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RELATIVE COST AND TRAINING EFFECTIVENESS OF THE 6883 F-111 CONVERTER/FLIGHT CONTROL SYSTEM SIMULATORS AS COMPARED TO ACTUAL EQUIPMENT

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The objective of this study was to design and implement a comprehensive comparative cost and training effectiveness evaluation of (a) a Converter/Flight Control (6883) three-dimensional simulator, (b) a 6883 two-dimensional simulator, and (c) an actual 6883 test station. In addition, the broader issues of training objectives, role(s) of the simulators in training, user acceptance, and the training environment were investigated as related to the expanded use of simulators for delivering maintenance training in the Air Force.

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Students were assigned to various training and testing modes utilizing the actual test station or one of the two simulators. The performance of these various experimental groups was compared using both an independent job sample performance test and a pencil-and-paper troubleshooting test instrument. Student knowledge of routine procedures, use of technical diagrams, and operation of equipment for troubleshooting malfunctions were assessed as a function of the training equipment used. User acceptance was evaluated based on student and instructor interviews and analysis of equipment use patterns. In addition, a questionnaire concerning training adequacy was administered to field technicians who had participated in the evaluation program and to their field supervisors. Costs of acquisition, installation, support, and maintenance were analyzed to determine the life cycle cost of each training device. The respective cost streams for each of the trainers were calculated for a projected 15-year life cycle. Operating costs were discounted at 10 percent annually to establish net present value in 1978 dollars.

Students were found to perform equally well following maintenance training on either of the simulators or the actual equipment. The simulators, however, were shown to be more consistent and more reliable in delivering a full range of training. Life cycle cost comparisons favored the simulators; the two-dimensional simulator in particular. User acceptance of the simulators was generally favorable, although some reservations were expressed regarding their fidelity and convenience of use.

SUMMARY

Objective

The objective was to conduct an empirical cost-effectiveness evaluation of three training devices within the 6883 Converter/Flight Control Test Station portion of an Avionics course at Lowry AFB. These devices were (a) the 6883 test station actual equipment trainer, (b) a high fidelity, three-dimensional simulator, and (c) a low fidelity, flat panel simulator.

Background

Maintenance of electronic military equipment is a critical component of preparedness. With the continued loss of experienced technicians from the Armed Services and the increased dependence on more junior, less experienced technicians to maintain electronic equipment, training has become a critical issue. Traditionally, hands-on training in the maintenance of the Converter/Flight Control System for that F-111 aircraft has been provided to Avionics Maintenance trainees using operational 6883 test station equipment. Yet, there are many problems with current practices of maintenance training. In particular, it is generally not possible to insert malfunctions into operational equipment for the purpose of teaching or practicing troubleshooting skills. Additionally, operational availability of actual equipment trainers, consistency of training, scope of training, safety, equipment reliability, and cost are additional limitations of actual equipment trainers.

Approach

At Lowry AFB, 129 F-111 Avionics Maintenance trainees in the 6883 Automatic Test Station block of training were randomly assigned to one of three training devices: (a) actual 6883 equipment trainer, (b) high fidelity three-dimensional 6883 simulator, or (c) low fidelity (flat panel) 6883 simulator. The training syllabus was not changed, and simulator training was limited to these malfunctions that could be presented on all three devices.

A specially developed "hands-on" troubleshooting performance test (TPT) was administered immediately after training in lieu of more traditional instructor subjective ratings of student performance. A paper-and-pencil troubleshooting test of complex switching problems was given at the end of the training block. Student and instructor attitudinal data pertaining to the use of simulators and actual equipment in training were obtained. Follow-up measures after 6883 training included performance in subsequent blocks of training and job proficiency ratings by field supervisors. The respective costs for each of the three training devices were analyzed and compared for a projected 15-year life cycle of the training block.

