimated to reach about \$120 million per year by 1985 (Fig. 1). The distribution of this procurement, according to type of trainer, is predicted to be as shown in Fig. 2. Outside the United States, the procurement of maintenance simulators is estimated to be about \$5.5 million per year.

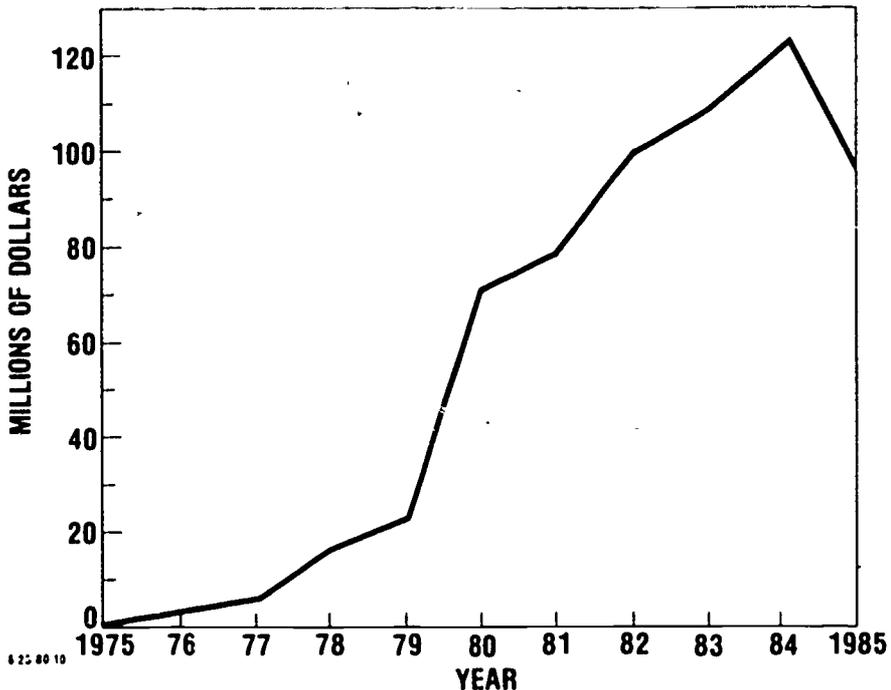
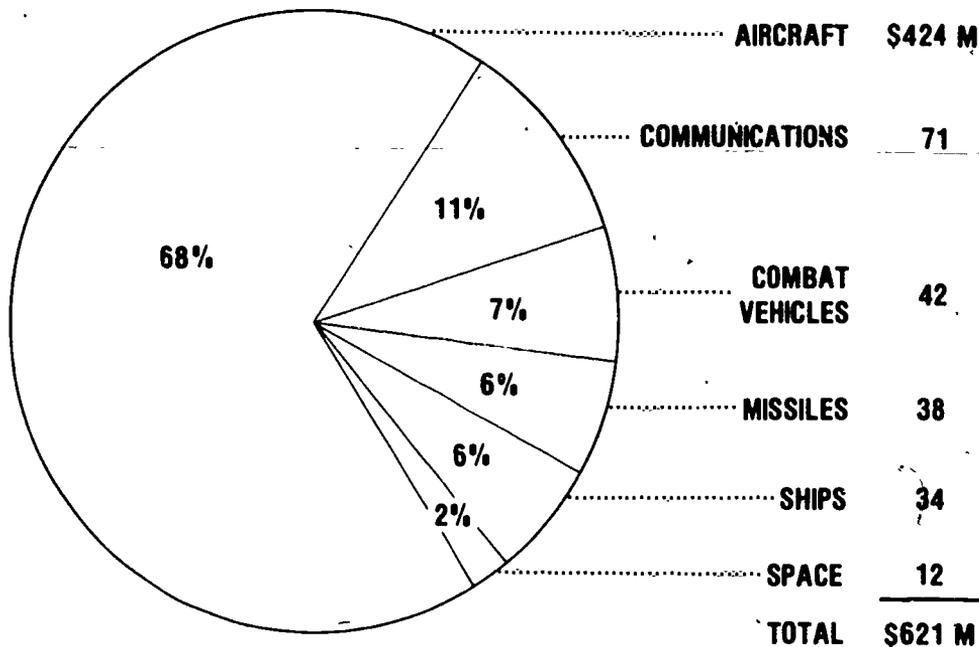


FIGURE 1. Estimated procurement of maintenance trainers by the Department of Defense, 1975-1985 (as of November 1979)



6 25-001

FIGURE 2. Predicted procurement of maintenance trainers by the Department of Defense, according to type of application, 1977-1985 (estimate made in November 1979)

The "Electronics-X" study, conducted in 1974, was a major effort to determine the cost and reliability of military electronic equipment (Gates, Gourary, Deitchman, et al., 1974). Four methods were used to estimate the cost of maintaining electronics equipment each year. The results ranged from \$3.4 billion to \$6.8 billion, with an average of \$5.4 billion per year (Gates, Gourary, Deitchman et al., 1974, Vol. II, p. 374). The estimate of \$5.4 billion per year for maintenance is about equal to the cost of procuring electronic equipment each year (Gates, Gourary, Deitchman et al., 1974, Vol. I, p. 52). Note that procurement costs relate to acquiring current technology;

the maintenance costs relate to systems whose average age is about 10 years.

Advanced military equipment has become more complex in order to provide improved performance. Increased complexity brought increased cost and decreased reliability, the latter imposing increased demands on maintenance personnel and resources. The Electronics-X study showed that the reliability of avionics equipment in the field decreases with increases in unit cost for aircraft in accordance with the following relationship:

$$\text{Aircraft MFHBF}^* = 1.3 \times 10^6 / \text{cost} .$$

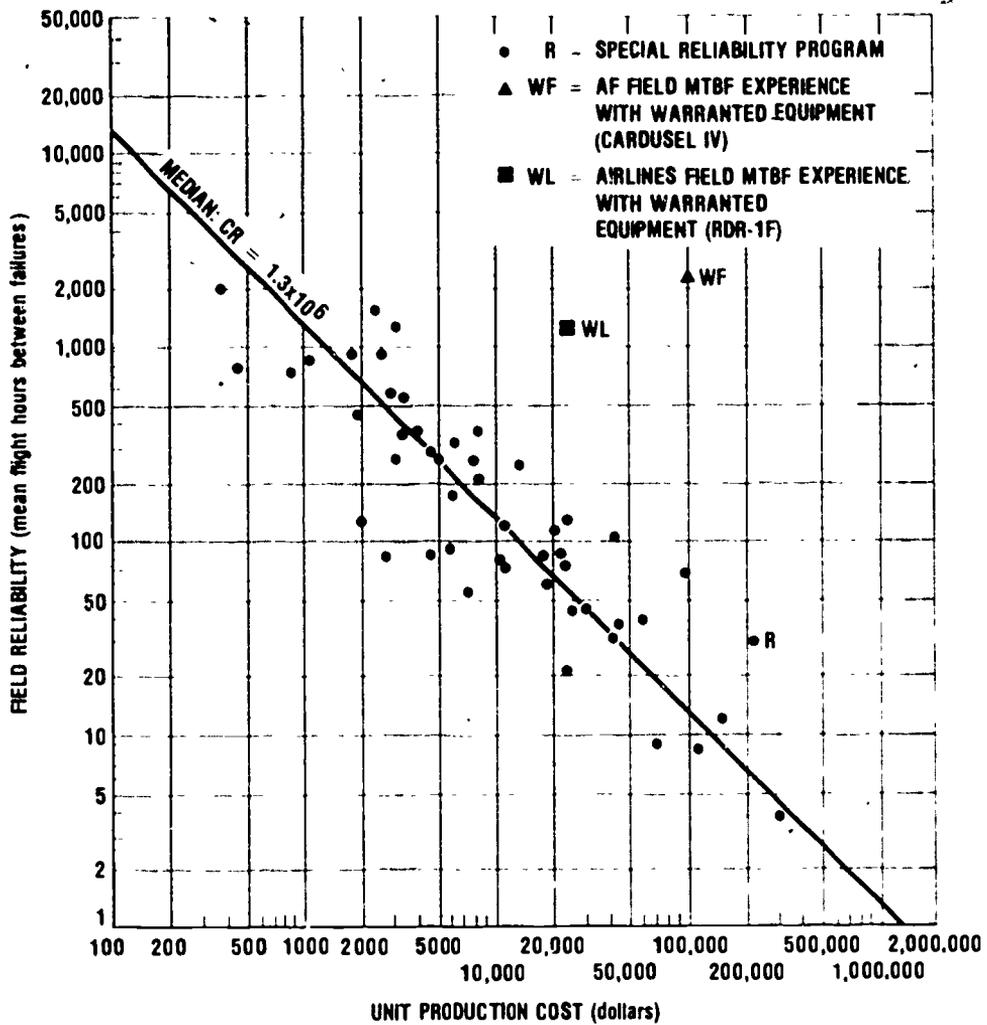
As shown in Figure 3, more expensive (and more complex) electronics equipment has a lower reliability and creates a larger demand on maintenance activities than does less expensive equipment (Gates, Gourary, Deitchman, et al. 1974, Vol. I, p. 56). A similar relationship, based on limited data, was found for Army Area Communications Systems (AACS) where

$$\text{AACS MTBF}^{**} = 10^7 / \text{cost} .$$

The costs for manpower were estimated by a Defense Science Board (DSB) Task Force on Electronics Management to account for perhaps as much as 75 percent of the military electronics maintenance costs; actual costs are unknown due to limitations in the cost allocation system (DSB, 1974, p. 14).

*Mean flight hours between failures.

**Mean time between failures.



11 18 80 12

3

FIGURE 3. Avionics field reliability versus unit production cost

D. TYPES OF MAINTENANCE SIMULATORS

Maintenance simulators now under development differ notably in their resemblance to actual equipment, their functional capabilities as instructional devices, and in their complexity and cost. Modern maintenance simulators are often characterized as 2-D or 3-D devices, i.e., as being two- or three-dimensional in their physical form; some simulators contain both 2-D and 3-D components.

The 2-D devices consist of flat panels with drawings of major components connected symbolically by flow diagrams to show electrical and/or hydraulic functional connections between components. The panels contain functioning instruments, signal lights, and controls, so that the technician can turn on power to the equipment, see if it is working correctly, and observe the effects of various actions he may take to identify and correct the malfunctions that are present. Such panels perform as if they were real equipment because each contains a computer, with a mathematical model of the real system that makes the displays respond appropriately to all settings of the controls under all environmental conditions likely to be encountered. By setting a switch on his panel, the instructor can select a malfunction from a large set contained in the computer. The equipment scores the student's performance and tells him whether he has correctly identified a malfunction. The instructor can stop the sequence of activities for instructional purposes, to repeat what the student has done, and demonstrate the correct way of isolating a malfunction; this is done automatically in some simulators.

The manufacturers of 2-D simulators have developed software packages and computer and support equipment that can be used with a number of different panels. This has led us to distinguish between what later in discussing costs we call "standard" and "non-standard" maintenance simulator systems.

Standard systems, whether they are 2-D or 3-D simulators, are likely to cost less than non-standard systems.

A 3-D maintenance simulator looks and performs very much like the actual equipment it mimics. If it is a test bench, it will be possible to connect components for calibration, checkout, and tests needed to identify malfunctions. It will differ from actual equipment in that it will be ruggedized to withstand student abuse and to prevent exposing students to dangerous electrical currents or hydraulic pressures. The simulator may not contain all the components present in the actual equipment, particularly those that are not relevant to its maintenance; if the equipment contains many identical components, only some will be represented. These components may be precise physical copies; in some cases, they are only accurate photographs (etched on plastic or metal) with active test-points for making test measurements. Being under computer control, all components perform or respond as if they were actual equipment; components may be tested, removed, and replaced. A 3-D simulator permits "hands on" practice in the manual maintenance skills not possible on most 2-D simulators; it also has greater physical similarity to the actual equipment. Whether or not greater physical similarity increases the effectiveness of training is not considered in this discussion.

E. OTHER INFLUENCES ON MAINTENANCE

Many factors beyond training and the use of actual or simulated equipment can profoundly influence our ability to maintain military equipment. These are noted here but they extend far beyond the scope of this paper. Among these factors are the quality of personnel recruited by the military Services (and thereby available for training as maintenance technicians), policies used by the Services to assign recruits to various occupational specialties (thereby influencing the quality of personnel who become maintenance technicians), the amount and

type of training to be accomplished at technical schools (as distinct from that to be accomplished on the job), and the complexity of the information that must be acquired in order to accomplish maintenance. Some factors that influence maintenance have little to do with personnel and training; these include equipment design and maintenance policy. The design of equipment influences both the need for maintenance (mean time between failure), and the means for accomplishing it whenever required (e.g., ease of access to components, built-in test points, manual or automatic fault detection). Maintenance policy determines whether failed components should be repaired or replaced, the availability of spare parts, tools, test equipment and up-to-date technical documentation.

F. ADVANTAGES OF MAINTENANCE SIMULATORS

The advantages of simulators for training maintenance personnel have been argued for more than 25 years (e.g., R.B. Miller 1954, Gagne 1962, Lumsdaine 1960, Valverde 1968, Kinkade and Wheaton 1972, G.G. Miller 1974, Montemerlo 1977, and Fink and Shriver 1978). The major advantage of a maintenance simulator is that, as a training device, it can be designed to provide facilities important for instructing students, in contrast to actual equipment that is designed to operate effectively in an operational environment.

Maintenance simulators can be designed to include a large variety of faults with which maintenance personnel should be familiar, including faults that cannot be demonstrated conveniently on actual equipment trainers or that occur rarely in real life. All modern maintenance simulators incorporate some type of computer support. Thus, the symptoms of many types of complex faults can be stored in the computer and selected simply by a control setting on the instructor's console. Computer-supported equipment can also record what the student

does, thereby reducing the need for constant observation by the instructor. The instructor can use information collected by the computer to guide each student; a computer can also assist the student without an instructor's intervention. Records of student performance and achievement can be maintained automatically. Simulators can be made rugged enough to sustain damage or abuse by students and thus provide greater reliability and availability in the classroom than is often possible with actual equipment. Training which would be avoided because of safety reasons, e.g., exposure of students to dangerous electrical charges or hydraulic pressures, can be undertaken with little risk with a simulator. If students using such equipment complete their training in less time, as has often been the case with computer-based methods of instruction, there are potential cost benefits due to savings in student time, increased student throughput, and reduced need for instructors and support personnel.

As noted above, a simulator need not contain all the components found in the actual equipment. Thus, it is often possible to build a simulator that offers greater flexibility and capacity for training at a cost less than that for an actual equipment trainer.

G. DISADVANTAGES OF MAINTENANCE SIMULATORS

There are also some disadvantages to the use of simulators. The procurement of maintenance simulators necessarily involves costs to design and build this special equipment, and to develop course materials, maintenance procedures, and documentation. The types of training provided by simulators may not provide the student with all the skills needed to maintain operational equipment, an outcome that seems assured when actual equipment is used for training. A simulator may not be ready when needed for training because its design and development requires some

effort in addition to or at least parallel to that needed for the actual equipment (which is being produced as part of some system); modifications in the design of the actual equipment may delay completion of the simulator, if it also must be modified. If there are many and frequent modifications, the original simulator may not resemble the operational equipment closely enough to be useful for training.

Data on the effectiveness and cost of maintenance simulators and actual equipment trainers are considered in the following chapters.

II. THE EFFECTIVENESS OF MAINTENANCE SIMULATORS

The purpose of maintenance training, whether with simulators or actual equipment, is to qualify technicians to maintain equipment in the field. In fact, however, the effectiveness of maintenance simulators for training technicians has been compared to that of actual equipment only on the basis of student performance at school and not on the job; there is one exception to this general statement (Cicchinelli, Harmon, Keller, et al., 1980). The lack of job performance data to validate training (and other activities relevant to personnel, such as recruitment, selection, and reimbursement) applies generally to all types of military training and not only maintenance training.

A. EFFECTIVENESS OF MAINTENANCE SIMULATORS AT SCHOOLS

We found 19 studies, conducted over the period of 1967 to 1980, that compare the effectiveness of maintenance simulators and actual equipment trainers for training in a variety of courses at military training schools; these are described in Appendix A. Only 12 of these studies provide enough detailed information to permit meaningful comparisons; these are summarized in Table 4.

Relatively complete data were found on five maintenance simulators evaluated in 14 different courses, e.g., radar, propellers, engines, flight controls, FM tuner, test equipment, and the Hagen Automatic Boiler Control; most are associated with aviation. These courses varied in length from 3 hours to 5 weeks (median 4.7 days, $N = 12$ courses); the number of subjects trained with simulators in these courses varied from 6 to 56 (median 16, $N = 14$ groups); a grand total of 267 students was

TABLE 4. SUMMARY OF STUDIES ON THE EFFECTIVENESS OF MAINTENANCE SIMULATORS, 1967-1980

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	COMPARISONS SIMULATOR TO ACTUAL EQUIPMENT				ATTITUDE TO SIMULATORS(2)	REFERENCE	
			NO OF SUBJECTS(3)	EFFECTIVENESS(1)					TIME SAVINGS
				POORER	SAME	BETTER			
Generalized Sonar Maintenance Trainer	Sonar maintenance (special course)	4 days(3)	9		•	22%(4)	Students favorable	Parker and DePaul, 1967	
	Intermediate General Electronics	4 weeks	20		•			DePaul and Parker, 1968	
ECB	APG 126 Radar		17				+	Spangenburg 1974	
	Mohawk Propeller System	3 hrs	33		•			Darst 1974	
	Hydraulic and Flight Control	32 hrs	13		•	•	•+	Wright and Campbell 1975	
	Engine, Power Plants and Fuel	24 hrs	12		•	•	+	Wright and Campbell 1975	
	Environmental/Utility System	32 hrs	9		••		+	Wright and Campbell 1975	
	APG 126 Radar	60 hrs	15		••		0+ 0+	McGura, Paper and Miller 1975 Puff 1976	
	Pilot Familiarization, T 2C	18 hrs	6				+	Bersner 1975	
Flight Officer Familiarization, TA 4C	11 hrs	30				+	Bersner 1976		
Automated Electronics Maintenance Trainer	FM Tuner							Medrick, Kanarich, Daniel and Gardner 1975	
	Power Control for ALM 64 Test Equip							Medrick, Kanarich, Daniel and Gardner 1975	
	ALM 106B Test Set							Medrick, Kanarich, Daniel and Gardner 1975	
	Visual Target Acquisition System							Medrick, Kanarich, Daniel and Gardner 1975	
Generalized Maintenance Training System	SRC 20 UHF Voice Command System		20			ABOUT 50%	+	Rigney, Teebe, King and Moran 1978	
	SPA 61 Radar Repeater	16 hrs	10				+	Rigney, Teebe, Moran, et al. 1978	
Fault Identification Simulator	Hagen Automatic Boder	5 wks	16		•	ABOUT 50%		Swezey (in Kintade 1978)	
6883 Converter/Flight Control Systems Test Station	F 111 Avionics Maintenance	6 days(5)	56		•		+	0+	Cicchone, Harrison, Keder et al. 1980

(1) Some studies provide more than one comparison

(2) + = favorable; 0 = neutral; - = unfavorable; • = neutral to mildly favorable

(3) Simulator only

(4) Average of five maintenance tests in that test

(5) Training with 6883 takes 3 days of a 25 week course; 6 days in the special test

(41)

3

involved in all of these studies. Effectiveness was evaluated by comparing the scores of students who used simulators with those of students who used actual equipment trainers in end-of-course tests. There are 13 comparisons; in 12 of these, students trained with simulators achieved test scores the same as or better than those trained with actual equipment; in one case, scores were lower. The differences, though statistically significant, have little practical significance.

Cicchinelli, Harmon, Keller, et al., 1980, compared supervisors' ratings of on-the-job performance of technicians trained either with a maintenance simulator (the 6883 Test Station 3-D Simulator) or actual equipment trainer. Two field surveys provided data on the job performance of 85 and 56 graduates, respectively (some twice); these comprised 74 and 49 percent, respectively, of the students in the original sample at school; some course graduates were on the job for periods of up to 32 weeks. The supervisors did not know how the students had been trained. Their ratings showed no noticeable difference between the performance of technicians trained with the simulator or actual equipment trainer. The abilities of the technicians increased with amount of time on the job.

The automated and individualized method of instruction that is an inherent characteristic of modern maintenance simulators should be expected to save some of the time students need to complete the same course when given by conventional instruction (Orlansky and String 1979). Such time savings are reported in three of these studies (Parker and DePauli 1967; Riney, Towne, King, et al. 1978; and Swezey 1978); compared to the use of actual equipment trainers, maintenance simulators were found in these studies to have saved 22, 50, and 50 percent, respectively, of the time students needed to complete the courses. Although no explanations are offered for these time savings, one could surmise that they are due to factors such as the fact that brighter students can complete a self-paced course faster than

one given by conventional, group-paced instruction, that maintenance simulators generally have greater reliability in the classroom than do actual equipment trainers, and that instructors need less time to set up training problems and/or to insert malfunctions in simulators than in actual equipment trainers.

Based on questionnaires administered at the completion of the courses, students favor the use of simulators in 9 of 10 cases and are neutral in one. Instructors are equally divided (about one-third in each category of response) in being favorable, unfavorable, or neutral in their attitude toward the use of simulators.

Overall, maintenance simulators appear to be as effective as actual equipment trainers for training military personnel at schools; there is only one contrary finding. Some of the presumed advantages of simulators were not examined in these studies and therefore cannot be evaluated, e.g., their ability to teach students how to correct a wider variety of malfunctions than can be done with actual equipment, their superior availability compared to actual equipment trainers, and their ability to measure and report student performance both to students and instructors. The findings do not suggest ways in which the use of maintenance simulators could be improved or where their use is likely to be more effective. There are no cases, except for Cicchinelli, Harmon, Keller, et al. 1980, where the effect of training upon job performance is examined; they found no difference between a simulator and an actual equipment trainer; however, Cicchinelli, Harmon, Keller, et al. do not report the amount of transfer of training from school to the job, i.e., transfer effectiveness ratios.

B. RELEVANT DATA FROM COMPUTER-BASED INSTRUCTION

Modern maintenance simulators can provide individualized instruction on a series of prescribed lessons. They can also

measure student performance and see that the student does not go to a new lesson until he has mastered the preceding ones. The instructional strategies employed in these simulators are derived from widely used methods of instruction called computer-assisted and computer-managed instruction; both are individualized and self-paced in nature and use computers to monitor student progress. In computer-assisted instruction (CAI), all the instructional material is stored in a computer and presented to the student in a controlled manner, e.g., via a cathode ray tube or a visual projection device with random access to a large reservoir of slides. The student responds to this material by touching portions of the screen sensitive to touch or by using a keyboard or teletypewriter. In computer-managed instruction (CMI), the lessons are performed away from the computer in a learning carrel or on a laboratory bench set-up. The student takes a test at the completion of each lesson; the answers, on a sheet, are scored by the computer which then directs the student to a new lesson or to additional practice on the current one.

CAI and CMI systems are not maintenance simulators but they have been used to provide certain aspects of maintenance training, e.g., knowledge of operating principles, troubleshooting procedures, fault identification, and the knowledge aspects of remove and replace actions (i.e., what the technician should do after a fault is identified rather than replace actual parts). Knowledge about maintenance procedures can be acquired on a CAI and CMI system, but this is accomplished with less fidelity and with little of the hands-on experience that can be provided by a maintenance simulator, particularly of the 3-D variety. Elsewhere in this paper, where we consider costs, we characterize some maintenance simulators as CAI-like.

In a previous study, the authors examined the cost-effectiveness of computer-based instruction in military training (Orlansky and String, 1979). Some of the courses on which

effectiveness data were available involved instruction similar to that provided on maintenance simulators, i.e., basic electronics, vehicle repair, fire control system maintenance, precision measuring equipment, and weapons mechanics. Data on student achievement in these courses are presented in Table 5; there are 28 data points which compare conventional instruction to the use of CAI and two to CMI. Student achievement in these courses at school with CAI or CMI was the same as or superior to that provided by conventional instruction; the amount of superior performance, when present, had little practical significance.

Data on the amount of student time saved by CAI or CMI in these courses, compared to conventional instruction, are shown in Table 6; there are 30 data points. The amount of time saved by computer-based instruction varied from -32 to 59 percent, with a median value of 28 percent.