Specifics

Student performances were essentially equal following training either on simulators or on actual equipment. Average hands-on student performance test scores were (a) actual equipment 85%, (b) high fidelity 88%, and (c) low fidelity 86%. Paper-and-pencil troubleshooting test scores in all three groups averaged 40%. The simulators were more reliable in delivering training. Training device availability rates were (a) actual equipment 60%, (b) high fidelity 73%, and (c) low fidelity 93%. The 15-year life-cycle cost comparisons favored simulators, and the low fidelity simulator in particular, (a) actual equipment $5.3M, (b) high fidelity $2.1M, and (c) low fidelity $1.6M. User acceptance of simulators was generally favorable.

Conclusions/Recommendations

When actual test equipment and specific simulators of that equipment were used in a traditional instructional course, no substantial student performance differences were found during or after the training. The traditional use of such training

equipment permitted only 2 days exposure for each group with respective devices. Individualized self-paced practice was precluded. Even under such restricted conditions, the more economical simulators produced equivalent student performance when compared to the actual equipment. In this traditional training setting, all students were deficient in handling complex switching problems as measured on the paper-and-pencil test at the completion of training. Simulators were decidedly less expensive to procure and operate, were more readily available, and in general were favorably accepted for the training.

Applications should more fully utilize the potential of maintenance simulators to increase student hands-on contact and provide more in-depth malfunction training, as well as providing greater opportunities for self-paced individualized practice.

PREFACE

This project was conducted for the Air Force Human Resources Laboratory, Brooks AFB. This evaluation was conducted under the technical monitorship of Dr. Gerard M. Deignan, Air Force Human Resources Laboratory, Project Scientist for Program 2361-02-01. Dr. Edgar Smith is the Simulation Program Manager.

This Final Report completes Phase III of the cost and training effectiveness evaluation of the 6883 3-D and 2-D simulators as compared to the 6883 AET, for training intermediate level F-111 avionics maintenance personnel at Lowry AFB. The plan for this evaluation was discussed in detail in the 1979 Phase I Interim Report (AFHRL-TR-79-13) and a comparison between the 3-D simulator and the 6883 AET was presented in the Phase II Report (AFHRL-TR-80-24).

The evaluation outlined in this report was developed and implemented by the Social Systems Research and Evaluation Division of the Denver Research Institute, University of Denver, Denver, Colorado, under Contract Number F33615-78-C-0018. Dr. Louis F. Cicchinelli was the Principal Investigator and overall Project Director.

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I. INTRODUCTION

Maintenance of electronic military equipment is a critical component of preparedness. With the continued loss of experienced technicians from the Armed Services and the increased dependence on the more junior, less experienced technicians to maintain electronic equipment, training has become an increasingly important concern (Fallows, 1981; Shriver & Hart, 1973). Traditionally, hands-on training in the maintenance of the F-111 Converter/Flight Control System has been provided to avionics maintenance trainees using an operational 6883 AET. In fact, the use of AETs has been standard procedure throughout the Air Force aircraft maintenance training schools. Yet there are many problems with this current approach to maintenance training including availability of AETs, consistency of training, scope of training, safety, equipment reliability and cost. In addition, the AETs are not designed to be training devices; therefore, they do not withstand the wear and tear of constant use by inexperienced operators and do not necessarily provide the best training experience (Beavers, 1980; Deignan & Cicchinelli, 1980; Folley & Elliott, 1967; Malec, 1980; Miller, 1980; Orlansky & String, 1977, 1981a; Shriver, Fink, & Trexler, 1964; Shriver & Foley, 1974; Siegel, Bergman, Federman, & Sellman, 1972; Spangenberg, 1974, 1976). In particular, it is generally not possible to insert malfunctions into operational equipment for the purpose of teaching troubleshooting skills.