These data on student achievement and on student time savings with computer-based instruction are consistent with that reported above for maintenance simulators. Orlansky and String (1979) found that students favor computer-based instruction while instructors do not. They also found that computer-based instruction may increase student attrition, a matter not considered so far in any study of maintenance simulation.

In summary, the data show that maintenance simulators are as effective as actual equipment when used for training military technicians. These results are consistent with the results of studies of computer-assisted and computer-managed instruction in courses that provide technical information similar to that provided in maintenance training. A few studies show that maintenance simulators save student time but most studies did not address this issue. Students favor the use of maintenance simulators; instructors favor, are neutral about, or do not favor such simulators in about equal numbers.

TABLE 5. STUDENT ACHIEVEMENT AT SCHOOL IN COURSES RELEVANT TO MAINTENANCE, CAI AND CMI COMPARED TO CONVENTIONAL INSTRUCTION

METHOD OF INSTRUCTION	SYSTEM	SERVICE	LOCATION	STUDENT ACHIEVEMENT AT SCHOOL (compared to conventional instruction)			TYPE OF TRAINING	REFERENCES
				INFERIOR	SAME	SUPERIOR		
CAI	IBM 1500	A	SIGNAL C&S SAN DIEGO	•	• • •	• • • • •	ELECTRONICS ELECTRICITY	IBM (1968); Longe (1969, 1972); Guntz and Longe (1973); Ford & Slough (1970); Hurlock & Lahey (1971, 1972); Ford, Slough et al (1972)
		N		•	• • •	• • • • •		
	PLATO IV	N	SAN DIEGO	• •	• • • •	• • • •	ELECTRONICS VEHICLE REPAIR	Stern (1975); Lahey, Crawford et al (1976); Slough and Coody (unpubl); Dahman, De Leo et al (1977)
	AF	CHAMUTE	• • • •	• • • •	• • • •			
	LTS 3	AF	KEESLER	• •	• •	•	ELECTRONICS	Harris, Grossberg et al (1972); Reesler AFB (1972, 1973)
100M	N	DAM NECK	•	•	•	FIRE CONTROL TECHNICIAN	General Electric Ordnance Systems (1975); Radstien and Glasston (1975)	
CMI	PLATO IV	N	DAM NECK	• •	• •	•	FIRE CONTROL TECHNICIAN	General Electric Ordnance Systems (1975); Radstien and Glasston (1975)
		AF	LOWRY	•	•	•	PREC MEASURING EOPI WEAPONS MECHANIC	Biehing (1978) Biehing (1978)
		AF	LOWRY	•	•	•		
TOTAL			1	15	17			
TOTAL				0	2	0		

Source: Oransky and Siring (1979)

011002

TABLE 6. AMOUNT OF STUDENT TIME SAVED IN COURSES RELEVANT TO MAINTENANCE, CAI AND CMI COMPARED TO CONVENTIONAL INSTRUCTION

METHOD OF INSTRUCTION	SYSTEM	SERVICE	LOCATION	STUDENT TIME SAVINGS (compared to conventional instruction)			TYPE OF TRAINING	REFERENCES
				40	20	0		
CAI	IBM 1500	A	SIGNAL C&S SAN DIEGO	•	• • •	• • • • •	ELECTRONICS ELECTRICITY	IBM (1968); Longe (1969, 1972); Guntz and Longe (1972, 80); Ford & Slough (1970); Hurlock & Lahey (1971, 1972); Ford, Slough et al (1972)
		N		•	• • •	• • • • •		
	PLATO IV	N	SAN DIEGO	•	• • •	• • • •	ELECTRONICS VEHICLE REPAIR	Stern (1975); Lahey, Crawford et al (1976); Slough and Coody (unpubl); Dahman, De Leo et al (1977)
	AF	CHAMUTE	• • • •	• • • •	• • • •			
	LTS 3	AF	KEESLER	•	•	•	ELECTRONICS	Harris, Grossberg et al (1972); Reesler AFB (1972, 1973)
100M	N	DAM NECK	•	•	•	FIRE CONTROL TECHNICIAN	General Electric Ordnance Systems (1975); Radstien and Glasston (1975)	
CMI	PLATO IV	N	DAM NECK	•	•	•	FIRE CONTROL TECHNICIAN	General Electric Ordnance Systems (1975); Radstien and Glasston (1975)
		AF	LOWRY	•	•	•	PREC MEASURING EOPI WEAPONS MECHANIC	Biehing (1978) Biehing (1978)
		AF	LOWRY	•	•	•		

Source: Oransky and Siring (1979)

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Claims have been made that maintenance simulators are superior to actual equipment for training because of their capability to demonstrate more malfunctions, provide greater freedom from breakdown in the classroom environment, provide an opportunity to save instructor time, and so on. No studies were found that examine these capabilities. No data were found on student attrition when simulators are used.

C. PERFORMANCE OF TECHNICIANS IN THE FIELD

The effectiveness of maintenance training is determined ultimately by how well maintenance personnel perform in the field rather than at school. Only Cicchinelli, Harmon, Keller, et al. 1980, among the studies we were able to find, compared the performance of students trained with a simulator (the 6883 Test Station 3-D Simulator) or actual equipment trainer for varying periods of time after leaving school. According to ratings made by supervisors, no differences were found between both groups of students.

The military services use five large data management systems to provide detailed information on the current maintenance status of military equipment. These data systems are identified below:

<u>Service</u>	<u>Maintenance Management System</u>	
Army	TAMMS	The Army Maintenance Management System
Navy	Ships' 3-M	The Naval Ships' Maintenance and Material Management System
Navy	Aviation 3-M	Naval Aviation Maintenance and Material Management System
Air Force	66-1 and 66-5	Air Force Maintenance Management Systems

We examined the possibility of using data available in these systems to describe the performance of maintenance technicians in the field (see String and Orlansky, 1981). If this yielded useful information, we might be able to compare, for example, the real short- and long-term effects of training personnel with maintenance simulators or with actual equipment trainers. We know, as was shown earlier in the chapter, that both are about equally effective at school.

As presently constituted, these systems cannot provide information useful for assessing the effectiveness of alternative methods of training. In a more general sense, this applies also to information needed to validate many personnel practices, such as recruiting, selection, and policy on pay and allowances. The names of individuals who performed maintenance actions are not kept in the records maintained in the central data files. The ability to identify and track individuals is a mandatory requirement in any attempt to relate method of training with subsequent performance. This type of data is kept only at the field activities but it is discarded after 6 months. The use of maintenance records with personal identification for analytical purposes would require special methods of processing in order not to infringe on provisions of the Privacy Act. Even so, such records are not precise enough to distinguish what parts of a maintenance action were performed by a particular individual, particularly when the work is performed over more than one shift. The practice of cross-skill maintenance, to train individuals to maintain a wide variety of equipment under combat conditions, assigns individuals to tasks for which they were not trained at school and it would complicate any analytical effort. In brief, it was concluded that presently available maintenance data records can not be used to assess the effectiveness on the job of various methods of training at school; it is conceivable that these systems could be modified to provide the data that would be needed.

That the performance of maintenance technicians affects the quality of maintenance can hardly be doubted. A few studies have examined this possibility by analyzing selected data on components removed for replacement or repair that were found later not to contain any malfunction. These studies examine data produced by a group of technicians in a particular work center; they do not review the performance of individual technicians and do not address the method(s) by which these technicians were trained.

Findings from seven studies are summarized in Table 7. All involve corrective maintenance at the organizational level, although one also involved intermediate maintenance. Most concern maintenance of aircraft, a few of surface vehicles. The periods of observation are relatively long (6 months or 1 year; one is for only one month). The removal of non-faulty parts, in these studies, accounted for 4 to 43 percent of all corrective maintenance actions and 9 to 32 percent of all maintenance man-hours. One study (Gold, Kleine, Fuchs, et al., 1980) found instances where faulty parts were not removed and where good parts were damaged during corrective maintenance.

These findings suggest strongly that, properly modified, the maintenance data systems might provide data on human performance useful for validating different methods of training. Even so, it is well to recognize that not all instances of removal of good parts necessarily imply inadequate performance of technicians. Such removals could also be due to inadequate test equipment that cannot distinguish between good and bad parts. It is also possible that, when under great pressure to return equipment to an operational status, technicians may deliberately remove and replace a large number of components just to make sure that the faulty ones have been eliminated. Validation of training devices and procedures would probably need more data on job performance than just that concerning the unnecessary removal of good parts.

TABLE 7. SUMMARY OF STUDIES OF ORGANIZATIONAL ECHELON CORRECTIVE MAINTENANCE WHERE NON-FAULTY PARTS WERE REMOVED

Equipment or System	Size of Sample	Period of Observation	Data Source	Corrective Maintenance Where Non-faulty Parts Were Removed			References
				Maintenance Echelon	Percent of Actions	Percent of Man-Hours	
F-14A Aircraft	72 Aircraft	1 yr	IM and analyses	Organizational	43		Gold, Vleine, Fuchs, et al., 1980, and private conversations with the authors
Armored reconnaissance and airborne assault vehicle (M 551)	Brigade	1 yr	Maintenance Request Form (DA 2407) and special form for study	Organizational	42	32	Dressel and Shields, 1979
Aircraft: EA-6B, E-2C, SH-3H, S-3A	All Navy 1.8M man-hours D. 4M actions	1 yr	IM and interviews	Organizational Intermediate	15 16	17 9	Jewell and Webber, 1979
Electrical components: generators, regulators, alternators, distributors, starters	Fort Carson CO	1 mo		Organizational	35		Buchan and Knutson, 1977
Vehicular Components				Organizational	43		Brown Board Survey, 1966
Aircraft: A-7D, F-111A, F-4D				Organizational Organizational Organizational	1c 9 0		Johnson and Peel, 1972
Helicopters UH-1H		6 mo	Component removed and repaired/overhaul Record (DA 2418)	Organizational	15 to 25		Holbert and Newport, 1975
CH-47C	12 ^a	6 mo		Organizational	15 to 25		

- a. Percent of total removals found serviceable, values estimated from a graph.
 b. Number of records with failure code data, 53 other records (39 percent) had no failure code.
 c. Estimated percent of transmissions found at depot to contain no defects, as reported by personnel in interviews. Due to inadequate records, study not able to compare defects reported at organizational level with those found later at depots.
 d. As above, 13 other records (10 percent) had no failure code.

III. COSTS OF MAINTENANCE SIMULATORS

A. INTRODUCTION

This chapter discusses the costs of maintenance training simulators. Three classes of simulators are defined, their characteristics and uses within the Services are discussed, and a structure of data for analyses of their costs is formulated. Available cost data for maintenance of simulators are discussed in terms of the problems, with respect to costs, that arise from their physical characteristics, procurement quantities, and contracting practices. The costs and characteristics of selected simulator programs are presented in Appendix B.

B. CLASSES OF SIMULATORS

- With respect to the costs of maintenance training simulators, it is useful to distinguish among three classes of devices, denoted here as "standard" systems, "non-standard" systems, and "CAI-like" systems. Differences among these three types lie in the following areas:
 - Physical characteristics,
 - Complexity and cost,
 - Extent of use within the Services (i.e., the inventories of devices in use and under contract), and
 - Contracting practices employed in their procurement (and hence cost data that are available).

1. Standard Systems

The critical distinction between standard and other classes of maintenance simulators is standardization of the physical configuration. Simulators of this class consist of two elements: one element, called here the "general simulation system" constitutes a generalized and adaptable (but incomplete) simulation capability that can satisfy a wide range of specific training applications. The second element, that tailors the general simulation system to a particular training application, is typically limited to courseware and pictorial or other representations (i.e., the simulation model) of the particular equipment being simulated. Standard systems were the earliest type to be used for maintenance training and are the only class to achieve extensive use. The three Services have procured close to 650 simulators for nearly 200 separate training applications (training courses or course segments).

Only four companies have manufactured standard maintenance simulator systems: Educational Computer Corporation (ECC); Burtek, Inc.; Ridgeway Electronics, Inc.; and Lockheed Aircraft Services Co. (LAS). For all but Ridgeway, this type of simulator is only one of several product lines; and for all but LAS, these companies manufacture only educational and training equipments.

Compared with the other classes of simulators, the standard systems are generally low in cost and limited in terms of the complexity of processes that can be simulated. Development of particular training applications typically involves small risks. With few exceptions, these devices have been procured through fixed-price contracts.

2. Cost Impact of Standardization

The four manufacturers have produced six standard simulator systems or models. The elements that are typically common to a model consist of data-processing hardware (a central

processor and a partial set of input/output devices), the software operating system, audio-visual devices, and structures for housing all the components of the simulator. Taken together, these are generally referred to as the "mainframe" or "console". The components that are tailored to the particular application consist of other input/output devices (typically a display panel depicting the operational and test equipment being simulated) and courseware in the form of an application program [contained in magnetic tape, disc, or plug-in programmable-read-only-memory (PROM) units].

The size and structure of display media may vary within a single model, and the same simulation application may be produced with two sizes of display panels--one for classroom demonstrations and one for individual use. Advances in micro-processor technology appear to have fostered further variations, within a model while retaining the essential attributes of standardization. One ECC model has been delivered with processor memories ranging between 16 and 48 thousand bytes. The variation in memory size has permitted corresponding variations in complexity of simulation and the use of audio/visual devices. For example, the 48-thousand-byte devices procured through an Army contract for XM-1 tank training will drive a cathode ray tube (CRT), printer, random-access slide projector, and an audio device in addition to the normal simulator display panel. A contemporary Navy contract (for entry-level skill training) specifies the same model with a 16-thousand-byte memory and with only the display panel.

The physical arrangement of standard systems appears especially adaptable for 2-dimensional trainers. However, 3-dimensional simulation is possible.

One impact of standardization is interchangeability, and this serves to reduce costs of both manufacture and repair. Individual consoles may be easily modified to different training applications. Two of the standardized models are designed

so that the tailored, specific components of any training application (the display panel and courseware) can be mated with a single console in the classroom or laboratory; a third model can be ordered with either classroom-changeable or fixed panels. As a result, a single console may be used in a number of training applications at the same location. One of these models (the ECII) provides the bulk of the simulators used in Naval aviation weapon-specific training. Naval aviation training is organized so that both maintenance and a part of pilot ground training for one model of aircraft are conducted at the same Naval Air Station (NAS) by Naval Air Maintenance Training Detachments (NAMTD). While a large number of different display panels (up to 25) may be employed for maintenance training by one detachment, a NAMTD will generally have no more than two main frames that will be shared by all pilot and maintenance training courses.

The more important cost impact of standardization lies in the commonality of system software. Available evidence points to the programming and programming design effort as the major cost of non-standard simulator development. This high cost provides a strong incentive for producers to develop a single basic software system that is both comprehensive and adaptable to a wide range of potential training applications. Development of such a software system reduces the programming associated with a particular training application to a relatively small set of courseware written in a high-level and relatively simple language that may (in the case of maintenance simulation) reduce to a sequential coding of the maintenance procedures/steps set out in technical orders.

Commonality of software is the distinguishing aspect of standardization, and manufacturers have placed a heavy emphasis on developing versatile software packages. Once developed, they are tightly held, considered proprietary, and may (at least in part) be hardwired into simulators. In addition, the software

packages have been retained while other features of the general simulation systems have been allowed to change. ECC has produced two generations of standard training simulators; the later one employs an advanced, higher capability processor and has a quite different physical appearance, but uses the earlier software package. LAS produces two models of simulators that employ different types of display panels. Yet, the two employ the same software system and seem best considered as a single generalized system.

3. Non-Standard Systems

The non-standard systems present a picture that is quite different from the standard systems. Seventeen non-standard programs (discussed in Section C, below) have been initiated; with one exception, each appears to involve a complete (i.e., ground-up) development effort. Taken as a group, their outstanding characteristic is diversity, encompassing different contractors and types of contracts, program purpose, numbers of devices manufactured, physical characteristics, complexity, and cost.

Two programs (the AT Trainer and AN/TSP-43E radar) have been in-house projects at military installations while the remaining 15 have been contracted to one or more firms. The 15 contracted programs have involved 10 firms as principal contractor; one company (Honeywell) has played this role on five projects. Only one firm (ECC) has also had experience in producing a standard device; four firms (Grumman, RCA, Hughes, and Sperry) also produced the tactical equipment being simulated.

Three programs (the MA-3, A-7 HUD, and 6883-Test Benches) have research in maintenance simulation as their principal purpose and employ cost-plus-fixed-fee (CPFF) contracts. The other 14 programs (including the two in-house programs) serve main-line training. Ten of the 12 that were contracted were funded

through either fixed-price-incentive-fee (FPIF) or firm-fixed-price (FFP) contracts; the remaining two (MK 92 FCS and Firefinder) employed cost-plus contracting.

When completed (as currently planned), the 17 programs will result in the development of 47 unique simulations and delivery of 687 units, i.e., trainers. The MK 92 FCS, CIWS, and F-16 programs will be responsible for 30 of the different simulations and 632 of the trainers; both the CIWS and F-16 address training in a number of skills for a single weapon system and will result in the development of a family of devices with extensive commonality, rather similar to the standard systems. Typically, the other programs are concerned with single training applications and a single training device.

The physical characteristics of the non-standard simulators appear to be similarly diverse. There are two- and three-dimensional trainers. Since software is normally closely held by contractors, wide variability can be expected. Further, since a non-standard system typically simulates only one tactical system, it is not necessary to provide a definitive separation between software and courseware functions.

The total program costs of the non-standard systems (adjusted to current price levels) differ by factors of up to 300:1, and the average costs of devices differ by factors of up to 40:1.

4. CAI-Like Systems

A CAI-like maintenance simulator is a computer-assisted instruction (CAI) system with courseware designed specifically to train maintenance skills. A typical CAI system uses a 2-dimensional display (CRT and/or random access slide or microfiche projector) to present lesson materials (pictures of equipment and the like) under control of a computer that also monitors student progress, prescribes lessons, and scores tests. When adapted to maintenance training, the CAI features are retained,

and the trainer may also employ 3-dimensional depictions of equipment.

One experimental system of this class (the Rigney Trainer) has been built, and two other systems have recently been placed under contract: A contract for the design and fabrication of prototype units of the Electronic Equipment Maintenance Trainer or (EEMT) was awarded to Cubic Corporation by the Navy Personnel Research and Development Center (NPRDC) in August of 1980, and a preliminary design has been formulated. The Army has let several contracts for the study of design concepts for the Army Maintenance Training and Evaluation Simulation System (AMTESS) and let a contract to Grumman Aerospace in December 1980 for construction of two "breadboard" units for further evaluation.

EEMT is intended for initial skill ("A-school") training, primarily in electronics. It is to provide both 2-dimensional displays (generated through a cathode ray tube) and 3-dimensional simulations and is to be capable of simulating a variety of particular electronic systems. This latter capability is the basis for distinguishing CAI-like from the other classes of maintenance simulators. The software system must be comprehensive and adaptable (as in the case of standard systems). In addition, both the software system and the courseware must be more extensive since they must also provide the information that would be contained on the display panels of simulators that are tailored to a particular training application (whether standard or nonstandard types).

The only information available to this project on the costs of CAI-like systems is contained in the cost proposal for the EEMT system. In this proposal, requirements for labor (of all types) were stated in terms of hours, with insufficient information to convert them to dollar costs to develop an estimate of total program costs. As a result, the CAI-like systems are not discussed further in this chapter.

C. SERVICE USE OF MAINTENANCE SIMULATORS

Service inventories of maintenance simulators show quite diverse policies regarding their use. Table 8 presents a summary of the different types and total quantities of trainers procured by each Service and distinguishes between Naval/Marine Corps aviation and other Navy and Marine Corps usage. The differences in reliance on simulation are more evident in the case of standard systems. The bulk of Navy afloat and Air Force non-standard systems result from the Mk-92, CIWS (Phalanx), and F-16 programs. In the absence of these two programs, there would be little difference among any of the Services. It is noteworthy, though, that these large programs are in areas that have shown the least use in the standard systems in the past.

TABLE 8. SUMMARY OF MAINTENANCE TRAINING SIMULATORS DELIVERED AND ON-CONTRACT SINCE 1972, BY SERVICE AND BRANCH

Service and Branch	Standard Systems		Non-Standard Systems	
	Number of Different Devices	Total Number of Units	Number of Different Devices	Total Number of Units
Navy/Marine Corps Aviation	137	354	6	11
Marine Corps Ground Forces	27	129	0	0
Navy Afloat	4	10	25	581
Army	24	158	2	34
Air Force	2	2	14	61
Totals	194	653	47	687

One result of standardization is that it is difficult to identify specific simulator development or procurement programs. The standard devices that provide training for a particular system (e.g., a given model of aircraft) may have been procured

through several contracts initiated at different times. A single contract may encompass varying quantities of devices for several equipments and include procurement of the general simulation system as well as the unique components for different training applications. As a result, the discussion of usage of these devices is limited to procurement quantities by Service and according to skill areas trained and to the market shares of four contractors. The non-standard systems are developed and procured within well-defined programs that are related to particular simulator systems and training applications and are discussed in that context.

1: Standard Systems

The first procurements of standard maintenance simulators occurred in the 1972-1973 period when limited quantities were delivered to the Air Force, to the Navy for surface training, and to the Marines for ground forces training. The first deliveries for Naval/Marine Corps aviation training occurred a few years later, and since that time this training has become the most extensive user of standardized systems. The current inventory of 354 devices accounts for 70 percent of the different simulations, and nearly 55 percent of the total units employed in military training.

The Marine Corps was the earliest service to contract for a significant number of standardized systems. A 1972 contract called for delivery of 15 units (encompassing 11 different simulations) for training of ground equipment maintenance; this was followed in 1975 with a contract for 114 units of 27 different simulations (including reprourement of the 11 types of simulations contracted for in 1972). The last of the Marine Corps inventory was delivered in 1976 and none have been contracted for since that time.

The first known Army use of standard systems for maintenance training was in 1977, with the delivery of two devices

for training of the Mohawk propeller control system. Since that time, the Army has procured devices for training of other aircraft systems and several armored vehicles. Note that the numbers shown in Table 8 include only devices that were procured through the Program Manager for Training Devices (PMTRADE). The devices listed in Table 8 may be an incomplete listing as Army management procedures allow training devices to be contracted for through weapon system program offices and individual base commands. Such devices are not registered in a central inventory record and cannot be readily identified.

Both the Air Force and Navy afloat have made little use of standardized simulators. The Air Force procured one device in the early 1970s to evaluate its use in training AN/ALQ-126 radar maintenance personnel (as part of a research project). A second device simulating the 6883 Test Bench was delivered in 1980, also for evaluation as part of a research program. The Navy procured five copies of one device for training in the tuning of traveling wave tubes in 1973. The next delivery of this class of simulator (the Hagen Automatic Boiler Control Simulator) was in 1978 as part of a research program investigating training strategies for equipments the maintenance of which requires personnel trained in different skill areas. The only current use of standard simulators for main-line training consists of two devices for training maintenance of the Trident submarine air-conditioning and air-compressor systems.

The standard systems have been used for training in a variety of skill areas, as shown in Table 9, with training applications spread rather equally among the broad groupings of electrical and electronic, propulsion, and combinations of mechanical/hydraulic/pneumatic areas. This stands in contrast with the non-standard systems discussed below where, excepting the two large weapon-system-oriented programs (F-16 and CIWS), all but the MA-3 and DD 963 boiler programs have been limited to simulation of electronic systems.

TABLE 9. STANDARD SYSTEMS DELIVERED AND UNDER CONTRACT, BY SERVICE AND SKILL AREA.

Skill Area by Military Service	Number of Different Simulations	Total Number of Devices
Marine Corps Ground Forces		
Electrical	12	38
Propulsion	11	75
Hydraulic-Pneumatic	4	16
Naval and Marine Corps Aviation ^a		
General Skill Training ^a		
Electrical-Electronic	10	78
Propulsion	16	80
Electro-Hydraulic	14	76
Weapon-Specific Training		
Electrical	18	24
Electronic	23	34
Propulsion	14	14
Electro-Hydraulic	1	1
Mechanical-Hydraulic	29	35
Unknown	12	12
Navy Afloat		
Hydraulic-Pneumatic	2	2
Combination of Skill Areas	1	3
Electronic	1	5
Air Force		
Electronic	2	2
Army		
Aviation		
Electrical	4	22
Electronic	4	48
Hydraulic	1	2
Mechanical-Hydraulic	1	7
Electro-Mechanical	2	14
Ground		
Electrical-Electronic	2	4
Propulsion	4	16
Hydraulic	2	9
Electro-Hydraulic	4	36

^aIncludes training in aircraft and ground support equipment.

A relevant point to be seen in Table 9 is that while these systems have found a wider range of applications (in terms of different simulations) for weapon-specific Naval aviation training, one or two units (trainers) of a given simulation will satisfy a training requirement. That is, 97 different simulations (training applications) are satisfied by 120 devices, an average of only one and one-quarter units of each simulation. This contrasts with the larger numbers of identical units required for general aviation skill training (or for training for widely held equipments such as those employed by the Army and Marine Corps ground forces). Non-recurring costs involved in bringing a simulation on-line are high compared with the costs of fabricating additional units of an already designed simulation, and this relation has a large impact on the average costs of simulation in training for different types of equipments.

Table 10 shows the number of standard systems delivered and under contract, according to manufacturer. ECC appears to dominate the market, but the extent of this domination is decreasing. Ridgeway is a new company that appears to be aggressively marketing its system. As of mid-summer 1980, all of the 107 Ridgeway devices shown were under contract, but none had been delivered. ECC, by contrast, had undelivered orders for 100 devices. When all of these deliveries are completed, the percent of devices in use that are manufactured by ECC will drop from 90 to 75.

Standard maintenance simulators are not major products of either Burtek or Lockheed Aircraft Services. Burtek produces a wide range of training devices (from aircraft evacuation and ejection seat trainers to automated study carrels) for both the civilian and military markets. Lockheed Aircraft Service provides a wide range of aircraft-related products and services (including aircraft modifications, full-scale models, mock-ups, and training services) for both military and civilian customers.

TABLE 10. STANDARD SYSTEMS DELIVERED AND UNDER CONTRACT,
BY MANUFACTURER SINCE 1972

	Manufacturer			
	Educational Computer Corporation	Ridgeway Electronics, Inc.	Burtek, Inc	Lockheed Aircraft Service
Marine Corps Ground Forces Unique Models	27	--	--	--
Total Held	129	--	--	--
Naval & Marine Corps Aviation				
General Skill Training Unique Models	21	18	1	--
Total Held	119	103	12	--
Weapon-Specific Training Unique Models	74	--	11	12
Total Held	97	--	11	12
Navy Afloat Unique Models	1	--	3	--
Total Held	5	--	5	--
Army Unique Models	22	1	1	--
Total Held	152	4	2	--
USAF Unique Models	1	--	1	--
Total Held	1	--	1	--
Total Unique Models	146	15	17	12
Total Held	503	107	31	12

2. Non-Standard Systems

The non-standard simulators are relatively recent developments. A listing and description of the programs that have been initiated to date are shown in Tables 11 and 12. In fact, there has been little experience in training with this class of simulator. Several of these programs have yet to result in deliveries; for several others, deliveries have not been completed or deliveries have been of less than complete or full-design configurations. There is generally an installation and checkout period and a significant period between the initial and final deliveries of a program so that, even where a full configuration has been delivered, actual use for training would be less than is suggested by Table 12.

TABLE 11. NON-STANDARD SIMULATOR PROGRAMS, DESCRIPTION

Trainer Designation	Description of Associated Operational Equipment	Designation of Operational Equipment	Training Equipment Contractor(s) ^a
<u>Naval Aviation</u>			
VTAS	Visual Target Acquisition System of F-4H.	AN/AVG-8	Honeywell
AI-Trainer	All equipment maintained by AI rating on F-4, J/N and RF-4B.	(See Table C-6)	In-House (North Island NARE)
A-6 TRAM DRS	Detection and Ranging System of A-6E TRAM.	AN/AAS-33	<u>Grumman</u> , Applied Science
A-7 HUD Test Bench	Heads-Up Display of A-7E ^b	AN/AVM-11, AN/AVQ-7	Educational Computer Corporation, Applimation, Honeywell, Vought, AACTIS Engineering
MA-3 Test Bench	Aircraft 12KVA generator test bench.	MA-3	<u>Applimation</u> , Seville
EA-6B ICAP-1 TJS	Tactical Jamming System	AN/ALO-99 AN/ALO-92	Grumman
<u>Navy Afloat</u>			
IRR	Integrated Radio Room of Trident submarine.	AN/B' C-1	RCA, Educational Computer Corporation
CINS	Short range anti-aircraft gun system for surface ships (Phalanx close-in weapon system)	..	Cubic
Waste Heat Boiler	DD 963 Waste Heat Boiler	..	Applimation
MK 92 FCS	Fire Control System MK 92, Mod (1).	FCS MK 92 Mod (1)	Sperry
<u>Air Force</u>			
6883 Test Bench	Test bench for a portion of F-111 avionics	AN/ASM-327	Honeywell
AWACS Navigation	Navigation System of E-3A.	AN/ASN-118	Honeywell, American Institute for Research
AWACS Radar	Radar system of E-3A	AN/APY-1	Honeywell, American Institute for Research
F-16	Avionics, electrical, propulsion, hydraulic, weapon control systems of F-16	..	Honeywell ^b
FPS-43E	Ground radar system	AN/TPS-43E	In-house (Keesler AFB)
<u>Army</u>			
Firefinder	Mortar and artillery-locating radar systems.	AN/TPQ-36, AN/TPQ-37,	Hughes Aircraft
REES	Tactical communication system	AN/TRC-138, AN/TCC-73 (3), AN/TRC-145, AN/TRC-151, AN-TSQ-84, AN-TSQ-85	Gould

^aWhere more than one contractor has been involved in a program the name of the principal contractor is underlined.

^bSubcontractor to the weapon system contractor.



TABLE 12. NON-STANDARD SIMULATOR PROGRAMS, CHARACTERISTICS

Designation	Quantities		Maintenance Echelon Trained (Organizational or Intermediate)	Purpose of Simulator Program ^a	Type of Simulator; 2 or 3 Dimensional	Appropriation ^b	Type of Contract	Date of Contract or Program Initiation	Date of Initial Delivery	Number of Devices Delivered Through FY 1980	Program Cost, Then Year* (900)	Program Cost, C 1981 \$ (600)
	Unique Devices	Total										
Naval Aviation												
VIAS	1	2	0	I	3	P	FFP	7/75	7/76	2	300	450
AI-Trainer	1 ^d	3	0	I	3	P, O	FFP	12/75	6/79	1	1,850 ^e	2,520
A-6 TRAM DRS	1	2	0	I	3	P ^f	FFP	5/78	8/79	2	520	630
A-7 HUD Test Bench	1	1	1	R	3	R	CPFF	6/76	7/77	1	1,390	1,730 ^g
EA-3 Test Bench	1	1	1	R	3	R	CPFF	9/78	8/80	1	640 ^h	780 ^h
EA-6B ICAP IJS	1	2	0	I	3	P	FFP	12/80	1/81	0	1,600	1,600
Naval Afloat												
IRR ^h	2	2	0	I	3	P	FFP	9/79	3/81	0	7,090	7,090
CTMS	8	288	0	I	2	P	FFP	10/80 ⁱ	11/81 ^j	0	5,900 ^k	5,900
DD963 Waste Heat Boiler	3	3 ^l	0	I	1	P	FFP	12/80	12/81	0	300	300
M. 92 FCS	12	RR	0	I	2	P	CPFF	10/80 ^k	1/81	0	9,000	9,000
Air Force												
6883 Test Bench	1	1	1	R	3	R	CPFF	6/76	6/78	1	800	1,130
AWACS Navigation	1	1	0	I	2	P	FPFF	6/78	12/79	1	1,510 ^c	1,870
AWACS Radar	1	1 ⁿ	0	I	2	P	FPFF	9/80	5/81	0	8,700 ^o	8,700
F-16	10	50 ^p	0	I	2 & 3 ^q	P	FPFF	9/77	1/79 ^r	7	8,890	38,370
TPS-43E ^s	1	2	0,1	I	3	C	--	early/77	late/78	1	100 ^t	120
Army												
Firefinder ^h	1	10 ^u	0	I	3	R, P	CPFF	8/77	1/80 ^v	28	21,380	26,930
REES ^h	1	1	0	I	3	P	FPFF	7/77	7/81	1	1,800 ^w	4,640

(see next page for footnotes)

TABLE 12. (Continued)

^aR: Research; T: Training.

^bP: Procurement; R: RDT&E, O: Operations and Maintenance.

^cAdjustments to 1981 cost level are based on DoD Inflation Rates (for RDT&E or Procurement) dated 4 July 1980 assuming that the mid-point of the program expenditures falls mid-way between contract and initial delivery dates.

^dOne unit contains a capability to simulate the F-4J, F-4N, and RD-4B while the other units simulate only the F-4J.

^eDoes not include the costs associated with simulation to provide a minor level of AE rate training (estimated at \$300,000).

^fInitially funded through RDT&E and intended for research purposes. The purpose was changed early in the program to training and funded through procurement.

^gIncludes \$30,000 for development of training materials for a new course addressing maintenance of the MA-3 test bench.

^hAlso provides operator training. Establishment of an East Coast training facility will require an additional unit of each type of simulator letter contract. Contract value and other provisions to be definitized by March 1981.

ⁱPrototype.

^jIncludes \$600 (thousand) estimated for Maximum Funded items.

^kTo be terminated.

^lCost to the government. Includes contractor fees but not unreimbursed overruns.

^mThe one device consists of a central processor and instructor station controlling 10 student stations.

ⁿNot including program support effort to be provided by American Institute for Research.

^o30 devices delivered to USAF. The remaining 26 devices are for delivery to NATO countries. The cited cost included all 56 units.

^pTwo devices are cockpit mock-ups while the remaining 16 are flat panels.

^qDelivered as interim configurations, limited to demonstration of system operations, that will be field retrofitted for malfunction capabilities.

^rOne unit was delivered in late 1978. A second unit has recently entered fabrication.

^sFirst unit only.

^tFive complexes of six student stations. Three complexes provide only operator training, two complexes are configured to provide both operator and maintenance training.

^uThe delivered trainers do not simulate the current configuration of operational equipment and will be retrofitted in the field.

^vProgram cost is in dispute. The initial contract value was \$1,793 (thousands), but the contractor has recently filed a claim for an additional six million.

These 17 programs do not seem to provide a representative sample of the potential range of application for the non-standard simulators. All but the three research programs (A-7 HUD, MA-3, and 6883 Test Benches) are concerned only with organizational maintenance, and these three were developed as research vehicles. Initially, none were envisioned to provide main-line training, although current planning is for the MA-3 to provide training. Only four programs (MA-3 Test Bench, F-16, CIWS, DD 963 boiler) simulate other than electronic equipments. The F-16 and CIWS are large simulation programs to provide training in several of the skills (including electronics) required for maintenance of a weapon system. This seems hardly representative of overall maintenance training requirements and is quite different from the pattern observed for the standard systems.

a. Concurrent Development. The sample is sufficient, though, to illustrate some of the characteristics associated with non-standard simulators, three of which are discussed here. The timing of deliveries of training devices is critical for the introduction of new or modified operational equipments. Training equipment, of whatever type, must be in place before training can commence, and personnel must be trained before the operational equipment can become an effective part of the force. Training simulators require their own development period, and this must occur concurrently with development of the operational equipment. However, the operational equipment is subject to frequent modification during development and for a considerable period after its initial fielding. Even minor modifications can have a large impact on the costs of simulator development. At least five of the 17 simulator programs involved concurrent development; the A-6 TRAM DRS, the A-7 HUD, the Trident Radio Room, the F-16 trainers, and Firefinder. In each case, the simulator programs incurred significant engineering changes that increased their costs. The A-6 program required

extensive software changes that amounted to 30 percent of the final program cost. The addition of FLIR to the A-7 HUD trainer accounted for approximately 40 percent of the total program cost. In the F-16 program, it seems impossible to attribute a dollar cost to changes, but they are generally acknowledged to be a major portion of a cost overrun that amounted to three times the initial program estimate. Not only were changes to the aircraft frequent, but documentation of the changes that were necessary for simulator design ran as much as 12 months behind implementation of the changes themselves. Changes in the Trident Radio Room and Firefinder program were not as dramatic but still had a significant impact on development costs.

A related problem is that modifications and configuration changes are common for aircraft that have been fielded for a considerable period. Changes to operational systems may result in simulator modifications whose costs approach the cost of development of the original device. This is close to the situation of the A-7 HUD simulator; a day version of the operational equipment had been in use for several years, and the FLIR version entered development during development of the trainer. Contract costs attributable to modifying the trainer to simulate the FLIR amounted to 85 percent of the original contracts for the day version trainer. Modifications to operational equipment have resulted in the obsolescence (and discarding rather than modification) of a number of standard simulators.

b. Quantities Fabricated. For nine programs in this sample, for which cost information was available, development cost averaged over three times the recurring cost of simulator fabrication and initial support. This provides a large potential for reducing average costs by simulation of equipment for which there is an extensive training requirement, such as equipment used for general skill training and equipment that is used on widely held weapon systems. Only three of the 17 programs in the sample simulate this type of equipment. The MA-3 Test Bench

is a universal test stand used throughout the Navy for onshore testing of all models of generators and constant speed drives that supply aircraft primary electric power; although the MA-3 Simulator is a research device, with only one unit built, it has a potential for providing training at all Naval and Marine Corps air stations. The CIWS and Mk 92 Fire Control System are to be installed on a large number of surface ships, generating an extensive training requirement; current planning calls for fabrication of 36 sets of eight simulations for CIWS training and 24 sets of 12 simulations for Mk-92 FCS training. In contrast, a few units appear to satisfy the training requirements for the bulk of the other simulators in the sample. As examples, the present F-16 contract provides for delivery of equipments to only three air bases; training for specific types of Naval/Marine Corps aircraft is provided at only one to three air stations so that buys of weapon-specific simulators (such as the A-6 TRAM DRS) will be limited to a small number.

c. Substitution Relations. Simulators are generally viewed as substitutes for actual equipment trainers. Whether this is a correct way to view simulators should be argued separately; simulators and actual equipment can each be used for training in ways that are not possible by the other. The question of substitutability is not a simple one and the extent of substitution depends on the nature of the simulation, the equipment being simulated, and the extent of training provided. Within these 14 programs are examples of four different relations between simulators and actual equipment trainers.

The MA-3 Test Bench and 6883 Test Bench programs illustrate cases approaching pure substitution. Each program provides training in both the operation of a test bench (i.e., maintenance of operational equipment) and maintenance of the test bench itself. Each simulator was designed to replace some (but not necessarily all) operational equipment that had been used for training.

In the case of the AWACS system, the navigation system simulator has been used to implement a substitution of school training for on-the-job training (OJT). Prior to introduction of the simulator, formal (school) training was limited to the classroom, and hands-on systems training was provided only as OJT at an operational base. Introduction of the simulator permitted the hands-on training to commence at the training school and should result in a shorter period of OJT before personnel are qualified for independent work.

Trident radio room training employs both the simulators and a modified complete operational radio room (actual equipment trainer). That is, they complement one another, with each contributing to different elements of the curriculum. They are also substitutes. An early assessment of Trident training requirements developed two alternative equipment configurations for radio room training. One was the current combination of simulation and AET. The second was the use of three AETs only. The choice of the combination of actual equipment and simulation was based, at least in part, on cost considerations.

In the case of several other programs, both actual equipment and simulators are used, but for somewhat different reasons. The A-6-TRAM DRS contains both electronic and mechanical components. The simulator is limited to training on the electronic portion of the system, and the actual equipment is required for the mechanical training. None of the organizational echelon aviation simulators can wholly substitute for operational equipment. Typically, both organizational and intermediate maintenance training is provided at the same location and, frequently, in the same training course. The intermediate level training will require actual equipment, but normally in the form of individual components rather than an integrated system.

The cost effectiveness of simulation for training maintenance skills depends upon its impact on total training costs. Variations in the substitutability of simulators for actual equipment trainers imply that simple comparisons of the relative costs of the two types of training equipment cannot be taken as reliable guides to the relative costs of training. Assessments of the cost advantage of using simulation must be based on comparisons of the total costs of satisfying particular training requirements with and without such simulators.

D. STRUCTURE FOR COLLECTING COST DATA

The set of cost elements shown in Table 13 is an initial formulation of a functional cost structure for collecting data to develop cost-estimating relationships and other tools for assessing the costs of maintenance training simulators. It is a mixture of elements that are generally associated with other types of military equipment as well as those that seem particularly relevant to processor-driven simulators; it relies heavily on discussions with people who have had experience with simulator procurements.

This cost element set is incomplete in two ways. First, it is at a level of aggregation that may prove insufficient for identifying the basic cost drivers. Second, even at this relatively high level of aggregation, we are uncertain that it is fully specified. With our current knowledge regarding the determinants of cost, it does not appear feasible to carry the specification further.

This structure does, though, treat the two important cost characteristics of maintenance training simulators evident in the data currently available -- the separation of recurring from non-recurring costs to identify program development costs and the separation of software (and courseware) from other development costs to identify the (apparently) dominant requirement.

TABLE 13. COST DATA STRUCTURE

	In-house	On Contract		
Front End Analysis				
Task Analysis				
Performance Specification				
Engineering Specification				
.				
.				
Design and Development				
Hardware				
Software				
Courseware				
Technical Data				
.				
.				
Test and Evaluation				
Acceptance				
Training Effectiveness				
.				
.				
Fabrication				
Hardware				
Installation and Check-out				
Special Tools/Test Equipment				
.				
.				
Logistics Support				
Interim Maintenance Support				
Other				
Facilities (Construction/Modification)				
Initial Training				
Program Management				

Further, it is structured as a matrix. Several contractors may be involved in a single program; one contractor may be engaged in several (sequential) contracts on a single program; programs are generally sectioned into distinct and identifiable phases; and, changes in program scope and statements of work are frequent. In each case, the types of work and relations among costs may differ in systematic fashion, and these differences should be preserved in whatever data are collected.

A major problem with formulating a structure for collecting cost data at this time is the current paucity of data. There is no general requirement for systematic and periodic reporting of all elements of the costs incurred by contractors of training equipment. With a single exception, standardized work breakdown structures (WBS) for training equipment have not been developed and employed; thus even if contractor costs were to be reported, there would likely be incompatibilities among the data from different programs.

A periodic cost reporting system addressed to simulators should be based on a single basic WBS that would be applicable to a variety of simulator types and other training equipments and serve both program-management and cost-assessment functions. The Army is currently developing a general WBS for all training equipment. It has yet to be imposed on a procurement program, and it appears to be directed only to cost assessment. The Air Force has developed a WBS that has been used for both management and cost assessment, but its application is limited to flight simulators. There appear to be significant differences between these two structures, and neither seems to satisfy the criterion of general applicability (e.g., neither appears to provide for a definitive separation of recurring and non-recurring costs).

In general, the program costs collected during this project (contained in Appendix B) are assessed in the format of Table 13. A next step in assessing the format (i.e., the adequacy of data it displays) would be to obtain measures of simulator physical

and performance characteristics for the current programs, to test for relationships between these characteristics and levels of costs and, since this structure addresses only assessment of costs, to reconcile it with the data requirements of program management.

E. COSTS OF MAINTENANCE TRAINING SIMULATORS

1. Standard Systems

For practical purposes, the data now available on standardized systems are insufficient for analysis of cost and especially for relating costs to physical and performance characteristics of the trainers. Almost all procurements are under FFP contracts where formal documentation is typically limited to performance specifications issued with the request for proposal (RFP), contractors' technical proposals, and the contract itself. The physical and performance characteristics may change, as the result either of contract negotiations or of subsequent contract modifications, with the corresponding documentation not being revised.

Cost documentation is normally limited to the line-item structure of the contract; for the standard systems this is sketchy at best and can be misleading. A major problem is that contract line-item structures are in terms of the products (or deliverables) that result from the contract (e.g., trainers, data, contractor field services, conferences). While this structure does provide useful information for cost control and management, it provides none of the attributes of a functional WBS necessary for evaluation. The contract line item "trainers" typically encompasses over 70 percent of a total contract value. Within this 70 percent are contained (or hidden) those cost distinctions that allow simulator and procurement program characteristics to be related to program cost (e.g., between recurring and non-recurring costs, between development and fabrication, between hardware and software).

Nine contracts were reviewed, and the information they contain is shown in Table 14. (In the discussion below, these contracts are referred to according to the column number of the table.) This set of contracts includes four models of standardized systems built by three contractors and appears to present a representative sample of available data.

Individual contracts show a wide range in the number of different types of trainers or simulation models developed (1 to 27), the number of trainers procured (2 to 114), and their average costs (from under \$10,000 to over \$80,000). An important feature for assessing costs is that most contracts involve development and procurement of trainers for a number of training applications and several copies of each type of trainer.

The line item listing shown in Table 14 is close to the full cost detail given in the contracts. The only items contained in the "other" category are conferences, training, and reliability and maintainability programs and demonstrations. A separate line item is normally shown for each type of trainer delivered on the contract, but that single line will contain the cost of both the first or prototype unit (with the development costs it entails) and all follow-on units.

Separation of costs between the prototype and follow-on units is contained only in contracts 1, 6, and 9. In contract 1, the same unit cost is charged to all 101 follow-on units; in contract 9, follow-on units (not included in the Table 14 values) are specified as a contract option at a cost different from the prototypes, but four of the six trainer types are attributed with the same follow-on unit cost. In three other contracts, the same unit cost is charged to several different types of trainers (both prototypes and follow-ons). In contract 1, the average ratio of prototype to follow-on unit costs is approximately 16 to 1, while in contract 9 the ratio averages 3 to 1. Since ECC is the contractor in each case (although different

TABLE 14. STANDARD SIMULATOR CONTRACT INFORMATION AND COSTS
(NINE CONTRACTS)

Service	Contract ^a								
	1	2	3	4	5	6	7	8	9 ^b
	Navy	Navy	Navy	Navy	Army	Army	Army	Army	Army
Fiscal Year of Contract	1975	1978	1979	1978	1978	1977	1978	1979	1979
Simulator Model	EC11	EC3	Ridgeway	Burtek	EC3	EC3	EC3	Ridgeway	EC3
Type of Contract	FFP	FFP	FFP	FFP	FFP	FFP	FFP	FFP	FFP
Contract Value (000)	\$1,132	\$1,301	\$1,131	\$259	\$552	\$1,770	\$1,556	\$236	\$2,651
Number of Trainers Procured	114 ^c	91	103	2	17	72	28	4	13
Number of Simulation Models Developed	13	14	18	2	5	7	1	1	6
Average Number of Trainers of Each Type	4.2 ^c	6.5	5.7	1.0	3.4	10.3	25	4.0	2.0
Average Contract Cost Per Trainer (000)	\$9.9	\$14.3	\$11.0	\$129.5	\$32.5	\$24.6	\$55.6	\$59.0	\$203.9
Average Cost of Trainers (000)					\$23.8	\$18.3	\$34.0	\$26.6	\$26.6
Range of Unit Cost of Trainers (000)	^e	\$8.9-16.9	\$6.5-9.0	\$56.3-61					
Contract Costs by Line Item (000)									
Trainers (including installation) ^f	\$901	\$1,268	\$805	\$117	\$410	\$1,363	\$1,065	\$106	\$1,548
Technical Data	142	181	27	93	18	244	57 ^g	18	293
Interim Support	19	15	75	17	60	70	304	4	*3
Factory Repair of Spares and Parts		5	45		20	10	75		
Contract Field Service			40	12	25	12	110		145
Spares and Spare Parts	38	10	50	3				70	
Support and Test Equipment and Tools	22		65	9	8	18	10	30	
Logistic Support Analysis							29		145
Other	10	3	24	8	11	52	13	8	437 ^h
Contract Total	1,132	1,482	1,131	259	552	1,769	1,663	236	2,641

^aSeveral contracts have undergone modifications. Where information was available, the values in this table reflect the modifications.

^bContract included one hands-on trainer with a cost of \$567 thousand and 12 simulation trainers. Cost of the hands-on trainer is included in the costs below, except as noted.

^cProcurement included 16 EC11 consoles, 13 different simulations (66 total devices) developed on this contract, 11 different simulations (45 total devices) developed on an earlier contract, and three devices, addressing basic skills, that were developed by the contractor for the Civil market.

^dExcluding cost of the hands-on trainer.

^eThe range of prototype (first unit) costs was \$27.9 to \$32.2 thousand. All follow-on units were priced at \$18 thousand, regardless of whether the device was developed in this contract or the earlier contract. Consoles were priced at \$16.5 thousand each.