Technician preparedness for field duty is based primarily on maintenance training received at ATC schools. Limitations in training (Engel & Rehder, 1970; Orlansky & String, 1981b) have directed attention to the use of simulated training devices to deliver electronic maintenance training. The application of simulation techniques and equipment to technical training is not a new concept. However, only in the past few years have extensive efforts been undertaken to carefully and systematically investigate the use of computer-based simulators for electronic maintenance training. These efforts have resulted in several important conclusions:

- Maintenance training simulators (MTSs) can be cost effective (Deignan & Cicchinelli, 1980; Eggemeier & Klein, 1981; Fink & Shriver, 1978; Fink, Shriver, Downing, and Miller, 1978; Montmerlo, 1977; Orlansky & String, 1981a; Vestewig & Eggemeier, 1981; Wheaton, Rose, Fingerman, & Leonard, 1976)

- MTSs can provide training comparable to AETs (Cicchinelli, Harmon, Keller, & Kottenstette, 1980; Daniels, Datta, Gardner, & Modrick, 1975; Orlansky & String, 1981a; Wright & Campbell, 1975)

- MTSs may provide the best instructional approach for tasks requiring problem solving skills and cognitive strategies (Brown, Burton, Bell, & Bobrow, 1974; Deignan & Cicchinelli, 1980; Kearsley, 1977; Mallory & Elliott, 1978; Spangenberg, 1974, 1976)

- MTSs can deliver part-task training to which the AET is not highly amenable (Folley, Joyce, Mallory, & Thomas, 1971a, 1971b; Miller, 1980; Siegel et al., 1972)

While only a few simulator maintenance training programs have been in operation long enough to assess their long-range impacts, some common problems associated with the use of training simulators have become apparent. First, there is the need to assess the degree to which the fidelity of the training device will allow establishment of equivalent training objectives and contexts (Mallory & Elliott, 1978). Criterion-based measures of training effectiveness are important in this context of training assessment. Previous researchers have had difficulty in establishing such measures without incurring high costs (Deignan & Cicchinelli, 1980; Siegel et al., 1972). Second, it is critical that the manner in which the simulator will be incorporated and used in the existing training protocol be determined in advance. Without such a plan, it is unlikely that simulators designed to be an integral component of training will be used as such. And third, problems can arise as a result of instructor opposition. That is, instructors may consider their teaching role to be threatened by the incorporation of simulation methods, or they may disagree with required changes in the academic structure (Miller, 1980). These three issues are more fully discussed in the following sections.

Fidelity

One key consideration in the design, application and evaluation of most simulated training devices is the degree of fidelity of the simulator to the AET. This issue is important due to the assumption by instructors that only an AET (or a highly similar unit) can provide the necessary hands-on training, and to the belief that the training environment must continue to be highly comparable to the field environment (Miller, 1980; Winthrop, 1981). The focus may be on physical fidelity, which is defined as the comprehensiveness and level of detail with which the real world (AET) is physically represented (Narva, 1978), and/or psychological fidelity, which is defined as the degree to which the trainee perceives the simulated device as a duplicate of the AET (Foley, 1963; Miller & Gardner, 1975).

Despite attempts to incorporate realism into the training environment, some differences between training and field environments usually exist. In the classroom, there are often limitations on the number and types of tasks which can be taught. Artificial conditions associated with training environments are often uncontrolled; and emotional and attitudinal elements of the field environment are difficult to duplicate in the classroom.

For these reasons, Miller (1980) and Mallory and Elliott (1978) have suggested that the techniques used in training must relate to the context of the training, and that fidelity of simulated training devices should be based on the behavioral cues associated with task performance. Opportunities for technicians to make errors or perform inadequately must be equally represented in simulated training as in real world conditions. It has been suggested that part-task simulation and increased physical fidelity of maintenance simulation, requiring the simulation of the internal functions of the original equipment and not just the outward functions, can address these deficiencies (Miller, 1980; Winthrop, 1981).

More importantly, there have been difficulties associated with simulation design. For example, there has been a tendency for simulated training tasks to be less difficult than real-world tasks (Cicchinelli et al., 1980; Mallory & Elliott, 1978), thus detracting from the overall level of skills training achieved. On the other hand, Fink and Shriver (1978) maintain that only task-specific components of training equipment should be simulated and that they should have a high degree of psychological fidelity. Displays and controls beyond those required for selected maintenance tasks may be irrelevant or even distracting to the novice technician. In fact, too much fidelity of equipment may retard learning of the critical knowledge or skills to be acquired (Deignan & Cicchinelli, 1980; Dwyer, 1971, 1975).