^fContract line item listings normally show each type of trainer and its costs as a single contract item. However, the costs of all trainers of one type will generally be contained in that single entry.

^gIncludes \$170 thousand for claims resulting from contract modifications and \$241 thousand for extensions to the software system described as "for test sets", procedure and performance monitoring.

standard systems are involved), we would expect that the distinction between recurring and non-recurring functions would be the same for each contract. If this is true, the wide variations in the recurring/non-recurring ratios are difficult to accept. In only two contracts (1 and 6) are the costs of main frames and panels shown separately, and the ratio of main frames to panels varies. No contract provides for a separation of functions associated with development (e.g., hardware, courseware) except for technical data, and in this case a single line entry applies to all trainers included in the contract.

There is a considerable difference in the structure of costs among the contracts, and it appears that the meanings of ~~contract line-item names have not been consistently applied.~~ For example, contracts 2 and 3 involve deliveries (by different contractors) of devices that satisfy the same training application and have display panels constructed to a single specification. On the basis of the ranges of unit costs that are given, it would appear that ECC costs are higher. However, on the basis of average contract cost per delivery (total contract value divided by the number of trainers procured) the difference is considerably narrower, and it would appear that a number of contract functions that are costed separately in the Ridgeway contract are included under the cost of the trainers in the ECC contract.

This discouraging assessment of available data has been reinforced by discussions with procurement office personnel at the Naval Training Equipment Center (NTEC). Several have expressed opinions on two points that impact on the validity of contract item costs. One is that contract negotiators focus on "bottom-line" (total) costs and that, within this constraint, contractor representatives will trade-off the amounts charged to individual line-items until the relationships among them look "reasonable". The second point is that contractors have an incentive to inflate the cost of simpler devices and to

deflate the cost of the more complex devices. In this way, as contractors are successful in delivering the simpler devices early in a contract, they can speed up their receipt of progress payments relative to actual expenses. One result of these practices is that the relationships among different elements of contract costs will be distorted, and providing more detailed cost statements will do little or nothing to provide accurate relationships between physical and performance characteristics and costs.

2. Non-Standard Systems

The program costs discussed in this section are based on nine programs for which information was either received in or translated to the format shown in Table 13. These programs are discussed briefly and their individual costs displayed in Appendix B.

The cost information comes from two sources. One consists of contracts and contractors' proposals; there is no way to determine if the level and structure of costs contained in these early estimates did occur. The second source is program office estimates of incurred costs based on the records and the expertise of program office personnel.

In either case, there is no way to compare these estimates against true costs. Simulator programs fall below the cost threshold of major procurements for which contractors are required to submit periodic reports in a prescribed WBS. Contractors employ different terminologies; the structure of their accounting systems differ, and there is an ever-present possibility of misinterpretation in translating the available information into the categories and format shown in Table 13. Considering the wide range of possible differences among simulators and simulator procurement programs, we question whether a sample of nine programs is satisfactory. However, it does provide insights into two important cost characteristics that are discussed below.

Table 15 shows the percent distribution of program total cost, according to cost element, in terms of the lowest and highest observed percentages in this table and the average of the percentages. Note that the percentages have been normalized in the following two ways:

1. Recurring production costs have been adjusted to the level of costs that would have been incurred if only one unit had been produced by dividing recurring fabrication costs by the quantity fabricated. This adjustment provides a consistent base for the relation between recurring and non-recurring costs.
2. The MA-3 and 6883 Test Bench research programs incurred significant costs for evaluation that were not included in calculating the test and evaluation percentages in order that all simulator programs might be treated as though they were intended for main-line training.

Two distinct patterns emerge from this small sample. The first is the consistently high proportion of total costs that are devoted to the non-recurring functions (primarily design and development) when small production quantities are involved. Further, the average recurring production cost (18 percent) is probably overstated as only the AT Trainer and 6883 Test Bench programs identified the non-recurring* portion of fabrication cost that, in these cases, averaged 40 percent of the first unit recurring fabrication cost.

Figure 4 is a plot of the non-recurring percentages when program costs are adjusted only to exclude evaluation costs of the MA-3 and 6883. The outlying high point is the AWACS Navigation/Guidance system program, and there is no explanation why the percentage is this high. The outlying low point is the Visual Target Acquisition System (VTAS) program. A review of

*Tooling, planning, and the other requirements normally charged to production accounts that do not increase with quantity.

TABLE 15. PERCENT DISTRIBUTIONS OF COST BY CATEGORY FOR EIGHT NON-STANDARD SIMULATOR PROGRAMS (NORMALIZED)^a

Cost Category	Percentage Distributions		
	Lowest Observed in Any Program	Highest Observed in Any Program	Average of Observed Percentages
Non-recurring Costs			
Front End Analysis	0	18	8
Design and Development	34	81	54
Hardware	2	35	16
Software/Courseware ^b	12	53 ^c	31
Technical Data	0	21	6
Hardware Fabrication (Non-recurring) ^d	4	6	5
Test and Evaluation ^e	1	3	1
Program Management	3	24	11
Total Non-recurring	61	92	78
Recurring Costs			
Production	5	38	18
Hardware Fabrication	4	36	15
Other	0	9	4
Logistic Support	0	13 ^f	5
Initial Training	0	4	2
Total Recurring	8	39	25

^aRecurring production costs were adjusted to reflect a production quantity of one. Test and evaluation costs of the research programs were not included.

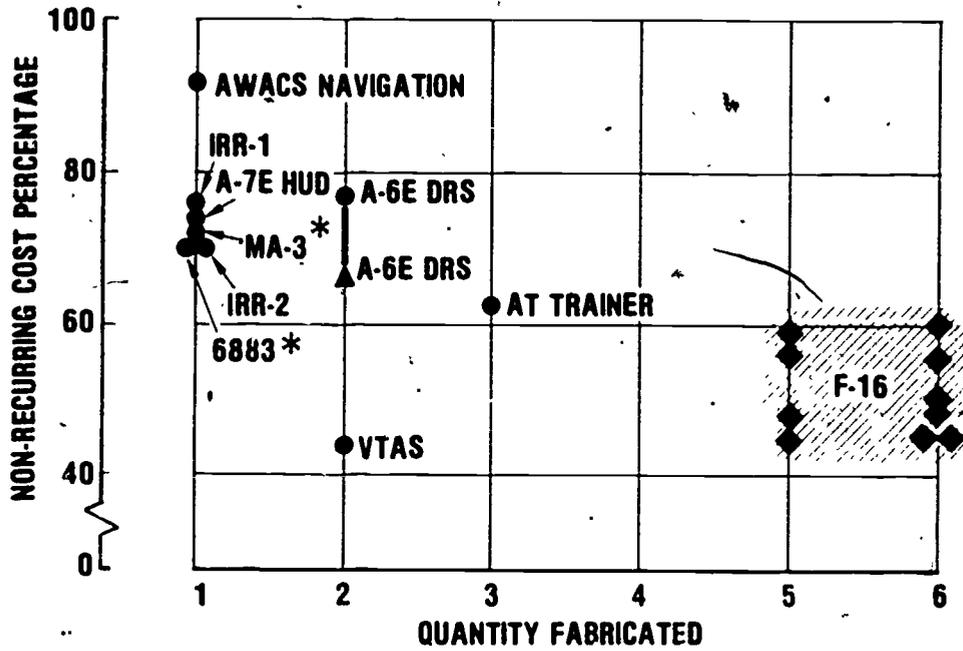
^bData on several programs did not separate software and courseware development costs. In this table and remainder of this section, these cost elements are combined and referred to as "software/courseware."

^cThe high percentage case is a program that incurred software problems because of concurrency. The next highest program incurred 42 percent of total costs for software/courseware.

^dBased on two programs.

^eBased on six programs.

^fThe two highest percentages arose from (1) development of a complete depot maintenance facility and (2) over three years of contractor maintenance during an extensive evaluation program. The next highest percentage is 7.



KEY: IRR-1, TRIDENT maintenance trainer
 IRR-2, TRIDENT operations/maintenance trainer
 ▲ A-6E DRS, excluding engineering change
 * Excludes evaluation costs

5-27-81-11

FIGURE 4. Non-recurring cost as a percent of program total cost according to quantity fabricated

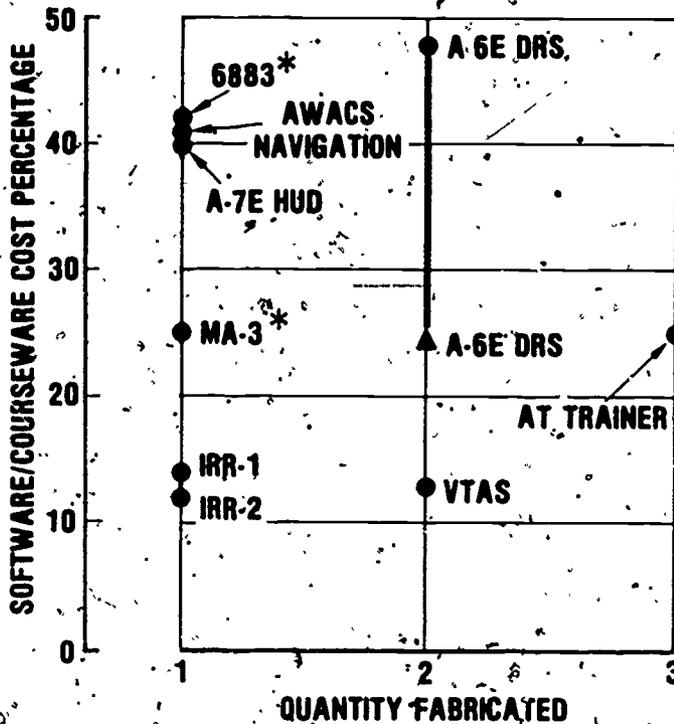
the VTAS simulation and features of the procurement program suggests that it is different in some fashion from other current (and probably future) non-standard simulator programs. Other than the research and in-house programs, VTAS was initiated 2 years earlier than any other non-standard simulator. Also, the avionics system simulated was quite simple by the then-current standards and the training requirement was similarly simple. These considerations suggest possible differences

in the mix of resources employed and the contractor's organization and management of the program. In either case, the differences would impact on the percent distributions.

The A-6 TRAM DRS program incurred a large cost for software changes resulting from changes in the operational hardware. When the change costs are disregarded, the percentage is quite consistent with the other programs. The split between recurring and non-recurring costs was available for the F-16 simulator program. The percentages associated with this program (the shaded area) are consistent with the pattern of the other six. It would appear that production quantities of five and over are required before recurring costs will equal non-recurring costs.

The second feature to emerge is the high cost of developing software and courseware. Within this sample, the combined cost of software and courseware averages over 30 percent of total program costs (as adjusted to reflect production of one unit) and over 40 percent of total design/development costs (with a range from 17 to 72 percent). When software/courseware costs are plotted against total costs (not adjusted for the production quantity) no distinctive relationships are evident (Fig. 5).

We have no explanation for the absence of an orderly pattern or for the wide range of observed percentages. This small sample contains programs with diverse characteristics and, on a case-by-case basis, a number of reasons appear plausible. A likely reason for at least part of the range of values is differences in accounting practices among contractors. It is also possible that our inability to separate software and courseware serves to obscure underlying relationships that may be present. Further data and analyses will be required to provide any understanding of the determinants of cost. Considering the magnitude of the costs in this sample, such data and analyses are warranted.



KEY: IRR-1, TRIDENT maintenance trainer
 IRR-2, TRIDENT operations/maintenance trainer
 ▲ A-6E DRS, excluding engineering changes
 * Excludes evaluation costs

65-27-81-12

FIGURE 5. Software/courseware cost as a percent of program total cost, according to quantity fabricated

It is unfortunate that available data do not permit the separation of software and courseware development costs (or, for the standard systems, the separation of software and courseware from hardware development and production costs). It is quite evident, at least for the non-standard systems, that software and courseware are significant cost items. A relevant

question, then, is how these costs can be reduced for future simulation systems. One promising avenue appears to be the development of a single software system with the following attributes: (1) it would be non-proprietary (e.g., owned by the government), (2) it would permit courseware to be written in a high-level language that could be composed and/or modified by (e.g.) in-house subject matter experts, (3) it would be sufficiently general that its use could be imposed as a contract condition or design parameter. The development of the Ada language may be a large step in this direction.

This concept is not without problems of implementation. It is only reasonable to expect contractors to resist use of such a non-proprietary system. By definition, the standard systems employ proprietary standardized software. Some of the contractors of non-standard systems appear to have put efforts into developing their own software systems. In both cases, contractors have expended assets in the development of these software packages, the values of which would be greatly diminished.

Figures 4 and 5 focus on one problem in identifying training programs as candidates for simulation. Judging by the current non-standard simulator programs, most maintenance simulator applications arise in system-specific training and particularly in aviation training. This type of training is generally provided at a small number of sites and requires a limited number of training devices, implying a limited potential for quantity production of a particular model of training simulator and thus a limited opportunity for reducing simulator costs through their widespread adoption. From a cost standpoint, the more promising employments lie in the training of general skills and system-specific training for widely held equipments where a relatively large number of simulators can be used.

F. SUMMARY

For assessing costs of maintenance training simulators, it is useful to distinguish between what are defined as "standard," "non-standard," and "CAI-like" systems. Differences among these three classes lie in the following areas:

- Physical characteristics,
- Complexity and cost,
- Extent of use within the Services, and
- Contracting practices employed for their procurement.

A standard system consists of a standardized physical configuration that can be adapted to many training applications through courseware and pictorial representations that are tailored to the particular equipment being simulated. Non-standard systems are typically unique, in total, for each specific training application. A CAI-like system typically uses a 2-dimensional display (e.g., CRT, random access slide projector) to present lesson materials, and can simulate different equipments through courseware introduced into its computer.

Available cost data are not adequate for developing the cost relationships necessary for comparative assessments of alternative maintenance training simulators. Factors contributing to this condition are as follows.

- Simulator programs fall below the cost threshold for periodic reporting of incurred costs in a standard WBS.
- The data that are available may contain systematic biases so that their reliability may be questioned.
- For the standard systems firm-fixed-price (FFP) contracts have been prevalent; the only generally available cost information is limited to precontract documentation and the contracts themselves.
- Within the small number of non-standard systems that have been built, there has been a wide range of program

arrangements and purposes, device complexity and characteristics, and training capabilities. It is doubtful whether this small number would provide a satisfactory base for developing a cost-analysis capability.

- For practical purposes, cost data on CAI-like maintenance simulator system costs are not available. Only one experimental system has been built, and contracts for prototype development of two other systems have only recently been let.

There is an obvious advantage in the concurrent development of operational and training equipments so that trainers are available at the time operational equipment is first fielded. However, this practice entails risk since the operational equipment is subject to continual change and even minor changes may result in high cost modifications to training simulators (especially to the simulation software and courseware).

For the non-standard simulators, non-recurring costs account for the major portion of total costs when production quantities are small (e.g., five or less). However, most potential applications appear to be in weapon-system-specific training (especially in aviation) where a limited number of devices would be required.

For the non-standard simulators, software/courseware (i.e., program design and programming) appears to be the single largest element of cost. Where cost overruns have occurred, they appear to have been primarily due to software development problems. There should be a significant cost advantage gained by development of a widely applicable and non-proprietary software system.

IV. COST-EFFECTIVENESS OF MAINTENANCE SIMULATORS

The crucial question is whether maintenance simulators are cost-effective for training military technicians. Since cost, effectiveness, and cost-effectiveness are not, in themselves, absolute quantities, this question must be answered in relative terms, i.e., compared to what else is a particular maintenance simulator cost-effective? All of the studies with relevant data compared the cost and effectiveness of maintenance simulators to that of actual equipment trainers.

With respect to effectiveness, the data from 12 studies show that student achievement at school is about the same for those trained with simulators as for those trained with actual equipment trainers; there was one case where students trained with simulators had poorer achievement scores. We would prefer to estimate the effectiveness of maintenance simulators and of actual equipment trainers by comparing the performance of technicians (trained with one or the other) on the job rather than just at school. Job performance could be measured by data such as the time needed to identify malfunctions and to repair or replace faulty components, the number (or percent) of repairs where good parts were removed unnecessarily or bad parts not identified and so on.

No evaluation of a maintenance simulator reported objective job performance data. In one study, supervisors' ratings (i.e., subjective data) showed about the same level of job performance for technicians trained with the 6883 Test Station 3-dimensional maintenance simulator or the actual equipment (Cicchinelli et al., 1980). Based on the data on student achievement at school and the one case of supervisors' ratings of on the job performance,

we conclude that maintenance simulators and actual equipment trainers are equally effective for training maintenance technicians.

This finding is based on a wide spectrum of simulators, i.e., maintenance simulators of radars, vehicles, electromechanical equipment, 2-D and 3-D designs, and simulators that are used for training organizational and intermediate maintenance. It would be tempting to infer that one type of simulator or a particular way of using them, among these classes, is more effective than another. No such breakdown appears possible with the limited data available. We cannot answer such interesting questions as how effectiveness might vary with cost or how cost might vary with effectiveness, because no such trade-offs have been undertaken. We have only one-point comparisons of the costs of maintenance simulators and of actual equipment trainers that have been shown to have equal effectiveness for training at school. So, we are left with the general conclusion, as stated above, that maintenance simulators and actual equipment trainers are equally effective for training technicians.

Our evaluation of cost uses the cost data presented in Chapter III; these describe acquisition but not life-cycle costs. The costs of acquiring actual equipment or simulators do not include the costs of their use for training purposes, e.g., the operating costs of training such as instructors, student pay and support, maintenance of training equipment, and management of the school. A cost-effectiveness evaluation based on acquisition costs alone must be regarded as incomplete compared to one that includes all life-cycle costs. A single exception, in the case of the life-cycle cost comparison of the 6883 Test Stand 3-D simulator and actual equipment trainer, reported by Cicchinelli et al. (1980), will be considered separately.

Table 16 shows the acquisition costs of comparable simulators, actual equipment trainers, and operational equipment

TABLE 16. ACQUISITION COSTS OF COMPARABLE MAINTENANCE SIMULATORS, ACTUAL EQUIPMENT TRAINERS AND OPERATIONAL EQUIPMENT NOT CONFIGURED FOR TRAINING

System/Subsystem Test Bed for Trainer Designation	Operational Equipment Model Number(s)	Quantity of Trainers	Operational Equipment Unit Cost	Actual Equipment Trainer Unit Cost	Maintenance		Total Unit Cost	Operational Equipment	
					Yearly	Monthly		Yearly	Monthly
A-7E Heads Up Display Test Bed	AN A-7E	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
A-1E PRAM Detection and Warning System	AN A-1E	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
MA-3 Generator Constant Speed Drive Test Stand	MA-3	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
Trident Integrated Wash Room Operator/Maintenance Trainer (Maintenance Trainer)	MA-3	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
Trident High Pressure Air Exposure Unit	MA-3	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
Trident Air Conditioner Unit	MA-3	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
F-4U, RF-4B (N) and F-4U (N) Trainer	F-4U	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
F-111A Aerosols Test Bed (1965) Trainer (Maintenance Trainer)	AN A-111A	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
F-111D Aerosols Test Bed (1965) Trainer (Maintenance Trainer)	AN A-111D	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AdA's Navigation Trainer (Maintenance Trainer)	AN A-111	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AdA's Radar System	AN A-111	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
Mark 30 Radar Trainer (Maintenance Trainer)	AN A-30	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-201 AM-1	AN-201	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-202 AM-1	AN-202	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-203 AM-1	AN-203	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-204 AM-1	AN-204	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-205 AM-1	AN-205	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-206 AM-1	AN-206	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-207 AM-1	AN-207	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-208 AM-1	AN-208	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-209 AM-1	AN-209	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-210 AM-1	AN-210	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-211 AM-1	AN-211	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-212 AM-1	AN-212	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-213 AM-1	AN-213	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-214 AM-1	AN-214	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-215 AM-1	AN-215	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-216 AM-1	AN-216	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-217 AM-1	AN-217	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-218 AM-1	AN-218	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-219 AM-1	AN-219	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-220 AM-1	AN-220	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-221 AM-1	AN-221	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-222 AM-1	AN-222	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-223 AM-1	AN-223	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-224 AM-1	AN-224	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-225 AM-1	AN-225	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-226 AM-1	AN-226	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-227 AM-1	AN-227	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-228 AM-1	AN-228	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-229 AM-1	AN-229	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-230 AM-1	AN-230	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-231 AM-1	AN-231	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-232 AM-1	AN-232	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-233 AM-1	AN-233	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-234 AM-1	AN-234	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-235 AM-1	AN-235	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-236 AM-1	AN-236	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-237 AM-1	AN-237	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-238 AM-1	AN-238	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-239 AM-1	AN-239	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-240 AM-1	AN-240	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-241 AM-1	AN-241	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-242 AM-1	AN-242	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-243 AM-1	AN-243	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-244 AM-1	AN-244	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-245 AM-1	AN-245	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-246 AM-1	AN-246	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-247 AM-1	AN-247	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-248 AM-1	AN-248	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-249 AM-1	AN-249	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-250 AM-1	AN-250	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-251 AM-1	AN-251	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-252 AM-1	AN-252	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-253 AM-1	AN-253	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-254 AM-1	AN-254	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-255 AM-1	AN-255	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-256 AM-1	AN-256	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-257 AM-1	AN-257	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-258 AM-1	AN-258	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-259 AM-1	AN-259	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-260 AM-1	AN-260	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-261 AM-1	AN-261	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-262 AM-1	AN-262	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-263 AM-1	AN-263	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-264 AM-1	AN-264	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-265 AM-1	AN-265	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-266 AM-1	AN-266	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-267 AM-1	AN-267	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-268 AM-1	AN-268	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-269 AM-1	AN-269	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-270 AM-1	AN-270	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-271 AM-1	AN-271	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-272 AM-1	AN-272	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-273 AM-1	AN-273	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-274 AM-1	AN-274	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-275 AM-1	AN-275	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-276 AM-1	AN-276	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-277 AM-1	AN-277	1	1,000,000	1,000,000	100,000	8,333	1,100,000	1,100,000	91,667
AN-278 AM-1	AN-278	1	1,000,000	1,000,000					

TABLE 16. (Continued)

Note: All costs are on a "then-year" basis. Costs obtained from the Consolidated Management Data List represent latest contract cost but do not reference the applicable years.

^aWhere more than one source was available the figures shown are the highest values found.

^bRecurring production costs adjusted to reflect a production quantity of one, test and evaluation costs of research program are not included, see discussion in Chapter III and Table 15.

^cThis is a maximum value. Where data did not provide a separation between recurring and non recurring production cost the value shown is total production cost. Where data did not allow an estimate of production cost no value is shown.

^dSource: Program Office.

^eSee Table B-7.

^fSource: Joint Tactical Electronic Design System, Master Consolidated Reference List, October 1981, Consolidated Management Data List, October 1980.

^gCicchinelli, et al., 1980, p. 68. The actual equipment trainer is an operational 6883 test bench with no modifications. The value of \$1,955,000 represents the cost of the operational test bench in 1972, adjusted for subsequent price level changes. It excludes 7.5 percent attributed to acquisition management.

^h10 student stations.

ⁱPer student station.

^jA second unit is currently being fabricated. See Table 12.

^kEach unit consists of 12 student stations, each student station is outfitted with 12 different simulations.

^lAN/TC-33, AN/TRC-138, AN/TRC-145, AN/TSQ-34, AN/TSQ-85.

^mOne network consisting of four simulated stations that can operate independently or in concert.

ⁿProgram cost is in dispute. The contractor has filed claim for an additional six million.

^oEquipment required for one class of 15 students.

^pFive complexes of six trainers each. All complexes provide operator training, two complexes provide both operator and maintenance training (one for the AN/TPQ-36 and one for the AN/TPQ-37).

^qEach trainer contains eight different simulations (panels).

(before modification for use in training) in 20 maintenance simulator programs. It is important to understand the different types of cost data shown in this Table.

Operational Equipment Unit Cost - Production cost of an additional unit of equipment designed to meet some military purpose; these values do not include RDT&E costs. Where the costs of an actual equipment trainer are not available, these costs are used as a proxy for actual equipment cost.

Actual Equipment Trainer Unit Cost - Cost of operational equipment, immediately above, that has been adapted for use in training, e.g., power, special inputs and controls, etc. Such modifications require additional costs.

Simulator Total Program Cost - Cost of RDT&E, prototypes, and manufacturing facilities needed to produce one or more maintenance simulators. In our sample of 20 simulator programs for which total program cost data could be compiled, there were 12 instances in which only one simulator was built; in the eight other programs, from 2 to 36 units were built.

Simulator Normalized Total Program Cost - Total production costs adjusted to reflect a production quantity of one; includes the costs of research and development but not test and evaluation of simulators developed in research programs.

Simulator Unit Recurring Fabrication Cost - The cost of producing a follow-on unit of equipment after the costs of RDT&E, prototypes, and manufacturing facilities have been accounted for. This is a maximum value; where data did not provide a separation between recurring and non-recurring production costs, the value shown is total production cost. No value is shown where cost data did not allow an estimate of production cost.

There are, thus, several ways to compare the costs of acquiring maintenance simulators and actual equipment trainers. The cost of an actual equipment trainer is set, approximately, by the incremental cost of procuring one additional unit of operational equipment plus the cost of any modification necessary for its use in a classroom. This is a unit recurring fabrication cost, devoid of RDT&E and non-recurring production costs. We have these costs for six AETs. Where AETs have not been built, we can use the operational equipment unit cost as a surrogate AET cost for comparing the costs of simulators and AETs.

The average ratio of AET unit cost: operational equipment unit cost is 1.27; that is, AETs cost, on the average, about 25 percent more than operational equipment before the latter is modified for training (Table 17); the data are based on only five cases. These ratios, which vary from 1.00 to 1.59, presumably relate to the degree of modification involved in the various cases; whether further modification at even greater cost would improve the effectiveness of instruction has not been examined.

We will estimate the cost of acquiring a maintenance simulator in two ways. The first estimate includes non-recurring costs (e.g., research, development, and manufacturing facilities) and the costs of manufacturing one unit. This value is the normalized total program cost, as defined above. The second estimate includes only the unit recurring fabrication cost (as defined above), i.e., the cost to produce an additional unit (after research, development, and other non-recurring functions have been accomplished). Each of these estimates is relevant because of the large disparity between recurring and non-recurring costs. Maintenance simulator programs have typically involved small quantities so that relative cost-effectiveness of their use will vary greatly with quantity procured. To the extent

TABLE 17. COMPARISON OF THE ACQUISITION COSTS OF ACTUAL EQUIPMENT TRAINERS AND COMPARABLE OPERATIONAL EQUIPMENT BEFORE IT WAS CONFIGURED FOR TRAINING

	Unit Cost (thousands of dollars)		Cost Ratio: AET/Operational Equipment
	Operational Equipment	Actual Equipment Trainer	
MA-3	110	175	1.59
Trident Integrated Radio Room	12,100	17,500	1.45
Trident High Pressure Air Compressor	315	400	1.27
Trident Air Conditioner	530	550	1.04
F-111 Avionics Test Bench (6883 Test Stand)	1,955	1,955	1.00
			Mean 1.27

permitted by the data, we have estimated the recurring costs even if only one unit was actually fabricated.

The actual equipment trainers and operational equipment shown in Table 16 vary widely in cost (from \$45,000 to \$17,500,000). Therefore, we have used ratios to compare the costs of simulators and actual equipment trainers. The central tendencies of the cost ratios, for both the normalized total program and unit recurring estimates, are shown at the bottom of Table 16.

Plots of the individual ratios of estimated simulator costs (both recurring fabrication and normalized program) to actual equipment trainer and operational equipment costs are

shown in Figs. 6 and 7.* In both figures the operational equipment costs have been adjusted by the average ratio of costs developed in Table 17. With two exceptions, the recurring fabrication costs of simulators (Fig. 6) are 20 percent or less of the costs of either operational equipment (as adjusted) or actual equipment trainers, and this conclusion does not depend upon including operational equipment in the sample. Nine of the 11 cases (80 percent) fall below this arbitrary threshold, but there is a large dispersion among them ranging from 3 to 19 percent. Available data provide no explanation for this range. The available data provide some insight into the two cases that fall above 20 percent. The VTAS simulates avionics equipment that has been out of procurement for many years, and we suspect that the cost of the operational equipment is seriously underestimated. The MA-3 is a research device and may contain features that serve only the research function. However, it does not appear reasonable that these special features alone would account for its relatively high cost.

The relationship between simulator normalized program costs and the costs of actual equipment trainers or operational equipment are not as clear-cut (Fig. 7). In seven of the 11 cases the simulator cost is less than 60 percent of the cost of the actual equipment trainer or operational equipment (with a range of 25 to 55 percent). However, in the other four cases, the percentages range from 160 to 400. At first appearance, this sample seems to come from two populations, but we can find no support for this argument in the characteristics of either the simulators or the procurement programs. Similar to the previous ratios of recurring (fabrication) to actual equipment costs,

*The Trident IRR maintenance trainer has been excluded from this analysis as it appears to be as much a complement to as a substitute for either the actual-equipment trainer or the operations/maintenance trainer.

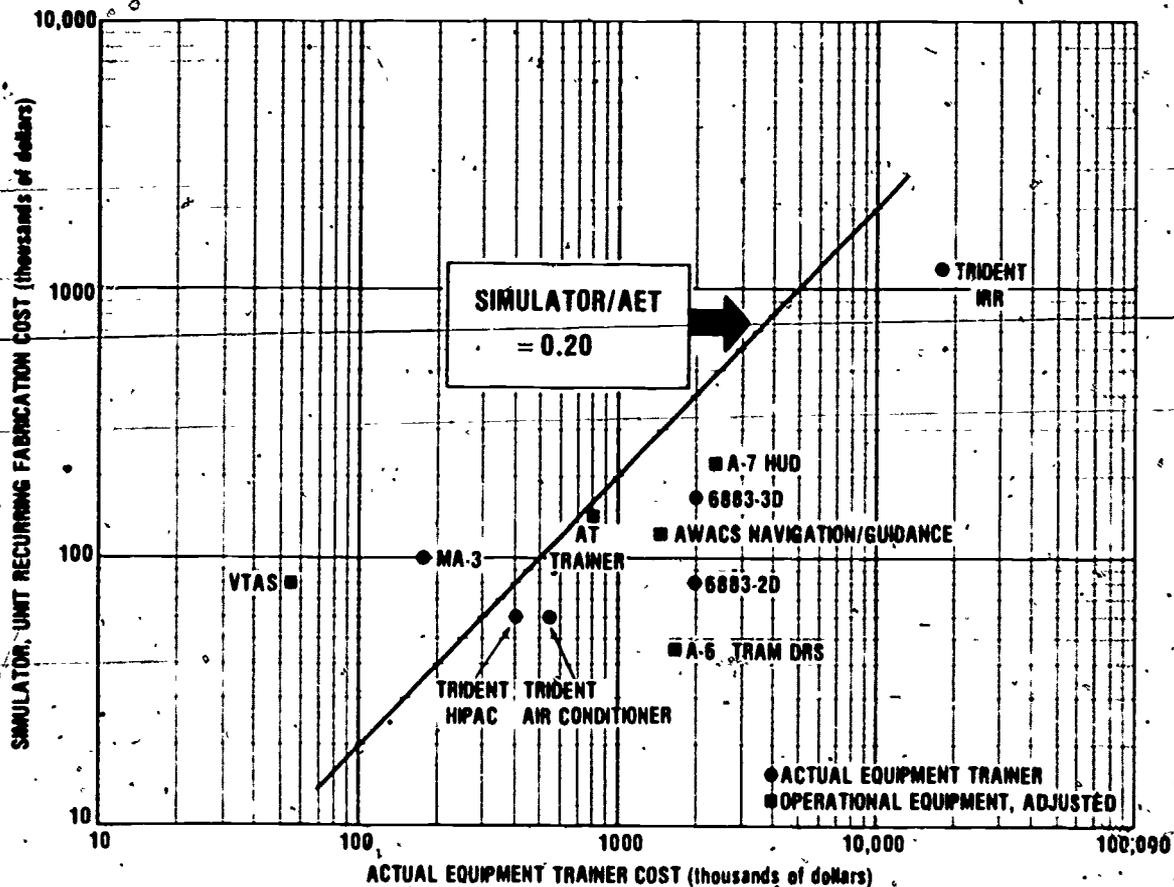


FIGURE 6. Relation between actual equipment trainer and simulator recurring fabrication costs

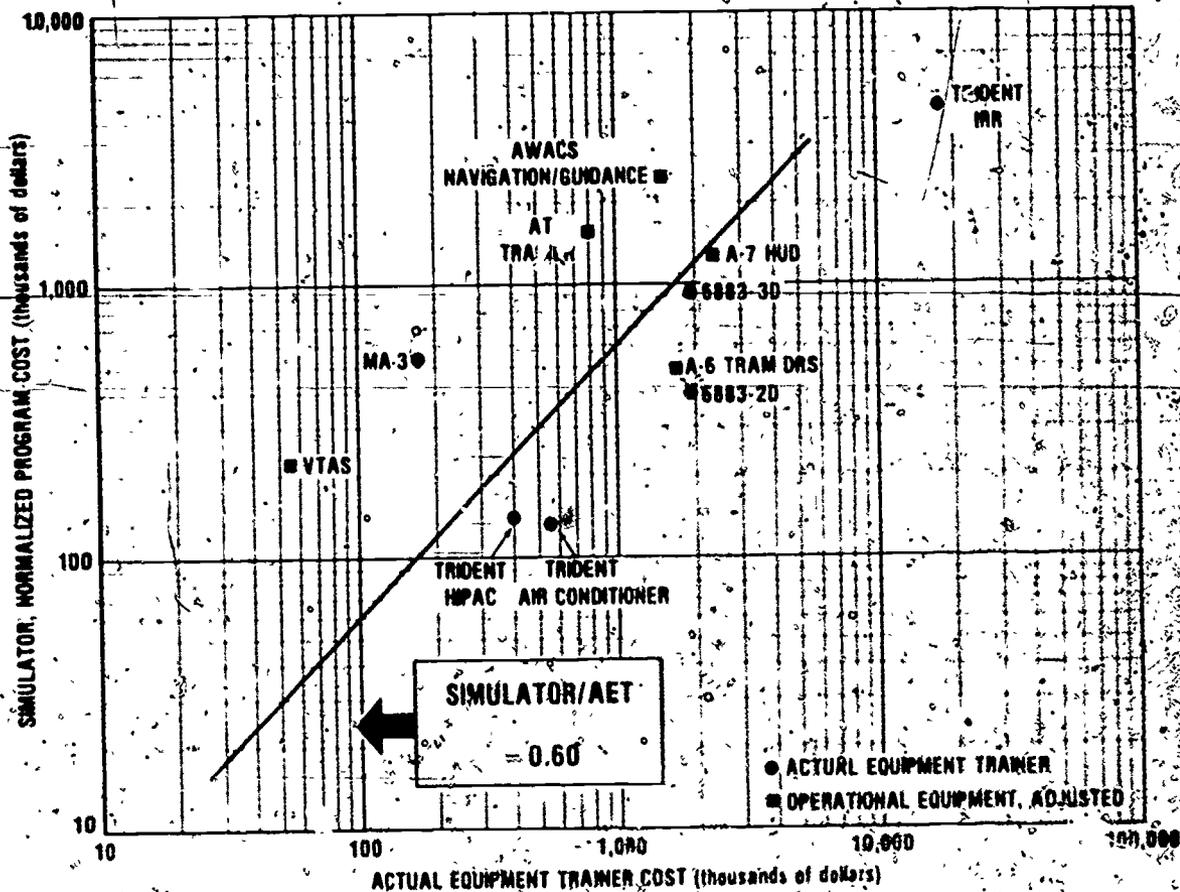


FIGURE 7. Relation between actual equipment and simulator normalized program costs.

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the VTAS and MA-3 simulators are "outliers" here too, and we suspect for the same reasons. The AT Trainer also simulates avionics equipment that has been out of production for a number of years, and we suspect the cost of the operational equipment is considerably underestimated. We have no explanation for the relatively high cost of the AWACS Navigation/Guidance Simulator. The contractor of this program incurred a significant (and non-reimbursed) overrun that has been attributed to his independent development of a courseware translation system (discussed in Appendix B). Even when the overrun is subtracted, the normalized program cost still exceeds the full adjusted cost of the operational equipment by close to 25 percent.

Note that three of the four cases with relatively high cost ratios involve the comparisons with adjusted operational equipment costs, and again, it appears that the sample comes from two populations. For example, in 80 percent of the cases where ratios are based on actual equipment trainers, the simulated normalized program cost is less than 50 percent of the unit cost of the actual equipment trainer; for those ratios based on adjusted operational equipment costs, the normalized program cost is greater than 50 percent of the unit operational equipment cost in 80 percent of the cases. We can find no rationale for this observation. No such distinction can be made with respect to simulator recurring fabrication cost, and we feel it is spurious.

The cost-effectiveness of a maintenance simulator on a life-cycle basis has been evaluated only in one case, that of the Air Force 6883 Test Stand 3-dimensional simulator and actual equipment trainer (Cicchinelli, Harmon, Keller, et al., 1980). In a later study, these authors will also evaluate a 2-dimensional version of this simulator. The 3-dimensional simulator and actual equipment trainer were equally effective when measured by student achievement at school; supervisors' ratings

showed no difference between the job performance of students trained either way for periods up to 32 weeks after leaving school.

The life-cycle cost comparison of simulator and actual equipment trainer is shown in Table 18. Costs were estimated in constant 1978 dollars over a 15-year period and discounted at 10 percent. The results show that the cost per student hour was \$23 for the simulator and \$60 for the actual equipment trainer, i.e., 38 percent as much for the simulator, compared to the actual equipment trainer, for all costs over a 15-year period. The simulator cost less to procure (\$594,000 vs \$2,104,000, or 28 percent as much) and less to operate (\$1,588,000 vs \$3,367,000 or 47 percent as much) over a 15-year period.

Using net present value (1978 constant dollars), the recurring costs were \$1,791,000 or 85 percent of the non-recurring costs of the actual equipment trainer. The recurring costs of the simulator were \$906,000 or 152 percent of its non-recurring costs.

We draw the following conclusions:

Cost: Maintenance simulators cost less than actual equipment trainers. On the average, to develop and fabricate one simulator costs less than 60 percent of the cost of an actual equipment trainer; to fabricate one unit of a simulator (once it has been developed) costs less than 20 percent of the cost of an actual equipment trainer. However, there is a large dispersion about these averages.

Effectiveness. Achievement at school is the same whether students are trained with maintenance simulators or with actual equipment trainers. This finding applies to 12 out of 13 cases in which such comparisons were made. Therefore, maintenance simulators are cost-effective compared to actual equipment trainers.

TABLE 18. LIFE-CYCLE COST COMPARISON OF 6883 TEST STAND, ACTUAL EQUIPMENT TRAINER AND 3-DIMENSIONAL SIMULATOR^a

Cost Category	Costs (thousands of dollars)			
	Actual Equipment Trainer		3-Dimensional	
	Non-recurring Costs	Recurring Costs	Non-recurring Costs	Recurring Costs
Facilities	1	110	1	110
Equipment	2104	2798	594	1000
Instructional materials		28		26
Instructors and overhead		73		94
Students and support		358		358
Total	2105	3367	595	1588
Grand Total		5472		2183
(Net present value, 1978)		(3896)		(1501)
Cost per student hour ^b		\$60		\$23

^aEstimated based on 15-year life cycle discounted at 10 percent, in 1978 constant dollars. Modified from data presented in Cicchinelli, Harmon, Keller, et al., 1980, p. 67-69. Table corrected to show cost of instructors for simulator and cost per student hour over a 15-year period for AET and simulator, based on discussion with senior author. Analysis assumes 720 instructor hours per year and operation of equipment for 2.1 shifts per day to handle student load.

^b180 students per yr x 3 days per student x 8 student hrs per day x 15 yrs = 64,800 total student hours.

This finding is necessarily qualified by the limited nature of the data from which it is derived. Effectiveness, as used here, is based on performance demonstrated at school rather than on the job. Cost, as used here, refers to the initial costs of acquiring training equipment and does not include the costs associated with the operation of simulators or of actual equipment for training, e.g., maintenance and upkeep, instructors and

support personnel, student time, and the like. In the one case where a life-cycle cost comparison was made, total costs over a 15-year period for the 6883 Test Stand 3-dimensional simulator was 38 percent as much as for the actual equipment trainer. Both were equally effective, as measured by tests at school and by supervisors' ratings on the job after school.

Insufficient information is available with which to draw conclusions as to whether 2-D simulators are cost-effective compared with 3-D simulators, the aspects of maintenance training for which simulators are most effective, and how to allocate the amount of time, for greatest cost-effectiveness, between maintenance simulators, actual equipment trainers, and on-the-job training. All of these topics are matters for further research, development, test, and evaluation that are discussed next in this paper.

V. DISCUSSION

On the basis of data presented in previous chapters, we find that maintenance simulators are cost-effective compared with actual equipment trainers. Both are about equally effective for training maintenance technicians at schools; in general, maintenance simulators cost less to acquire than do actual equipment trainers. In this chapter, we wish to discuss the significance of these findings, the limitations of the data upon which these findings are based, and the steps that should be taken both to improve our knowledge and to increase the cost-effectiveness of maintenance simulators used to support training for future systems.

A. EFFECTIVENESS

Students trained on maintenance simulators perform as well on tests at school as do students trained on actual equipment. This finding is consistent with results of studies with use of computer-based instruction for technical courses on electricity, electronics, vehicle repair, precision measuring equipment, and weapons mechanic (i.e. not maintenance training per se).

We would expect that individualized, self-paced instruction, an inherent characteristic of maintenance simulation, would save some of the time students need to complete instruction given with equipment, particularly where the actual equipment trainers are used more for classroom demonstration than for individual practice by students. Only three studies of maintenance simulators report data on the time needed by students to complete their courses (Parker and De Pauli 1967; Rigney, Towne,

King, et al., 1978; and Swezey 1978). Here, students saved 22, 50, and 50 percent, respectively, of the time needed previously in courses given with actual equipment trainers. Time savings, if any, when maintenance simulators are evaluated, should be recorded in future studies; it is anticipated that the few results reported so far will be confirmed. It is important to understand that all findings, although positive with respect both to simulators and computer-based instruction, apply only to training at school; there are no data about the effect that such training, including that using actual equipment, may have on job performance in the field. The importance of collecting information about maintenance performance on the job, and relating it to method of training at school, can hardly be overemphasized.

B. COST

Maintenance simulators appear to cost less to procure than do actual equipment trainers. With some exceptions, the cost to develop and fabricate one simulator is less than 60 percent of the cost of an actual equipment trainer, and to fabricate one unit of a developed simulator is less than 20 percent of the cost of an actual equipment trainer. This finding is based on 11 cases where meaningful cost comparisons could be devised. Because of the limited number of cases, no attempt was made to investigate the determinants of cost.

It is important to emphasize that these comparisons are based only on procurement costs; they are not life-cycle costs. Simulators and actual equipment trainers are used for training over relatively long periods of time such as, for example, 10 years. In addition to the costs of acquisition, they incur costs for operators, maintenance, instructors, and students. Therefore, life-cycle costs are more significant than acquisition costs alone as a basis for evaluating the costs of alternative

training devices. There is one recent estimate that the life-cycle costs of a training program using a maintenance simulator (the 6883 Test Station) would be about 40 percent that of one using the actual equipment (Cicchinelli, Harmon, Keller, et al., 1980).

However, the cost data that are now available are not adequate for definitive conclusions regarding the cost-effectiveness of simulators vis-a-vis actual equipment trainers. Some of the data that are available appear to contain such systematic biases that their reliability may be questioned. The way in which maintenance simulators are procured appears to contribute to the inadequacy of currently available cost data:

- The cost of simulator programs fall below the cost threshold of major procurements, with their associate requirements for use of a standard work breakdown structure (WBS) and for contractor cost reporting within the WBS structure. Contract line item listings, that might serve as a functional cost structure, vary considerably, both among the Services and among separate contracts within a single Service, with a result that cost documentation may not be comparable among contracts.
- Most maintenance simulators with standardized software systems have been procured by means of firm-fixed-price (FFP) contracts. Here, the only costs that are generally available are limited to those spelled out in the contract itself. For the systems with non-standard software, fixed-price-incentive-fee (FPIF), and cost-plus fixed fee (CPFF) contracts, and CPIF have also been employed. However, FPIF contracts provide the Services with little leverage in requiring contractors to provide cost information; none of the program offices that have employed cost-plus contractors have required contractors to provide this type of data.

- Some of the maintenance simulators for which cost data are available were procured primarily for purposes of research and development. In these cases, both the programs and the resulting devices contain features that would not be present had the devices been intended only for routine training. Costs for features peculiar to research may be considerable but, in general, they cannot be identified and separated. Thus, such cost data probably contain an upward bias.

We believe, but cannot document, that currently available cost data on maintenance simulators must be qualified even further for the following reasons:

1. Contractors of some systems with non-standard software appear to have incurred losses that (in whole or in part) they have not divulged. This would introduce a downward bias in the available data. This judgement has been offered by personnel in the program offices involved.
2. Contracts for standardized systems typically encompass procurement of several different simulators; negotiations appear to focus on total contract cost. This has two impacts: (1) it allows trade-offs among individual contract line-item costs in order that the relationships among them appear "reasonable" to the government; (2) contractors have an incentive to inflate the costs of simpler devices and deflate the costs of more complex devices. The result is to distort the cost relationships among contract elements.
3. The market appears highly competitive for simulators with both standard and non-standard software, and it is difficult to get contractors to provide detailed cost data.

4. Within the small sample of non-standard systems, there exists a wide range of program arrangements, device complexity, physical characteristics, and training capabilities. Considering this wide spectrum, it is questionable whether the sample provides a sufficient base for developing a cost analysis capability, even in the absence of the cost data problems discussed above.

C. COST-EFFECTIVENESS

Maintenance simulators appear to be cost-effective compared to actual equipment trainers for training technicians. Since the qualifications that apply to this finding have been explained above, they will only be cited here: the finding is based on acquisition rather than life-cycle costs, on effectiveness as measured by the performance of students at school rather than on the job and only on a limited number of cases (N=11). Here, we will try to explain what this finding does and does not tell us.

We can realize the cost advantages of maintenance simulators only by using them instead of actual equipment trainers (among other training resources) in our maintenance training programs. This is likely to cause some problems for those who believe that, even if maintenance simulators are used, it is still necessary to use actual equipment trainers at school to train technicians how to work later on actual equipment on the job. This dilemma can be resolved by comparing on-the-job performance of those trained at school only with different mixes of both actual equipment trainers and simulators. An evaluation of on-the-job performance has been reported in only one instance (Cicchinelli et al. 1980). Here, supervisors' ratings showed no difference in the job performance of technicians trained

only with the 6883 Converter/Flight Control System Test Station 3-dimensional Simulator or with the actual equipment trainer. Additional studies of this type would be most welcome.

Suppose that on-the-job performance turns out to be the same for students trained only with simulators or with a combination of simulators and actual equipment trainers. If students' loads were such that only one item of training equipment were required, then the additional costs attributed to the actual equipment trainer would make the combination more costly and no more effective than using only the simulator for training. If simulators cost less, the same result would also apply to cases where, because of a large student load, two or more items of training equipment were required. The school might use some combination of simulators and actual equipment trainers. This type of compromise, while not most cost-effective, might appear reasonable to skeptics who believe that actual equipment trainers are still required. Since, except for Cicchinelli, Harmon, Keller, et al., 1980, there are no data to support or reject the notion that both actual equipment trainers and simulators are needed for adequate training, there is much to be gained by collecting the job performance data needed to resolve this dilemma.

Maintenance simulators, it has been argued, cost less and are more effective than actual equipment trainers because they provide feedback to students, provide training in a larger number of malfunctions than is otherwise possible, and have fewer breakdowns when used by students. Cost data support the first claim; although the other claims appear plausible, there are no data to support (or reject) any of them. Some enterprising military laboratory is invited to consider these questions.

Maintenance simulators provide individualized, self-paced instruction and, because of this, one would expect them to save some of the time needed by students to complete the course of instruction. This result has, in fact, been reported in three

studies. If confirmed, as we would expect, the cost avoidance attributable to reduced expense for students' pay and allowances at school would increase the cost-advantages of simulators. This type of calculation has not been included in any evaluation of maintenance simulators.