Role of the Simulator

A second important issue related to the use of simulated training devices is the role of this equipment in the training program. Such devices can be used to complement the existing training on the AET or to replace the AET as a training instrument. Fink and Shriver (1978) suggest that a simulated trainer is most useful prior to contact with the AET. Actual equipment should be reserved for on-the-job training (OJT) whereas the simulator should be used in the classroom to teach logical skills. In addition, it is argued that significant cost reductions can be obtained through the substitution of simulators for expensive and frequently unavailable AETs (Beavers, 1980; Wheaton et al., 1976; Winthrop, 1981). An alternative viewpoint, that simulators should be used as complements to AETs, is presented by Miller (1980). He contends there is a need for both training devices: simulators to deliver primary skill acquisition and AETs for the final integration of discrete skills (see also Fleishman, 1975).

User Acceptance

The use of simulated trainers can be expected to meet with stiff opposition from the user community, primarily training instructors (Fink & Shriver, 1978; Pieper, 1969). The primary reason for this resistance is, of course, the presumption that the training environment is and must remain identical to the field environment. Further, there is the tendency to judge new training approaches against the existing curricula which have been accepted as standards. If change is to be accepted, it is clear that innovative training curricula must be accompanied by innovations in personnel training and support areas (Miller, 1980). These required changes in attitude and perceptions can be realized more easily if the benefits of simulated trainers (e.g., flexibility of training, safety to personnel, rapid adaptation to technological change, reduced need for large inventories of parts) are explained more completely or experienced directly.

In this report, the results of the comparative analysis of the Converter/Flight Control Test Station, a 3-D simulator and a 2-D simulator are presented. This analysis includes performance and cost comparisons, and concludes with a discussion of uses of simulators and trainers for avionics maintenance training.

II. EVALUATION DESIGN

This chapter provides an outline of the major components of the Phase III evaluation design and research objectives. This information is necessary to place the discussion of the evaluation environment presented in Chapter III in a proper context.

Research Objectives

The objective of this study was to design and implement a comprehensive cost and training effectiveness evaluation of a Converter/Flight Control (6883) 3-D simulator and a 6883 2-D simulator, as compared to the use of an operational 6883 AET in training intermediate level (I-level) F-111 avionics maintenance personnel.

The evaluation plan outlined in this section was developed as Phase III of an ongoing evaluation effort. The design was developed to be consistent with that used in Phase II to compare the training and cost effectiveness of the 6883 3-D simulator and the AET (Cicchinelli, 1979; Cicchinelli et al., 1980). While the general framework remained consistent with the proposed statement of work, some modifications were made in the number of experimental groups required to collect adequate data for the assessment. Additionally, some changes were made in the data collection instruments based on experience acquired during Phase II of the project. New preassessment instruments were also added in this phase to enable a comparison of groups on pre-existing abilities. The overall design was divided into three major components: classroom performance, field performance, and cost analysis.

Classroom Performance

The basic design actually used to assess student classroom performance as a function of training mode differed substantially from the one originally proposed for this Phase III study. Both designs are discussed in this section.

Original Phase III Design

The Phase II evaluation plan to assess classroom performance was revised for Phase III. Groups E and F in Figure 1 represent the experimental cells added to the design employed in Phase II of this effort (Cicchinelli et al., 1980). These additions were expected to make possible an examination of performance differences in student performance as a function of the training equipment used. Further, it would have been possible to identify the extent to which the use of the 2-D simulator for training would affect performance on the actual equipment by comparing the test scores of groups E and F.

Training Mode	Testing Mode: AET	Testing Mode: 3-D Simulator	Testing Mode: 2-D Simulator
AET	A	B	
3-D Simulator	C	D	
2-D Simulator	E		F

Figure 1. Research design originally proposed for Phase III.