It is conceivable that some maintenance simulators would be more expensive to procure than actual equipment trainers for the same applications. If all other things, e.g., effectiveness, are equal, then we should obviously choose the less expensive option. However, "all other things" are rarely equal. A simulator, though more expensive to procure than an actual equipment trainer, might sufficiently shorten student time at school, reducing the need for instructors and support personnel; to be less expensive on a life-cycle-cost basis; it might also improve student on-the-job performance sufficiently to be cost-effective in terms of the combined costs of training and (subsequent) maintenance. This statement is not intended to be an argument in favor of simulators. Rather, it is made to point out that, up to now, all studies of simulators and actual equipment trainers have been one-point comparisons, i.e., equal effectiveness and lower costs for simulators. Since no studies have been made between training devices of differing levels of both cost and effectiveness and that extend the analysis to later performance on the job, it is not yet possible to look for an optimum combination of maintenance training equipment.

D. RISK OF CONCURRENT DEVELOPMENT

There is an obvious advantage in the concurrent development of operational and training equipments so that trainers are available when, and preferably before, the operational equipment is first fielded. However, this practice also entails risk, since even minor changes to the operational equipment may result in large additional costs to modify the training simulators

(especially in the areas of simulation software and courseware). In five cases that have been identified as concurrent developments, a significant portion of final simulator costs has been attributed to modifications in the operational equipment. Although the sample is small, it suggests that concurrency will increase the costs of simulator development programs.

It also follows that if simulators for training are developed only after the design of the operational equipment has been frozen, the simulators may not be ready for training when needed. A possible alternative is to train the initial cadre of personnel with actual equipment or with simulators based on a preliminary design, knowing that more adequate simulators will be built later. Whether or not such an alternative is both effective enough and not too costly is a topic for systematic study.

E. IMPORTANCE OF SOFTWARE COSTS

Software and courseware (i.e., program design and programming) appear to be major elements of cost in non-standard maintenance simulator systems. No hard data were found on this point; nevertheless, it is the opinion of individuals who have been involved with the management of maintenance simulator programs. According to these individuals, cost overruns that have occurred have been due primarily to problems in developing software programs. Should this be true, it points to a cost advantage to be gained by developing widely applicable software systems for the more complex training applications. Although no data are available on this point, this would not apply to standard systems, since the same software system is employed in all applications developed by one contractor.

F. LIMITED POTENTIAL FOR QUANTITY PRODUCTION

The bulk of potential maintenance simulator applications appears to arise in system-specific training (as opposed to general skill training), and a majority of the more promising candidate applications seem to be associated with aviation training. However, training for a specific model of aircraft is concentrated at a small number of sites and involves low rates of student flow. As a result, there is a limited potential for quantity production of a given model of simulator over which development costs can be amortized and a limited opportunity for reducing unit costs through a widespread adoption of maintenance simulators.

G. WHAT SHOULD BE DONE NEXT

1. Cost-Effectiveness Trade-Off Studies

Maintenance simulators have been found to be cost-effective, although the data for this finding are limited. There is no reason to doubt the same result for additional comparisons of maintenance simulators and actual equipment trainers. Nevertheless, we should know how to optimize the design and use of maintenance simulators and to be able to make trade-offs between their effectiveness and cost. There is almost a total lack of systematic knowledge about the relation (i.e., trade-offs) between effectiveness and cost in the design and use of maintenance simulators; for example, what features increase their effectiveness in particular applications; conversely, little is known regarding the relationships between simulator features and their costs. Simulators can, naturally, increase in cost in many ways, such as by including more malfunctions in their courseware programs, by providing more complete realism in appearance and functional capabilities (in both 3-D and 2-D designs), and by providing more computer-based, instructional

guidance to students; the converse of any of these statements may also be considered. A substantive question is to determine the extent to which increases in the capability of maintenance simulators (with associated increases in cost) improve the effectiveness of training, i.e., student performance, beyond that which can be achieved without these incremental costs. No studies have been undertaken to explore such functional relationships, except for the still-to-be-completed effort of Cicchinelli, Harmon, Keller, et al., 1980 that will compare 2-D and 3-D versions of the 6883 Test Stand.

2. Validate Simulators with Performance on the Job

Student performance at school is, at best, an indirect measure for evaluating the benefits of simulators, compared to actual equipment trainers, at schools. The real issue is to compare how training with either of these devices improves the ability of course graduates to maintain equipment on the job. The purpose of school training is to qualify students to perform well on jobs in the field and not, per se, to complete a course at school. Data to show the effectiveness of maintenance simulators, compared to actual equipment trainers, as measured by field performance, is totally lacking and is essential for definitive evaluations. Cicchinelli, Harmon, Keller, et al., 1980, an oft-cited reference in this paper, reported supervisors' ratings of on-the-job performance of course graduates but did not collect objective data on the actual performance of these individuals.

3. Fidelity of Simulation

Instructors, in general, favor the use of actual equipment, rather than simulators, for the training of maintenance personnel. Reasons given for this preference are that students need to train with actual equipment and that the lack of realism in simulators can interfere with effective training. Such

reasons cannot be dismissed, because the views of instructors can influence the way in which simulators are used in a course; an inappropriate use of a simulator may easily make it not ineffective and therefore not efficient for training.

A number of studies have shown that low-cost devices, such as mock-ups, charts, and flat panel simulators are as effective as real equipment for training personnel to operate (rather than maintain) equipment (Grimsley 1969; Denenberg 1954; Torkelson 1954; Swanson 1954; Vris 1955; Spangenberg 1974; French and Martin 1957; Prophet and Boyd 1970, Dougherty, Houston, and Nicklas 1957; and Cox, Wood, Boren et al., 1965. Useful reviews of this topic may be found in Micheli 1972, Kinkade and Wheaton 1972, and Fink and Shriver 1978). These studies show that student achievement (i.e., learning the required information) is about the same with real equipment, expensive simulators, or inexpensive mockups; this is taken to represent a range of high to low fidelity in these devices. Some studies have shown that there no differences between individuals trained on high or low fidelity devices when measured by training time, amount of information remembered (after 4 or 6 weeks), or time devoted to additional training some time after leaving school. These findings apply primarily to teaching procedural tasks, e.g., nomenclature, equipment start-up, malfunction location, and troubleshooting logic. This evidence cannot be denied, but it has not had a major influence on the design or procurement of maintenance simulators.

All recent studies of maintenance simulators have evaluated a specific simulator as a direct alternative to some actual equipment for training purposes. Fidelity was not varied systematically or otherwise in any of these studies, with one exception. Flat panel (2-dimensional) and 3-dimensional versions of the 6883 Test Station simulator were developed so that a direct comparison could be made of their effectiveness for training maintenance technicians. The three-dimensional version, produced

by Honeywell, has been evaluated for use in training technicians to operate and maintain the 6883 Test Station (Cicchinelli, Harmon, Keller, et al., 1980). The two-dimensional version, produced by Burtek, will also be evaluated, but data collection and evaluation had not been completed when this report was written (April 1981).

There has been no effort to interpret what aspects of fidelity, if any, may have been varied in the studies that have been completed to date, although it is obvious that different pieces of equipment with different methods of presentation were involved and that these devices cost different amounts of money. There is, at present, no way of measuring, scaling, or defining what we mean by the fidelity of a training device, particularly with respect to its effectiveness for training students. A distinction made by Miller (1954) between psychological simulation and engineering simulation (and copied assiduously ever since) does not help very much: "engineering simulation [is] the copying of some physical model and its physical properties" (p. 19; emphasis in original); "psychological simulation.... provides stimuli so that responses learned to them will transfer from training [with training devices] to operations with little or no loss" (p. 19). ~ "Psychological simulation may be far removed from physical realism" (p. 20). "The development of training devices should rest on psychological simulation rather than engineering simulation" (p. 20).

It may be that less expensive devices are as effective as more expensive ones for maintenance training. However, we lack both a metric and a guideline to identify either the physical or functional characteristics of these devices that influence the effectiveness of training. The interrelationships of complexity, fidelity, and cost of training equipment and the transfer of training from training devices to operational equipment clearly deserve systematic attention, both for R&D on training devices in general and for particular

emphasis on maintenance training. Different levels of complexity and of fidelity may be required for manual, hands-on skills needed in maintenance than for those which involve primarily knowledge and procedures associated with diagnosis of malfunctions and troubleshooting.

4. On-the-Job Training

Technical training at school qualifies a maintenance technician to undertake further training on the job and is not expected, by itself, to produce a high level of competence. At stake, therefore, is assessing the cost-effective mix of training at school and on the job. This important question is beyond the scope of this paper. Nevertheless, a potential advantage of maintenance simulators, particularly as the newer ones become more compact and portable, is that they would permit us to measure the performance of maintenance personnel on or near their job sites and, where deficiencies are found, to provide refresher training to particular individuals. Thus, maintenance simulators provide a means of collecting objective data about technicians on the job (in a test-like situation), that could be used to validate not only the use of simulators in school but of actual equipment trainers; this also applies to any other feature of interest in the type of instruction offered at school.

5. Research on Maintenance

Even after about 30 years of research on maintenance training, we still lack some fundamental information about how humans perform the task of maintenance. As a consequence, we cannot accurately specify, as suggested above, whether a particular simulator should be simple or complex, two- or three-dimensional in form, the optimum mix of general and specific maintenance training, and the trade-offs between increased reliance on automatic and built-in test equipment versus reliance

on human ability to diagnose and perform various maintenance procedures. At least in principle, it is feasible to improve built-in test equipment to assist the technician to find malfunctions and to design a system so that components and test points are more accessible to maintenance personnel. The real issue is to determine whether increased expenditures during system development for engineering characteristics to facilitate maintenance will reduce expenditures for personnel, training, maintenance, test equipment, and spare parts over the life cycle of that system.

It is not yet possible to measure the complexity of maintenance tasks so that specifications for equipment which have an impact on maintenance and maintenance personnel can be set both for the design of weapons systems and for maintenance simulators and training programs (see Wohl 1980; Rouse; Rouse, Hunt, et al., 1980; Nauta and Bragg 1980).

It is not yet clear to what extent maintenance simulators should be designed to provide generic training applicable to a variety of equipments and/or specific training applicable primarily to particular models of equipment. A current program at the Navy Personnel Research and Development Center is attempting to address this issue (the Generalized Maintenance Trainer System).

There are insufficient data on the amount of time required to find, identify, and fix various types of malfunctions. Without such data, there appears to be little rational basis for determining the priority to be given to various types of maintenance tasks included in maintenance training course and, of course, in the design of the maintenance simulators to be used in these courses (Johnson and Reel 1973). The work of Rouse, Rouse, Hunt, et al. (1980) suggests that the more difficult fault isolation tasks are in equipment with feedback loops; humans benefit during training when they are given immediate knowledge of results about the rules they are using to identify faults; these skills appear to be transferable to situations where immediate knowledge of results is not provided.

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APPENDIX A
SUMMARY OF STUDIES EVALUATING TRAINING WITH MAINTENANCE SIMULATORS
AND ACTUAL EQUIPMENT TRAINERS

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
Generalized Sonar Maintenance Trainer (1) (4) (GSMT)	Sonar maintenance (Special course for this experiment) Fleet Sonar School San Diego, CA	4 days	AET: AN/SQ-4 Sonar SIM: GSMT	AET Simulator
	Intermediate general electronics (4-week segment of 14-week course in Sonar Maintenance Training) Fleet Sonar School Key West, FL	4 weeks	Note: Final test for both groups on AN/SQS-23 sonar AET SIM: GSMT	AET 1(2) AET 2 Simulator
<p>(1) Trains calibration alignment, preventive maintenance and troubleshooting of circuits and components common to six sonar systems.</p> <p>(2) Control group 1 trained before and control group 2 trained after experimental group.</p> <p>(3) Percent correct answers to special test with 141 items.</p> <p>(4) This is a low-power sonar system rather than a true simulator.</p>				

COMPARISON				COMMENTS	REFERENCES								
NO. OF STUDENTS	SCORES	TIME	ATTITUDES TOWARDS SIMULATORS										
9	Accuracy: Same or better	Average 22 percent faster in performing maintenance tasks on test	Students favorable	Transfer of training experiment. Students trained on AET or simulator; both groups tested on a new sonar. Performance compared on five maintenance tasks. Simulator group superior but differences not statistically significant.	Parker and DePauli, 1967								
9													
	<table border="1"> <thead> <tr> <th>Criterion Test(3)</th> <th>Avg. of weekly tests</th> </tr> </thead> <tbody> <tr> <td>54.4</td> <td>85.5</td> </tr> <tr> <td>54.9</td> <td>83.2</td> </tr> <tr> <td>54.6</td> <td>85.8</td> </tr> </tbody> </table>	Criterion Test(3)	Avg. of weekly tests	54.4	85.5	54.9	83.2	54.6	85.8			No significant difference between groups. Analysis of data shows that although students trained with GSMT had lower "academic potential" (GCT/ARI scores) than control groups, they performed as well as controls. Report does not describe equipment used to train control groups.	DePauli and Parker, 1969
Criterion Test(3)	Avg. of weekly tests												
54.4	85.5												
54.9	83.2												
54.6	85.8												
20													
20													

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
EC-II	APQ-126 radar for AD 7 aircraft Air National Guard Buckley Field, CO	OJT ⁽¹⁾		AET Simulator
	Mohawk Propeller System (53 C51), OV-1 Airframe. Repair Course U.S. Army Transportation School, Fort Eustis, VA	3 hrs	AET: Mock-ups and breadboards; conventional classroom instruction	AET
	Hydraulic and flight control system, T-2C aircraft	32 hrs	SIM: EC-II AET: Arresting gear and speed brake trainer, main and auxiliary landing gear trainer, flight control trainer. NAS Chase Field SIM: Elevator and elevator trim panel, aileron and trim panel, hydraulic speed brake panel, landing gear panel rudder and rudder trim panel, wheel brakes and flaps panel. NAS Meridian	Simulator AET Simulator
	Engine, power plants and fuel system	24 hrs	AET: Fuel systems trainer; engine NAS Chase Field SIM: Fuel panel; DC electrical start and run panel NAS Meridian	AET Simulator
	Environment/utility system	32 hrs	AET: Heat and vent training unit; seat, NAS Chase Field	AET

(1) On-the-job training; length not specified.

(2) 11 qualified, 6 untrained.

(3) 40 items, multiple choice

(4) Oral performance test on T-2C aircraft at end of course; aircraft part identification, knowledge of maintenance manual, situational troubleshooting. Scored by examiner from Naval Weapons Engineering Support Activity.

COMPARISON

NO. OF STUDENTS	SCORES	TIME	ATTITUDES TOWARDS SIMULATORS	COMMENTS	REFERENCES
17 ⁽²⁾			All Judged learning to be easy; 90 percent recommend simulator for training		Spangenberg 1974
28	87.9			Performance measured on same practical exercises; difference in favor of simulator statistically significant (p=0.0001)	Dorst 1974
33 17	93.7 End of ⁽³⁾ course 34.8 Performance ⁽⁴⁾ 82.6				Wright and Campbell, 1975
13	End of ⁽³⁾ course 35.5 Performance ⁽⁴⁾ 76.2		Students favorable; instructors neutral to negative	*Difference in favor of simulator statistically significant (p=0.10)	
19	End of ⁽³⁾ course 32.1			*Difference in favor of AET statistically significant (p=0.10)	Wright and Campbell, 1975
13	Performance ⁽⁴⁾ 69.7		Students favorable; instructors neutral to negative		
16	End of ⁽³⁾ course 31.9 Performance ⁽⁴⁾ 74.1				Wright and Campbell, 1975

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
EC-II (continued)	<p>Weapon control system mechanic, Block VI, radar Lowry AFB, CO</p> <p>Motor Transport School Marine Corps Base Camp Lejeune, NC</p>	60 hrs	<p>SIM: Environmental simulation panel; environmental and utility panel; seat; NAS Meridian</p> <p>AET: AN/APQ 126 radar for A-7D aircraft</p> <p>SIM: EC-II</p>	<p>Simulator</p> <p>AET</p> <p>Simulator</p>
EC-IIIVLP ⁽¹⁾	<p>Pilot familiarization for T-2C aircraft NAS Pensacola, FL</p> <p>Naval Flight Officer familiarization for TA-4C aircraft, NAS Pensacola, FL</p>	<p>18 hrs⁽²⁾</p> <p>11 hrs⁽²⁾</p>	<p>AET: mobile training unit, chalkboard</p> <p>SIM: EC-IIIVLP</p> <p>(as above)</p>	<p>AET</p> <p>Simulator</p> <p>AET</p> <p>Simulator</p>

(1) Large panel version, interded for class demonstrations.

(2) Eight (8) lesson units, e.g., electrical systems, instruments, ejection system.

(3) Naval Flight Officers.

COMPARISON				COMMENTS	REFERENCES
NO. OF STUDENTS	SCORES	TIME	ATTITUDES TOWARDS SIMULATORS		
9	Performance (4) 84.5 End of (3) course 35.4 Performance (4) 76.4		Students Favorable; instructors neutral, to negative		
24	Normal operations checkout (95 items); Solving 8 malfunction problems		Students neutral to favorable; 2 instructors favor simulator; 3 cautious	No significant difference between AET and simulator group	McGuirk, Pieper and Miller, 1975 (Also Miller and Rockway, 1975)
15	Normal operations checkout (N.S); solving malfunction problems (N.S)			Cost estimate for equipment (2 sets) in complete course: \$1,068,000 AET vs \$169,000 for simulators	
6 pilots			Students and instructors moderately to highly favorable to SIM (EC-11) Instructors favor simulator over other training aids	No data in paper, EC-11 judged effective for training and recommended for adoption, Project savings of \$386,000 over 15 years Finding based on factor analysis of attitudes Author judges training with simulator to be equally effective to use of AET at school; performance on-the-job unknown	Platt 1976 Biersner 1975 Biersner 1976
30 NFO's (3)			(as above)	(as above)	Biersner 1976

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
Automated Electronics Maintenance Trainer (AEMT)			<p>AET</p> <p>SIM: Conventional FM tuner</p> <p>AET</p> <p>SIM: Primary power control for ALM-64 manual test equipment for AN/ALQ-100 airborne EW transceiver</p> <p>AET</p> <p>SIM: ALM-106B semi-automatic test set for ALQ-126 EW transceiver</p> <p>AET</p> <p>SIM: Visual target acquisition system (VTAS), helmet-mounted sight</p>	

COMPARISON

NO. OF STUDENTS	SCORES	TIME	ATTITUDES TOWARDS SIMULATORS	COMMENTS	REFERENCES
				<p>Provides CAI and CMI services to multiple student stations; one instructor station</p> <p>No evaluation reported</p> <p>Evaluated favorably by 3 Navy instructors for fidelity of simulation and usefulness for training</p> <p>As above, plus comments by attendees at demonstrations that "AEMT approach appeared to provide as good if not better training effectiveness than is achieved using operational hardware," (p.27). No performance data</p> <p>No evaluation reported</p>	<p>Modrick, Kanarick, Daniel and Gardner, 1975</p> <p>Modrick, Kanarick, Daniel, and Gardner, 1975</p> <p>Daniels; Datta, Gardner, and Modrick, 1975</p>
				<p>No evaluation reported</p>	<p>Modrick, Kanarick, Daniel, and Gardner, 1975</p>
				<p>No evaluation reported</p>	<p>Modrick, Kanarick, Daniel, and Gardner, 1975</p>

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
<p>Generalized Maintenance Training System (GMTS)-Rigney System</p>	<p>AN/SRC-20 UHF Voice Communications System Advanced Electronics Schools, Department Facility, Naval Schools Command, San Diego, CA</p> <p>AN/SPA-66 radar repeater, Naval Mobile Technical Unit 5, San Diego, CA</p> <p>AN/WSC-3 transceiver for fleet satellite communication system. Advanced Electronic School Division Service School Command, San Diego, CA</p>	<p>4 days (16 hrs)</p>		<p>AET Simulator</p> <p>AET Simulator</p>

COMPARISON				COMMENTS	REFERENCES
NO. OF STUDENTS	SCORES	TIME	ATTITUDES TOWARDS SIMULATORS		
20		Average solution time per problem about half that above	Students favorable or very favorable		Rigney, Towne, King and Moran (Oct 1978)
10			Students favorable or very favorable	Average solution times per problem (N=11) reported for students trained with simulator; no baseline data for comparison	Rigney, Towne, Moran Mishler (1980)
				Improved, low cost version using a UCSD Pascal, high-level, transportable computer language. Training effectiveness to be determined	Towne and Munro (1981)

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
Fault Identification Simulator (FIS)	Hagen Automatic Boiler Control Fleet Training Center San Diego, CA	5 wks	AET ⁽¹⁾ Pneumatic Maintenance Simulator ⁽²⁾ and Boiler Control replica SIM: FIS and Boiler Control replica	AET Simulator

(1) Actual equipment trainer

(2) Actual components activated by pneumatic and electrical signals

(3) Individualized, self-paced instruction compared to conventional instruction above

COMPARISON

NO. OF STUDENTS	SCORES	TIME	ATTITUDES TOWARDS SIMULATORS	COMMENTS	REFERENCES
16	"same as above"	5 weeks 2.4 weeks (3)			Swezey in Kinkade (1979)

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
<p>6883 Converter/Flight Control Systems Test Station (for F-111 aircraft)</p>	<p>F-111 Avionics Maintenance</p>	<p>6 days (special block in 23 weeks course for this test)</p>	<p>AET: 6883 Converter/Flight Control Systems Test Station</p> <p>SIM: 3-dimensional simulation of above</p>	<p>Control</p> <p>Simulator</p>
<p>(1) Tests</p> <ol style="list-style-type: none"> 1. End of course 2. Projected job proficiency, Part I 3. Projected job proficiency, Part II 4. Ratings by supervisors on job performance after 2-32 weeks on job. 				

COMPARISON				COMMENTS	REFERENCES
NO. OF STUDENTS	SCORES	TIME	ATTITUDES TOWARDS SIMULATORS		
59	Assistance needed by instructors	To complete test	Students favorable; instructors neutral to slightly favorable	This Test Station used only two days in regular 23 weeks course (6 days in this test). Test shows equal effectiveness at school and in follow-up on job 2-32 weeks later, based on supervisors' comments. Study also says simulator costs about one-third that of actual equipment to acquire and use.	Ciccinelli, Harmon, Keller and Kottenstette (1980)
	Tests (1)				
	1. 23.1 2.2	54.2 min			
	2. 13.9				
56	3. 23.9				
	4. Same				
	1. 22.8 2.3	54.8 min			
	2. 14.0				
56	3. 23.0				
	4. Same				

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
Paper and pencil training aids Trainer-Tester ⁽⁵⁾ Punchboard Tutor	Basic electronics U.S. Naval Training Center, Great Lakes, IL	10 wks	AET: (1) AET + Trainer-Tester AET + Punchboard Tutor	
Paper and pencil training aids Trainer-Tester Custom-built simulator ⁽⁶⁾	Radar repair Army Signal School, Fort Monmouth, NJ	9 wks	Taped lectures(N=4) Trainer-Tester Custom-built simulator	
Flow Diagram Trainer and Automated Microfiche Terminal	JDA radar display HMS Collingwood	2 days	Panel board simulator Microfiche projector Equipment mock-up (JDA radar simulator)	

(1) Push-pull, three-stage transmitter superheterodyne receiver; twelve 45-minute classes for each

(2) 50 multiple-choice items

(3) Grade assigned by instructor

(4) 15 multiple-choice items

(5) Simulator malfunctions, tests and measurements on specially prepared paper layouts of equipment developed by Van Valkenburgh, Nooger, and Neville, Inc., 1954

(6) Locally designed to be more realistic than Trainer-Tester, uses schematic drawings

COMPARISON

NO. OF STUDENTS	SCORES	TIME	ATTITUDES TOWARDS SIMULATORS	COMMENTS	REFERENCES																		
230	Exam ⁽²⁾ 74 Lab ⁽³⁾ 80 Trouble-shooting ⁽⁴⁾ 63		Students believe aids improved troubleshooting skills.	No significant difference between groups trained differently when tested later in Advanced training	Cantor and Brown, 1956																		
230	Exam 75 Lab 81 Trouble-shooting 64		Instructors prefer lab work to Trainer Tester; least accept Punchboard Tester	Communications (N=126); Trainer-Tester group (N=210) superior on laboratory grades																			
230	Exam 76 Lab 81 Trouble-shooting 65			Effects measured at the end of the course by performance test (find malfunction in actual radar components), and written tests Main finding is that lectures on troubleshooting improve effectiveness of paper simulators. Custom-built simulators are more effective than Trainer-Tester	Glass, 1967																		
6 groups																							
N=26, 27 each																							
12	<p>No. of checks to find faults fault before after</p> <table border="1"> <tr><td>1</td><td>10</td><td>4</td></tr> <tr><td>2</td><td>16</td><td>5</td></tr> <tr><td>3</td><td>--</td><td>5</td></tr> </table>	1	10	4	2	16	5	3	--	5	<p>Average time to find faults (min) fault before after</p> <table border="1"> <tr><td>1</td><td>18</td><td>5</td></tr> <tr><td>2</td><td>21</td><td>6</td></tr> <tr><td>3</td><td>--</td><td>6</td></tr> </table>	1	18	5	2	21	6	3	--	6		Training with panel board trainer and microfiche projector; before and after tests with JDA radar simulator; no comparison with AET	Cunningham, 1977
1	10	4																					
2	16	5																					
3	--	5																					
1	18	5																					
2	21	6																					
3	--	6																					

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	EQUIPMENT	TYPE OF INSTRUCTION
Computer simulations for training in fault diagnosis (computer-assisted instruction)	Aircraft power plant conditioning and testing Institute of Aviation, University of Illinois	3 special training sessions (total of six hours) in semester course	Context free simulation Context-specific simulation Instructional TV film on troubleshooting engines Continental O-300 reciprocating (on test stand) Lycoming O-235 reciprocating engine (on test stand)	Instructional TV Context-free fault diagnosis Context-specific fault diagnosis
<p>(1) Fault-finding performances on two aircraft engines on test stands.</p>				

COMPARISON					ATTITUDES TOWARDS SIMULATORS	COMMENTS	REFERENCES
NO. OF STUDENTS	SCORES (1)			TIME (1)			
	Performance score	Percent of appropriate actions	Percent of inappropriate actions	Time/Problem	Attitudes (5 most favorable)		
12	4.4	44%	0.9%	1.3 hrs	4.2	Transfer measured from method of training to fault finding, 5 malfunctions, in 2 actual engines on test stand. Training with instructional TV yielded best troubleshooting performance, judged due to similarity of training of training with test. Evidence that computer simulation transfer also found but less pronounced.	Johnson, 1980
12	4.0	28	0.7	1.8	4.4		
12	4.0	30	1.4	2.2	3.8		

APPENDIX B

PROGRAM COSTS OF NON-STANDARD SIMULATORS

APPENDIX B

PROGRAM COSTS OF NON-STANDARD SIMULATORS

A. SUMMARY

Table B-1 provides a summary of costs for nine non-standard simulator programs for which data were available. Table B-2 shows the "normalized" costs of these programs. Normalization involved two adjustments to the program costs.

- (1) In order to provide a consistent base for comparison among programs, recurring production costs were divided by the quantity fabricated. Thus, each program will reflect the costs that (hypothetically) would have been incurred if only one trainer had been produced.
- (2) Two of the research programs (the 6883 and MA-3 Test Benches) incurred significant costs for evaluations. These costs were excluded so that each program will reflect the costs that (hypothetically) would have been incurred if they had been intended for main-line training.

The values shown in Table B-2 provide the basis of the percent ranges of the different cost elements shown in Table 15.

The remainder of this Appendix provides a short discussion of each of the nine programs and a more detailed display of their costs.

TABLE B-1. NON-STANDARD SIMULATORS, SUMMARY OF TOTAL PROGRAM COSTS

	6883 Test Bench	A-7E HUD Test Bench	MA-3 Test Bench	A-6E IRAM ORC	VTAs	AT Trainer	Integrated Radio Room		F-16 ^a Total Program	Aviatic Navigation/ Program
							Operations/ Maintenance Trainer	Maintenance Trainer		
Quantity Fabricated	1	1	1	2	2	3	1	1	--	1
Non-Recurring Cost										
Front End Analysis	19	234	87	40	--	20	422	248	--	100
Design & Development	427	650	217	311	74	1015	2163	1444	--	1998 ^b
Hardware	35	75	46	10	19	405	1442	936	--	506
Software/Courseware	384	521	131	249	36	460	520	359	--	943
Technical Data	8	38	--	46	17	150	201	179	--	539
Other	--	16	40	6	--	--	--	--	--	--
Hardware Fabrication (Non-recurring)	57	--	--	--	--	69	--	--	--	--
Test & Evaluation	155	--	90	7	6	8	12	12	--	40
Program Management	145	72	75	40	51	40	519	298	--	123
Total Non-recurring	803	956	469	398	131	1152	3117	2001	14,963	2261
Recurring Cost										
Production	169	249	100	92	163	453	1182	508	--	127
Hardware Fabrication	149	224	82	35	156	421	783	320	--	127
Special Tools/Test Equipment	20	--	--	13	--	--	78	39	--	--
Initial Spares	--	25	17	44	7	32	321	149	--	--
Logistic Support	134	76	39	11	--	205	47	47	--	70
Interim Maintenance Support	104	76	25	11	--	--	47	47	--	70
Other	--	--	14	--	--	205	--	--	--	--
Initial Training	--	15	7	17	3	30	118	68	--	--
Total Recurring	273	340	146	120	166	688	1347	623	14,073	197
Total Cost	1076	1296	615 ^b	518	297	1840	4464	2624	29,036	2458

^aThe current estimated F-16 program cost is \$26,890 thousand. This total could not be duplicated due to method used to separate recurring and non-recurring costs.

^bDoes not include cost expended for development of new training course.

TABLE B-2. NON-STANDARD SIMULATORS, SUMMARY OF NORMALIZED TOTAL PROGRAM COSTS^a

	6883 Test Bench	A-7E HUD Test Bench	MA-3 Test Bench	A-6E TRAM DRS	VIAS	AT Trainer	Integrated Radio Room		F-16 Total Program	AMACS Navigation/ Guidance
							Operations/ Maintenance Trainer	Maintenance Trainer		
Non-recurring Cost										
Front End Analysis	19	234	87	40	--	20	422	247	--	103
Design & Development	427	650	217	311	74	1015	2163	1444	--	1998
Hardware	35	75	46	10	19	405	1442	906	--	506
Software/Courseware	384	521	131	249	38	460	520	359	--	943
Technical Data	8	38	--	46	17	150	201	179	--	549
Other	--	16	40	6	--	--	--	--	--	--
Hardware Fabrication (Non-recurring)	57	--	--	--	--	69	--	--	--	--
Test & Evaluation	--	--	--	7	6	8	12	12	--	40
Program Management	145	72	75	40	51	40	519	298	--	123
Total Non-Recurring	648	956	379	398	131	1152	3117	2501	14,963	2261
Recurring Cost										
Production	169	249	100	46	82	151	1182	508	--	127
Hardware Fabrication	149	224	82	18	78	140	783	320	--	127
Special Tools/Test Equipment	20	--	--	6	--	--	78	39	--	--
Initial Spares	--	25	17	22	4	11	321	149	--	--
Logistic Support	104	76	39	11	--	205	47	47	--	70
Interim Maintenance Support	104	76	25	11	--	--	47	47	--	70
Other	--	--	14	--	--	205	--	--	--	--
Initial Training	--	15	7	17	3	30	118	68	--	--
Total Recurring	273	340	146	74	85	386	1347	623	3,535	197
Total Cost	921	1296	525	472	216	1538	4464	2824	18,498	2458

^aRecurring production costs were adjusted to reflect a production quantity of one, test and evaluation costs of research programs were not included.

B. RESEARCH PROGRAMS

The three research programs (simulating the Navy A-7E HUD and MA-3 and the Air Force 6883 Test Benches) have had mixed histories. Each was conceived as a vehicle for an extensive evaluation, comparing the effectiveness of maintenance simulation as an alternative to actual equipment for training, and there is no evidence that they were intended for use in regular training programs. However, current planning envisions using the MA-3 Test Bench for training. These three devices are the only ones, to date, that address simulation for intermediate (as distinct from organizational) echelon maintenance training.

Each of the trainers is a unique 3-dimensional device, and each has had a different principal contractor. For the two Navy devices, the contractors had no prior experience in developing similar systems. The contractor for the 6883 (Honeywell) previously had built one model of a 3-dimensional maintenance simulator.

1. Honeywell 6883 Test Bench

The 6883 device was procured as part of a continuing maintenance simulation research project of the Technical Training Branch of the Air Force Human Resources Laboratory (AFHRL). It is the only one of the three research devices that has been extensively evaluated; results have been published recently in Deignan and Cicchinelli (1980) and Cicchinelli, Harmon, Keller, and Kottenstette (1980). This evaluation addressed the simulator for training operations and maintenance of the 6883 Test Bench. A standardized 2-D system, also simulating the 6883, has recently been delivered and will be evaluated for training operation and maintenance of the test bench.

Program cost information (Table B-3), based on contract actuals and in-house costs, was obtained from the AFHRL program

TABLE B-3. 6883 TEST BENCH (Dollars, Thousands)

Contractor	In-House	Denver Research Institute	Honeywell		Total Program
	Management and Support	Training Evaluation	Original Contract	Engineering Changes and Maintenance Contract	
Non-Recurring Cost					
Front End Analysis			19		19
Task Analysis			19		19
Other					
Design and Development	26		313	88	427
Hardware			34	1	35
Software/Courseware	26		273	85	358
Technical Data			6	2	8
Other					
Hardware Fabrication (non-recurring)			57		57
Test and Evaluation		155			155
Program Management	145				145
Total Non-Recurring	171	155	389	88	803
Recurring Cost					
Production Hardware Fabrication (recurring) ^a			169		169
Special Tools/Test Equipment			149		149
Initial Spares			20		20
Other					
Logistic Support				104	104
Interim Maintenance Support				104	104
Other					
Initial Training					
Total Recurring			169	104	273
Program Total Cost	171	155	558	192	1,076

^a Including installation and checkout.

office. Honeywell contracted for this program at roughly the same time as its VTAS system was delivered to the Navy. There appears to be little similarity between the two, and it is unlikely that the prior VTAS experience proved significant in the 6883 program.

2. A-7E HUD Test Bench

The A-7E HUD (Head-Up-Display) Test Bench is one part of a Navy research program that envisioned development and evaluation of six 3-dimensional maintenance simulators -- one each for training in three types of skills (electronic, electro-mechanical, and mechanical) at two maintenance echelons (organizational and intermediate). In addition to evaluation of these different applications of simulators, the research program was to result in developing procedures for formulating simulator development specifications.

The A-7E HUD is the intermediate echelon, electronic skills portion of this research program. To date, the device has not been evaluated. An evaluation program was designed and the simulator was delivered to the training site. However, the program was not initiated, and its future is in doubt.

This was the first device to be initiated under the research program, and the first of its kind for the Navy. Personnel involved with management of the program (the Human Factors Laboratory of the Naval Training Equipment Center) are frank to state that it was a learning experience for them in terms of simulator specification (one objective of the research program) and development procedures. The device was initially limited to simulation of the "day" version of the HUD that was a mature A-7E system at the time. However, a FLIR (forward-looking-infrared) version was in development at that time, and the simulator program was later expanded to incorporate the FLIR capability. This opened the program to two problems -- modification and concurrency.

Program costs (shown in Table B-4) were developed by the Human Factors Laboratory from contract records and the expertise of Laboratory personnel. The costs show the impact of the decision to simulate the FLIR capability. Six contractors were involved in the program, three of these (including the A-7E prime contractor), because of the FLIR decision. Over one-third of the program total costs (and over 40 percent of contracted costs) resulted from the FLIR modification. Unfortunately, there is no way to separate FLIR-associated costs into those arising from modification, per se, and those arising from concurrent development of the simulation and the operational equipment. Program office personnel believe the latter was a significant element, and state that during several intervals development of the simulator was ahead of development and documentation of the operational equipment.

3. MA-3 Test Bench

The MA-3 is a second element of the Navy maintenance simulator research program, in this case addressing training of intermediate echelon, electro-mechanical skills. This program was initiated more than two years after the A-7E HUD and benefited significantly from the earlier experience, according to program office personnel. The device was delivered during the summer of 1980 and is currently undergoing evaluation that should be complete in June 1981.

Program costs are shown in Table B-5. These data were developed from contract records and expertise of personnel from the Human Factors Laboratory that managed the program.

The simulator has one noteworthy characteristic, different from any of the other non-standard devices, that is completely unrelated to its role as a research vehicle. It is the only device of its class to provide training that is not specific to a single weapon or support system. The MA-3 is a universal stand used throughout the Navy for on-shore testing

TABLE B-4. A-7E HUD TEST BENCH (Dollars, Thousands)

Contractor	In-House	Honeywell	Educational Computer Corporation		Vought Aircraft	Application, Inc.	AACT'S Engineering Inc.	Data General	Total Program	Recapitulation		
			Day System; Original Contract	Day System; Engineering Change						FLIR System; Expansion; Data Base Design	FLIR System; Expansion; Design	FLIR System; Expansion; Hardware
Non-Recurring Cost												
Front End Analysis	44	95	20		30	45			234	44	115	75
Task Analysis	20	65	20		30	45			180	20	85	75
Other	24	30							54	24	30	
Design and Development												
Hardware	72		215	48	115	195	5		650	72	263	315
Software/Courseware			15	20	15	25	5		80		35	45
Technical Data	48		185	28	100	160			521	48	213	260
Other	8		15			10			33	8	15	10
	16								16	16		
Hardware Fabrication (non-recurring)												
Test and Evaluation	24								24	24		
Program Management												
Program Management	72								72	72		
Total Non-Recurring	212	95	235	48	145	240	5		980	212	378	390
Recurring Cost												
Production Hardware Fabrication (recurring)			95	60	20	30	20		225		155	70
Special Tools/Test Equipment			90	45	20	25	20		200		135	65
Initial Spares			5	15					5		20	5
Other									20			
Logistic Support												
Interim Maintenance Support								76	76	76		
Other								76	76	76		
Initial Training												
Initial Training			5	5			5		15		10	5
Total Recurring			100	65	20	30	25	76	316	76	165	75
Program Total Cost	212	95	335	113	165	270	30	76	1,296	288	543	465

Installation and checkout.

TABLE B-5. MA-3 TEST BENCH (Dollars, Thousands)

Contractor	In-House Engineering and Support	Applimation, Inc.			Seville Training Cost/Effectiveness Evaluation	Total Program
		Initial Contract	Program Expansion/Modification	Cost Overrun and Spares		
Non-Recurring Cost						
Front End Analysis		80	7			87
Task Analysis		38				38
Other		42	7			49
Design and Development	40	20	111	47		218
Hardware		7	29	10		46
Software/Courseware		13	82	37		132
Technical Data						
Other	40					40
Hardware Fabrication (non-recurring)						
Test and Evaluation					90	90
Program Management	40	11	14	9		74
Total Non-Recurring	80	111	132	56	90	469
Recurring Cost						
Production		42	28	29		99
Hardware Fabrication (recurring) ^a		42	28	12		82
Special Tools/Test Equipment				17		17
Initial Spares						
Other						
Logistic Support		14		25		39
Interim Maintenance Support				25		25
Other		14				14
Initial Training		7				7
Total Recurring		63	28	54		145
Program Total Cost	80	174	160	110	90	614

^a Including installation and checkout.

of all generators and constant-speed-drives that comprise aircraft primary electric power systems. (A related test stand, the MA-2, serves the same function for all primary aircraft power systems on board ship.) As a result, knowledge of both its operation and maintenance is a widespread requirement and, if exploited, a variant of this simulator (modified for main-line training) might satisfy an extensive training requirement.

The MA-3 consists of two distinct components -- the test stand itself and associated equipment (such as electronic test sets and oil coolers) to adapt its use to the range of different generators and constant speed-drives that are used on various Navy aircraft. The simulator was designed with this in mind and maintains a separation of these two components. Although the current simulator was built specifically for training AV-8A maintenance personnel, the contractor has provided the following rough estimates.

- Modification of the current simulator system to allow simulation of other generator/constant-speed-drive combinations would cost \$15,000 to \$20,000 (including computer programming and fabrication) for each combination.
- Follow-on units in lots of two of the current configuration (including hardware, software, and documentation) would cost \$170,000 per unit.

Two points should be noted with regard to the second contractor estimate. The first is that the current simulator is configured for research and it can be anticipated that quantity production of a device that did not contain features needed for research would cost significantly less. The second point is that there is an apparent inconsistency between the contractor's estimate and the costs developed by Human Factors Laboratory personnel. The latter costs attribute only \$99 thousand to recurring device production and \$145 thousand to recurring program costs (and include all non-recurring fabrication costs that, in

in fact, were incurred). We have no explanation for the difference in estimates. However, the lower Laboratory estimate is consistent with data obtained on other programs. Either estimate totals to much less than the cost incurred in the research program, and the bulk of this cost reduction can be attributed to the high proportion of non-recurring costs associated with one-of-a-kind production.

C. A-6 TRAM DRS

The A-6 TRAM DRS (Detection and Ranging System - AN/AAS-33A) simulator was initiated as a research program, i.e., as one element of the Navy research program that includes the A-7 HUD and the MA-3 Test Stands. However, this aspect of the program was modified at an early stage, and the simulator was adopted as one of the primary devices for organizational echelon maintenance training of the electronic portion of the DRS. Two units were built and shipped to the two A-6 training detachments where they were placed in main-line training after a relatively short checkout and acceptance test period.

This appears to be one of the more successful non-standard simulator programs. The devices cannot be considered high cost and have been well received by training personnel. However, certain features of the device and its procurement point up problems that seem to recur with maintenance training simulators. Four of these are discussed below.

- The simulator provides only for organizational maintenance training on the electronic portion of the DRS. As a result, it did not relieve a requirement for using operational equipment for training on the mechanical portion of the DRS. While the existence of the simulator reduces the training load placed on the operational equipment, it does not necessarily reduce the amount or cost of actual equipment required for training.

- This model of DRS is peculiar to the A-6 aircraft. A-6 training is conducted at only two locations, and the two devices serve to fully satisfy the training requirement. This is typical of aircraft systems today, even those that are procured in large numbers. When it is considered that the major portion of simulator program cost is nonrecurring in nature (approximately 75 percent in this case) there appears to be little promise in reducing their costs, except by use of standardized systems where high development costs (such as for the software systems) can be spread to a number of training applications.
- This is the first device of this type to be contracted for by Grumman, and its capabilities and design (including the software package) are highly tailored to this single training application. Configuration changes and modifications are common to current combat aircraft and even apparently minor ones may result in major changes to maintenance simulators whose costs may be a major portion of those required for developing a new device.
- Decisions regarding the timing of training device deliveries are critical in providing training on new or modified operational equipment. Whatever types of training devices are used, they must be in place before that training can commence, and training must be provided to personnel before the operational equipment can become an effective part of the force. Since simulation trainers require their own development, this must occur concurrently with development of the operational equipment. However, the operational equipment is subject to frequent modification during development and for a considerable period after its fielding. As discussed above, these modifications can have a drastic impact on simulator costs. An example of this impact can be seen in

the A-6 DRS program. The DRS tactical configuration and the simulator were developed at the same time, both by Grumman, and the DRS configuration was not finalized at the time the simulator program was initiated. The simulator contract provided an allowance for changes in the simulator that were the result of anticipated modifications to the operational equipment, and at the time of final delivery the cost of these changes amounted to 35 percent of the final Grumman contract value.

Program cost information (Table B-6) was obtained from the program procurement manager at the Naval Training Equipment Center. At present, both trainers have been delivered and placed in service; the costs shown in Table B-6 appear to be the total costs to the government, except for updating the devices to reflect recent modifications to the operational equipment.

D. VTAS

The VTAS simulator had its origin in a change in configuration of the F-4J aircraft that entailed changes in training equipment then employed at two Naval Air Stations (NAS). An assessment of alternatives for these changes concluded that simulation would cost between 60 and 85 percent of the alternatives that involved modifying or procuring additional operational equipment for training.

The contractor (Honeywell) has produced several non-standard maintenance simulators. However, VTAS was the first and appears to be quite different from Honeywell's later programs. The relative distribution of program costs among cost elements is quite different from that on other programs (including the later Honeywell programs). It is concerned only with a single system that is not complex relative to current avionics systems. The Navy procurement program manager described the training requirement as relatively simple, and the simulator reflects

TABLE B-6. A-6 TRAM DRS (Dollars, Thousands)

Contractor	Applied Science Associates	Grumman Aerospace		Total Program
	Task Analysis	Initial Contract	Engineering Change	
<u>Non-Recurring Cost</u>				
Front End Analysis	40			40
Task Analysis	40			40
Other				
<u>Design and Development</u>				
Hardware		148	163	311
Software/Courseware		10		10
Technical Data		85	163	248
Other		47		47
		6		6
<u>Hardware Fabrication (non-recurring)</u>				
Test and Evaluation		7		7
Program Management		40		40
Total Non-Recurring	40	195	163	398
<u>Recurring Cost</u>				
<u>Production</u>				
Hardware Fabrication (recurring) ^a		92		92
Special Tools/Test Equipment		35		35
Initial Spares		13		13
Other		44		44
<u>Logistic Support</u>				
Interim Maintenance Support		11		11
Other		11		11
<u>Initial Training</u>				
Total Recurring		17		17
		120		120
Program Total Cost	40	315	163	518

^a Including installation and checkout.

the limitation (providing eight malfunctions that are integrated into the contractor-proprietary software system).

Cost information (Table B-7) was obtained from the contractor. In addition to the contract costs, the procurement program manager has estimated that, between one-half and three-quarters of a man-year was expended by in-house civilian and military personnel on various functions (including front-end analysis and program management).

E. AT-TRAINER

The AT-Trainer takes its name from its purpose of providing training in all equipments maintained by the Navy aviation technician (AT) rating on three series of the F-4 aircraft--the communication/navigation/identification and the electronic countermeasures suites. It was begun as a small scale in-house project at the North Island Naval Air Rework Facility to provide simulation of one model of UHF communication equipment on the F-4N. Since that time, it has expanded through a series of program changes to encompass all AT-maintained equipment on the F-4N, F-4J, and RF-4B and the inertial navigation equipment of the RF-4B maintained by the aviation electrician (AE) rating.

This simulator provides only for organizational maintenance training that is typically confined to troubleshooting of installed equipment. This involves a large number of equipments the controls and indicators of which are located on the aircraft instrument panel: the physical configuration of the simulator constitutes an extensive mock-up of the cockpits. The particular equipments simulated, by aircraft series, are shown in Table B-8.

At program completion three units will have been built. Two of these (to be used at Beaufort MCAS and Oceana NAS) will be limited to providing AT training for the F-4J. The third (delivered to El Toro MCAS) will provide simulation for AT

TABLE B-7. VTAS (Dollars, Thousands)

Contractor	Honeywell
Task/Function	Total Program
<u>Non-Recurring Cost</u>	
Front End Analysis	
Task Analysis	
Other	
Design and Development	74
Hardware	19
Software/Courseware	38
Technical Data	17
Other	
Hardware Fabrication (non-recurring)	
Test and Evaluation	6
Program Management	51
Total Non-Recurring	131
<u>Recurring Cost</u>	
Production	163
Hardware Fabrication (recurring) ^a	156
Special Tools/Test Equipment	
Initial Spares	7
Other	
Logistic Support	
Interim Maintenance Support	
Other	
Initial Training	3
Total Recurring	166
Program Total Cost	297

^a Including installation and checkout.

TABLE B-8. SIMULATED AT-TRAINER EQUIPMENT, BY AIRCRAFT SERIES

Equipment Designation (Function)	Aircraft Series		
	F-4N	RF-4B	F-4J/S
<u>Communication/Navigation/ Identification Equipment</u>			
AN/ASQ-19 (Integrated Electronics Central)	X		
AN/ARC-159 (UHF Communications)	X		X
AN/ASQ-160 (Integrated Electronics Central)		X	
AN/ARC-105 (UHF Communications)		X	
AN/ARN-118 (TACAN)			X
AN/AJB-3 (Computer)	X		
AN/AJB-7 (Computer)			X
AN/ASN-39 (INS)	X		X
AN/ASN-59 (Attitude, Heading, and Reference)*		X	
AN/ASN-92 (Carrier Alignment JNS)		X	
AN/ASW-25A (Data Link)			X
AN/ASW-25B (Data Link)		X	
AN/ASM-23 (GSE)	X	X	X
<u>ECM Equipment</u>			
AN/ALR-45 (ECM)		X	X
AN/ALR-50 (ECM)		X	X
AN/ALQ-126 (ECM)		X	X
AN/ALE-29 (Chaff Dispenser)			X
AN/ALE-39 (Chaff Dispenser)		X	X
AN/ALM-70 GSE (AN/ALE-29)			X
AN/ALM-164 GSE (AN/ALE-39)		X	X
AN/ASM-456 GSE (AN/ALR-45)		X	X
AN/ALM-140 GSE (AN/ALR-50)		X	X

training in all three aircraft series in addition to AE training. The multiple simulation capability is provided by "quick change" kits to reconfigure the simulator to each aircraft.

The El Toro unit serves as a test bed for the program. It was delivered as a partially completed device in mid-1979. Further capabilities (in terms of the equipments simulated) are delivered as they are developed, and the system will not be completed until mid-1981. The Oceana and Beaufort units were delivered in December 1980 without ECM simulations; this capability will be installed during 1981 as a field modification.

Throughout its term, the AT-Trainer program has been carried on strictly as an in-house activity. The tasks involved include development of simulation hardware (including some of the data processor) and the software operating system. As a result, it is a unique system. Apparently, there are no plans to carry these developments any further or to employ them in other simulations.

The AT program costs are shown in Table B-9. The program manager feels these values may understate true costs of the project, because many of the individuals involved provided extensive unpaid time. In addition, the costs are probably not comparable to those for other simulator programs. The accounting methods employed will differ from those used by contractors so that various categories of costs may have different meanings.

F. INTEGRATED RADIO ROOM

This is one of two programs to incorporate simulation into the initial design of the training program for a new major weapon system. A total of four simulators are employed in the complete Trident training system. Two are associated with the Integrated Radio Room (the communications system) while the other two are associated with pneumatics and are standardized simulation systems.

TABLE B-9. AT TRAINER (Dollars, Thousands)

Contractor	North Island Naval Air Research Facility		
	Initial Program	Modifications/Updates	Total Program
<u>Non-Recurring Cost</u>			
Front End Analysis	20		20
Task Analysis			
Other	20		
Design and Development	920	95	1,015
Hardware	355	50	405
Software/Courseware	415	45	460
Technical Data	150		150
Other			
Hardware Fabrication (non-recurring)	267 ^b	9	276
Test and Evaluation	8		8
Program Management	40		40
Total Non-Recurring	1,255	104	1,359
<u>Recurring Cost</u>			
Production	440	11	451
Hardware Fabrication (recurring) ^a	410	11	421
Special Tools/Test Equipment			
Initial Spares	30		30
Other			
Logistic Support			
Interim Maintenance			
Support			
Other			
Initial Training	30		30
Total Recurring	470	11	481
Program Total Cost	1,725	115	1,840

^a Including installation and checkout.

^b Includes \$205 for depot repair facility.

Trident communications system personnel are responsible for both operation and maintenance of the system; and both functions are trained in the same course employing the same training equipment. Three major training devices are used, designated A, B, and C; two of these devices (A and B) provide both operation and maintenance training, while trainer C is devoted to maintenance training.

- Trainer A is a reconstruction of the on-board radio room. It consists of a complete set of the operational equipment (along with training-unique equipments) to provide operator team and watch-standing training and hands-on, on-equipment maintenance training.
- Trainer B is a reconstruction of a part of the radio room using only simulation equipment. Its function is to provide individual and team operations training and training in the system fault isolation and diagnostic capabilities of the operators' console, and the use of the built-in test equipment
- Trainer C consists of both simulated and tactical equipment. It is a series of part-task-trainers to provide training in troubleshooting and fault isolation procedures at a module/component level and hands-on preventive and corrective maintenance.

This program provides a definitive demonstration of both complementarity and substitutability between simulation and operational equipment. Two trainers are used for operator training, and all three for system maintenance training. Early studies of Trident training requirements identified two alternatives for radio room training. One alternative was the current program combining operational equipment and simulators. The second alternative proposed only operational equipment trainers (consisting of three of the current A-Trainers).

RCA is the contractor for the operational equipment as well as the three trainers; both the trainers and the operational

equipment were developed concurrently. The training equipment contract is RCA's first experience in developing simulators. One could expect the simulation trainers to be closely patterned after the operational equipment and, perhaps, to be quite different from other non-standard simulators.

Our opinion that these simulators differ from others is bolstered by comparing the relative cost of software/courseware in this program with other programs. Roughly 15 percent of RCA costs are attributed to software/courseware, while the average for the other non-standard systems is close to 35 percent. The operational equipment employs extensive data processing, and the relatively low software/courseware costs for the simulators would be consistent with RCA incorporating its detailed knowledge of the operational equipment software into the development of the simulator software system--rather than developing a wholly new system, as appears to be the case of other non-standard simulators.

Simulator program costs (shown in table B-10) were obtained from the program office for Trident training (at the Naval Training Equipment Center). They are based on the original cost proposal and the program changes that have been negotiated to date.

G. F-16

The F-16 maintenance simulation system is the most ambitious non-standard program undertaken to date. Like the Trident Radio Room, the use of simulation was incorporated into the initial design of the maintenance training program and the simulators were developed concurrently with the operational equipment. Unlike Trident, though, simulation was developed by a second contractor (Honeywell) under subcontract to the weapon contractor (General Dynamics).

TABLE B-10. TRIDENT INTEGRATED RADIO ROOM (Dollars, Thousands)

Contractor	RCA				ECC	American Systems Corporation	In-House	Total Program
	Operator/Maintenance Trainer		Maintenance Trainer		Task Analysis	Program Office Support	Front End and Management Support	
Task/Function	Basic Contract	Contract Changes	Basic Contract	Contract Changes				
Non-Recurring Cost								
Front End Analysis					400		270	670
Task Analysis					400		270	670
Other								
Design and Development								
Hardware	1,856	307	1,417	27				3,607
Software/Courseware	1,238	204	886	20				2,348
Technical Data	431	89	353	6				879
Other	187	14	178	1				380
Hardware Fabrication (non-recurring)								
Test and Evaluation	12		12					24
Program Management	210	65	145	9		248	140	817
Total Non-Recurring	2,078	372	1,574	36	400	248	410	5,118
Recurring Cost								
Production								
Hardware Fabrication (recurring)*	1,124	58	506	2				1,690
Special Tools/Test Equipment	725	58	318	2				1,103
Initial Spares	78		39					117
Other	321		149					470
Logistic Support								
Interim Maintenance Support	47		47					94
Other	47		47					94
Initial Training								
Initial Training	114	4	68					186
Total Recurring	1,285	62	621	2				1,970
Program Total Cost	3,363	434	2,195	38	400	248	410	7,088

* Including installation and checkout



The simulators encompass eight of the aircraft systems, and are to be used by both USAF and NATO country personnel. The simulators are configured as both flat panels and cockpit mock-ups. The quantities procured, by aircraft system simulated, are shown in Table B-11. Typically, the simulation of one aircraft system employs two panels or one panel and a cockpit mock-up.

TABLE B-11. F-16 SIMULATOR QUANTITIES PROCURED, BY AIRCRAFT SYSTEM

Aircraft System	Number of Elements Per Simulator		Number of Simulators Ordered	
	Panels	Cockpit Mock-ups	USAF	NATO
Environmental Control	2		3	2
Navigation	2		3	2
Fire Control	1	1	3	3
Flight Control	2		3	3
Hydraulic	2		3	3
Electrical	2		3	2
Weapon Control	2		3	3
Engine Start	1		3	3
Engine Diagnosis	2		3	3
Engine Operation		1	3	2

USAF, in buying three sets of the simulator system, will receive 48 panels (of 16 different types), six cockpit mock-ups, and 30 processors; NATO countries, in total, are procuring two or three trainers for each aircraft system.

The F-16 maintenance simulator family resembles a standardized system. A common model of processor and a common software system is used for all training applications (panels/mock-ups). The F-16 system, along with the AWACS simulators discussed below, may well be the first members of a new standardized simulator system. One result of these simulator programs is Honeywell's development of what it has termed the "Data Base Generator." This is a programming language intended to allow for a simple manual translation of technical manual information into code and the machine translation of that code into FORTRAN.

The F-16 program provides a dramatic example of the problems that may arise when operational equipment and training simulators are developed concurrently. The initial contract, in September 1977, provided for a target price of \$7.5 million for development and procurement. Delivery to the Air Force of the first set of 18 panels and mock-ups and 10 processors was stipulated for September 1978.

The simulator design freeze was set for January 1978, and the configuration was to be based on the production version of the aircraft. However, the technical documentation of the production aircraft configuration was not available at that date; the aircraft continued to undergo engineering changes, and a lag developed in documentation of the changes. The aircraft configuration changes imposed configuration changes and rework of the simulation models (panel elements, software, and courseware); the lag in documentation increased the amount of rework required to accommodate the changes.

A recent contract amendment reset the target price of the training equipment at \$28.9 million. It is impossible to attribute a specific portion of the increase to the problems associated with concurrency. However, it appears that a sizable portion did arise from this cause.

Documentation of current program costs includes separate estimates of the costs (in terms of the target) for the training devices associated with each aircraft system simulated for each of the seven sets of simulators currently on-contract. These estimates are shown in Table B-12. Note that the total of non-recurring costs are attributed to simulator set number seven and that the values shown exhaust the contract total target cost. (That is, all costs have been allocated to the individual simulations even though some fraction of them, especially of the non-recurring costs, are support functions that are truly common to all elements of the program.)

The estimates contained in Table B-12 allowed a separation of recurring and non-recurring costs for the simulations associated with each aircraft system shown in Table B-13. (Note that the method used for separation provided a slightly different estimate of total program cost.) The resulting ratios between recurring and non-recurring costs are quite consistent with other non-standard simulator programs (see Figure 4).

H. AWACS NAVIGATION

The Air Force plans to provide training simulators for three AWACS systems--navigation, radar, and possibly the data display/processor systems. The navigation system has been delivered and is in operation, while the radar system trainer has recently been placed under contract. Both these simulators are contracted to Honeywell. Both are flat panel devices and, considering the continuity they afford Honeywell, it would appear that they will be quite similar. However, costs of the devices will be significantly different; one explanation for the large difference in cost is that the navigation trainer has a single student station while the radar trainer will have 10.

TABLE B-12. F-16 SIMULATOR COSTS BY AIRCRAFT SYSTEM AND SIMULATOR SET
(Thousands of Dollars)

Aircraft System Simulated	Simulator Set						Total
	1 USAF	2 Belgium	3 Netherlands	4 USAF	5 Norway	7 ^a USAF	
Fire Control	424	186	169	137	101	1750	2767
Flight Control	528	361	365	356	328	2495	4433
Navigation	321	--	240	229	234	1923	2947
Electrical	337	264	--	259	260	1514	2643
Environmental Control	215	--	172	144	133	1224	1868
Hydraulic	202	164	170	160	163	1004	1863
Weapons Control	297	253	216	168	121	1709	2764
Engine Start	280	173	170	191	166	1307	2287
Engine Diagnostic	543	331	327	348	326	2628	4503
Engine Operating	401	--	257	273	249	1474	2654
Total	3548	1732	2087	2265	2062	17,028	28,722 ^b

Note: Simulator set number 6, intended for Denmark, was cancelled. Totals may not add due to rounding.

^aIncluding non-recurring costs.

^bDoes not include \$165 thousand for proposal preparation.

TABLE B-13. F-16 SIMULATOR, RECURRING AND NON-RECURRING COSTS
(Thousands of Dollars)

Aircraft System Simulated	Total Cost	Non-Recurring Cost	Recurring Cost	Cumulative Average Recurring Cost
Fire Control	2756	1640	1116	186
Flight Control	4413	2174	2239	373
Navigation	2956	1699	1257	251
Electrical	2621	1269	1352	270
Environmental Control	1872	1110	762	152
Hydraulic	1849	852	997	166
Weapons Control	2781	1560	1221	203
Engine Start	2440	1125	1315	219
Engine Diagnostic	4635	2307	2328	388
Engine Operating	2713	1227	1486	297
Total	29,036	14,963	14,073	

The navigation system simulator is the first major training device USAF has procured for this system. Prior to its delivery, training was limited to providing introductory training, without the benefit of training equipment, at Keesler AFB and transferring graduates to an AWACS operational base for on-the-job training. The operational base represented the first hands-on experience received by the students.

Considering the continuity (and overlap) in the AWACS and F-16 programs, all three training systems should have extensive similarities in important features. Both the AWACS navigation trainer and the F-16 systems employ Honeywell's Data Base Generator, implying similarities in the software systems (with which the generator must be compatible). It is hard to escape

a conclusion that these three programs have provided Honeywell with the essentials of an advanced standardized simulation system that will find application in other training areas.

Cost information on this program was provided by the AWACS Project Office at the Electronics System Division (Table B-14). The original FPIF contract with Honeywell provided for a target cost of \$1274 thousand and a ceiling price of \$1528. One engineering change was negotiated for \$60 thousand, bringing the total cost to the Government to \$1588 thousand.

The contract has incurred a significant cost overrun. Honeywell has reported costs of roughly \$200 thousand over the ceiling price, but the Project Office believes the total overrun is approximately \$600 thousand (or 40 percent of the initial ceiling price). The Project Officer attributes the unreported \$400 thousand overrun to Honeywell's cost in developing its Data Base Generator (i.e., software). (See the discussion of the F-16 program, above.) Development of the Data Base Generator was an independent Honeywell decision, and its cost appears to have been charged to both the F-16 and AWACS programs.) The program costs shown in Table B-14 encompass the Project Office estimates of total costs (both reported and unreported). This is the only simulator program treated in this fashion. Maintenance of the simulator is provided through a separate FFP contract between Honeywell and the Air Force Logistics Command (AFLC). An estimate of Project Office in-house costs has not been obtained.

TABLE B-14. AWACS NAVIGATION/GUIDANCE. (Dollars, Thousands)

Contractor	American Institute for Research	Honeywell		Total Program ^b
	Analysis and Program Support	Contract with System Program Office (ESD)	Maintenance Contract with AFLC	
Non-Recurring Cost				
Front End Analysis	100			100
Task Analysis	100			100
Other				
Design and Development				
Hardware		1,998		1,998
Software/Courseware		506		506
Technical Data		943		943
Other		549		549
Hardware Fabrication (non-recurring)				
Test and Evaluation		40		40
Program Management	100	23		123
Total Non-Recurring	200	2,061		2,261
Recurring Cost				
Production		127		127
Hardware Fabrication (recurring) ^a		127		127
Special Tools/Test Equipment				
Initial Spares				
Other				
Logistic Support				
Interim Maintenance Support			70	70
Other			70	70
Initial Training				
Total Recurring				197
Program Total Cost	200	2,188	70	2,458

^a Including installation and checkout.

^b Except for in-house program management for which estimate is not available.

APPENDIX C

ABBREVIATIONS

AACS	Army Area Communications Systems
ABC	Automatic Boiler Control
ACTS	Adaptive Computerized Training System (Perceptronics)
ADP	Automated Data Processing
AET	Actual Equipment Trainer
AET	Automated Electronics Maintenance Trainer (Honeywell)
AFHRL	Air Force Human Resources Laboratory (Brooks AFB)
AFPTRC	Air Force Personnel and Training Research Center (now AFHRL)
AFSC	Air Force Specialty Code
AIDE	Automated Instruction, Direction and Exercise
AIS	Avionics Intermediate Shop
AMES	Aircraft Maintenance Effectiveness Simulation (a model developed by XYZYX Information Corporation for NTEC)
AMSAS	Advanced Manpower Concepts for Sea-Based Aviation Systems
AMTE	Automated Maintenance Test Equipment
AMTESS	Army Maintenance Training and Evaluation Simulation System (ARI/PMTRADE)
AN	Army-Navy
APL	Authorization Parts List
ARI	Army Research Institute
AT	Action Taken
ATACS	Army Tactical Communications System
ATE	Automatic Test Equipment
AWACS	Airborne Warning and Control System

BIT	Built-in Test
BITE	Built-in Test Equipment
CAI	Computer-assisted Instruction
CAM-T	Consolidated Aircraft Maintenance Training (Air Force hands-on training)
CASEE	Comprehensiveness Aircraft Support Effectiveness Evaluation
CB	Component Breakdown
CIWS	Close-In Weapon System (Phalanx Gun System)
CMI	Computer-Managed Instruction
CNR	Communication Navigation Radar
CNTT	Chief of Naval Technical Training
CPFF	Cost Plus Fixed Fee
CPIF	Cost Plus Incentive Fee
CRS	Component Repair Squadron
CRT	Cathode Ray Tube
CSD	Constant Speed Drive
CUT	Cross Utilization Trained (AF)
DCS	Deputy Chief of Staff
DRS	Detection and Ranging System
DS	Direct Support
DSB	Defense Science Board
ECC	Educational Computer Corporation
ECM	Electronic Countermeasures
EEMT	Electronic Equipment Maintenance Training (Navy Class A Training School, Honeywell)
EPICS	Enlisted Personnel Individualized Career System
EIC	Equipment Identification Code
ETM	Extension Training Materials
FCS	Fire Control System

FFP	Firm Fixed Price
FIS	Fault Identification Simulator (Navy)
FLIR	Forward-Looking Infrared
FOMM	Functionally Oriented Maintenance Manual
FPIF	Fixed Price Incentive Fee
FPJPA	Fully Proceduralized Job Performance Aid
FRAMP	Fleet Readiness Aviation Maintenance Personnel
FTD	Field Training Detachment (Air Force)
FVS	Fighting Vehicle System
GMTS	Generalized Maintenance Training System (Navy)
GNS	Guidance and Navigation System
GS	General Support
GSE	Ground Support Equipment
HHC	Headquarters/Headquarters Company
HUD	Heads-up Display
ICAP	Improved Capability
IHOMS	Intermediate Hands-on Maintenance Simulators (NTEC)
I level	Intermediate Level Maintenance
IMA	Intermediate Maintenance Activity
IMTS	Integrated Maintenance Training System (NTEC)
INS	Inertial Navigation System
IPSA	Integrated Personnel Systems Approach
IRR	Integrated Radio Room
ISD	Instructional System Development
ITDT	Integrated Technical Documentation and Training (Army; now called SPAS)
JCN	Job Control Number
JPA	Job Performance Aid
JTPT	Job Task Performance Test

LAS	Lockheed Aircraft Services
LRU	Line-Replaceable Unit
LTTA	Logic Tree Troubleshooting Aid
MACT	Malfunction and Circuitry Trainer
MAINTIP	Maintenance Training Improvement Program (NTEC)
MCAS	Marine Corps Air Station
MDC	Maintenance Dependency Chart
MDS	Model/Designation/Series (Air Force)
MFHBF	Mean Flight Hours Between Failures
MIL STD	Military Standard
MIMS	Maintenance Instruction Manual System
MITIPAC	Modular Integration of Training Information by a Performance Aiding Computer (Navy)
Mk/Mod	Mark/Model
MMTR	Military Manpower Training Report
MTTR	Mean Time to Repair
MOS	Military Occupational Specialty (Army)
MTBF	Mean Time Between Failures
MTBR	Mean Time Between Repairs
MTM	Maintenance Training Management
MTS	Mobile Training Set (for Field Training Detachment)
MTU	Maintenance Training Unit
NALCOMIS	Navy Air Logistics Command Management Information System
NAMP	Naval Aviation Maintenance Program
NAMTD	Naval Air Maintenance Training Detachment
NARF	Naval Air Rework Facility
NAS	Naval Air Station
NAVAIR	Naval Air Systems Command
NEC	Navy Enlisted Classification
NFE	Not Fully Equipped
NIP	NAMP Improvement Program

NOR Not Operationally Ready
 NORM Not Operationally Ready - Maintenance
 NORS Not Operationally Ready - Supply
 NPRDC Navy Personnel Research and Development Center
 NSN National Stock Number
 NSRDC David W. Taylor Naval Ship Research and Development Center
 NTEC Naval Training Equipment Center
 NTIPP Navy Technical Information Presentation Program
 NTIPS Navy Technical Information Presentation System

 OJT On-the-Job Training
 O level Organizational Level Maintenance

 PACAF Pacific Air Force
 PE Program Element
 PIMO Presentation of Information for Maintenance and Operation
 PINTO Performance Improvement for Navy Training Organizations
 PMTRADE Program Manager for Training Devices (Army)
 POMO Production-Oriented Maintenance Organization (AF)
 PROM Programmable-Read-Only-Memory

 REES Reactive Electronic Equipment Simulator
 RFP Request for Proposal
 ROM Read-only Memory
 RTE Resident Training Equipment (for technical training center)

 SAC Support Action Code
 SAMT Simulated Avionics Maintenance Trainer
 SDC Sample Data Collection
 SEL Selected Equipment List
 SIMMS Symbolic Integrated Maintenance Manual System

SMART	System Malfunction Analysis Reinforcement Trainer
SMTE	Simulated Maintenance Task Environment
SOJT	Supervised On-the-Job Training
SPAS	Skill Performance Aids System (Army; previously ITDT)
SQT	Skill Qualification Test (Army)
SRA	Shop-Replaceable Assembly
SRU	Shop-Replaceable Unit
STRES	Simulator Training Requirements and Effectiveness Study (AFHRL)
TAC	Tactical Air Command
TACAN	Tactical Air Navigation
TAMMS	The Army Maintenance Management System
TICCIT	Time-shared, Interactive Compute Controlled Information Television
TJS	Tactical Jamming System
TM	Type Maintenance
TMS	Type/Model/Series (Navy)
TOT	Task-Oriented Training
TRAM	Target Recognition Attack Multi-sensor
TRU	Tester Replaceable Unit
USAFE	United States Air Force - Europe
VAST	Versatile Avionics Shop Test (Navy)
VTAS	Visual Target Acquisition System
WBS	Work Breakdown Structure
WC	Work Center
WUC	Work Unit Code

3-M Maintenance and Material Management System (Navy)

66-1 Air Force Maintenance Management System (name
* 66-5 derived from the Air Force manual that sets forth
maintenance policy.)

APPENDIX D

GLOSSARY

Courseware: Student handbooks and manuals and that portion of the set of computer programs resident in a simulator that implements the simulation model and otherwise addresses the operation/functioning of the equipment being simulated.

Cross-Skill Maintenance: Maintenance associated with one skill area that is performed by personnel trained in a different skill area.

Depot-Level Maintenance: Rear area maintenance, major repair or equipment modifications performed largely by civilians in military organizations.

Direct-Support Maintenance: Intermediate-level maintenance performed in units attached to or organic with large combat units, e.g., divisions (Army).

Fidelity: A normative term that describes the extent to which a simulator duplicates its operational counterpart. Physical fidelity refers to physical appearance, since a simulator may be two-dimensional or three-dimensional, or some combination, in its construction. Functional fidelity refers to the extent to which the performance characteristics of operational equipment have been duplicated in the simulator.

General Support Maintenance: Intermediate-level maintenance performed in units attached to higher commands, e.g., Corps, Theatre forces.

Intermediate-Level Maintenance: Maintenance performed in a shop by a maintenance or repair unit.

Maintenance Action: All effort associated with the completion of a maintenance requirement (e.g., the correction of a malfunction) that permits the return of equipment to an operational status.

Maintenance Task: A single procedure that is performed as part of a maintenance action. For example, remove, troubleshoot, repair, and install are discrete tasks in a maintenance action that corrects a malfunction and restores equipment to operational status.

Off-Equipment Maintenance: Maintenance performed on equipment systems and assemblies that have been removed from weapon end-items.

On-Equipment Maintenance: Maintenance performed on equipment systems and assemblies while they are installed on weapon end-items.

Organizational Level Maintenance: Maintenance performed directly on operational equipment (e.g., fault detection, component replacement) by personnel assigned to units that operate the equipment.

Simulation: The imitative representation of the operation/functioning of one system by another system. It consists of the simulation model, display and control panels, and other input/output facilities peculiar to the system being simulated.

Simulation Model: A mathematical model that describes the operation/functioning of a particular system or equipment.

Simulator: The device (i.e., hardware and software) on which a simulation is implemented.

Simulator Model: Simulators of a given (complete or partial) configuration.

Software: That portion of the set of computer programs resident in a simulator that is not unique or peculiar to the system being simulated (i.e., the routines concerned with

utilities, input/output, translation, etc. that are employed for general control of the computer).

Team Maintenance: Maintenance actions or tasks that are performed by more than one person.