In addition to incorporating these new groups into the design, the amount of training on the 6883 test station was expected to be increased from about 3 days (Phase II level) to 6 days. This planned "increase" was more accurately described as a return to the level of training used before the evaluation began in February 1979. Not surprisingly, the Phase II experience indicated that 2 days of training on a specific test station were probably insufficient to observe differential impacts of training mode on student performance. Thus, it was proposed to collect Phase III student data from airmen trained for 6 days on one of the equipment trainers. All students would then be tested on the actual 6883 equipment. The groups proposed are shown in Figure 2.

Training Mode	Test Mode: AET
AET	G
3-D Simulator	H
2-D Simulator	I

Figure 2. Research design originally proposed for assessing performance differences under a 6 day training regimen.

Despite the attempt to maintain consistency between Phase II and Phase III data, subsequent training format changes precluded any direct comparison of student performance measures. First, the training period for the Converter/Flight Control block was extended to 9 days by combining the theory and practical portions of training. Revised training requirements included an additional 15 hours of diagnostic testing on the 6883 Test Station. This time represents the practical or hands-on portion of the training block, as compared to a theory portion which is taught primarily by use of technical orders (TOs), chalkboard, and classroom pencil-and-paper exercises. Second, each training device (i.e., AET, 3-D simulator, 2-D simulator) was scheduled to be used in varying amounts depending on its capability of providing specific Test Replaceable Unit (TRU) and Line Replaceable Unit (LRU) training.

Phase III Design Employed

These course format and training time changes were implemented in February 1980, after Phase II data collection was completed. Due to these changes, the proposed evaluation methodology was modified to include re-collection of data from 3-D simulator-trained students and AET-trained students. Data collection from 2-D simulator-trained students was planned to begin several months later when the 2-D simulator was scheduled to be available for student training. These changes in format and methodology necessitated a new evaluation design which again included the collection of performance data on students trained on the AET and the 3-D simulator. The final research design is shown in Figure 3.

	Testing Mode		
Training Mode	AET	3-D Simulator	2-D Simulator
AET	A	*	
3-D Simulator	C	D	
2-D Simulator	E		F

Figure 3. Phase III research design implemented.

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*This experimental group (B) was included in the Phase II study but eliminated in the Phase III plan.

It should be noted that whereas 2-D and AET training groups received all 6883 instruction on a single trainer, 3-D classes always had some limited experience with either the AET or 2-D devices for patch panel training. While this factor was tracked closely throughout the project period, it did not emerge as a significant experimentation consideration for final analyses.

Each student was assigned to one of the five experimental groups. It was planned that an equal number of students would be assigned to the three training modes with AET testing as shown in Figure 3 (A, C, E). Further, an equal number of students would be tested on the same equipment on which they were trained (A, D, F). In this manner, it would be possi''e to examine performance differences as a function of the training equipment used, while controlling for the possible effects of negative interference due to using different training and testing equipment for a single group.

The evaluation plan for assessing classroom performance also included administration of preassessment measures related to reading and technical vocabularies, figure recognition, and logical reasoning ability. Previous analysis has shown that neither scores from the Air Force Armed Services Vocational Aptitude Battery (ASVAB) nor previous block scores were adequate predictors of differences in student performance (Cicchinelli et al., 1980). Thus, the results of the preassessment instruments were expected to describe more completely the student population, and to provide statistical control for possible group differences resulting from pre-existing student abilities.

Job Performance

The design shown in Figure 4 was used to assess the impact of training mode on job performance in the field. The design includes 12 experimental groups and is sensitive to the possibility that testing classroom performance itself constitutes additional training. Thus, the assessment of field performance must be conducted in view of the levels of training resulting from the various combinations of classroom training and testing modes.

It should be noted that this design illustrates all the theoretical combinations of training/testing modes and field assignments of interest. However, since field assignments are dictated by the need for specific personnel, it was not expected that an equal number of students would be in each cell, or even that all cells would be filled.

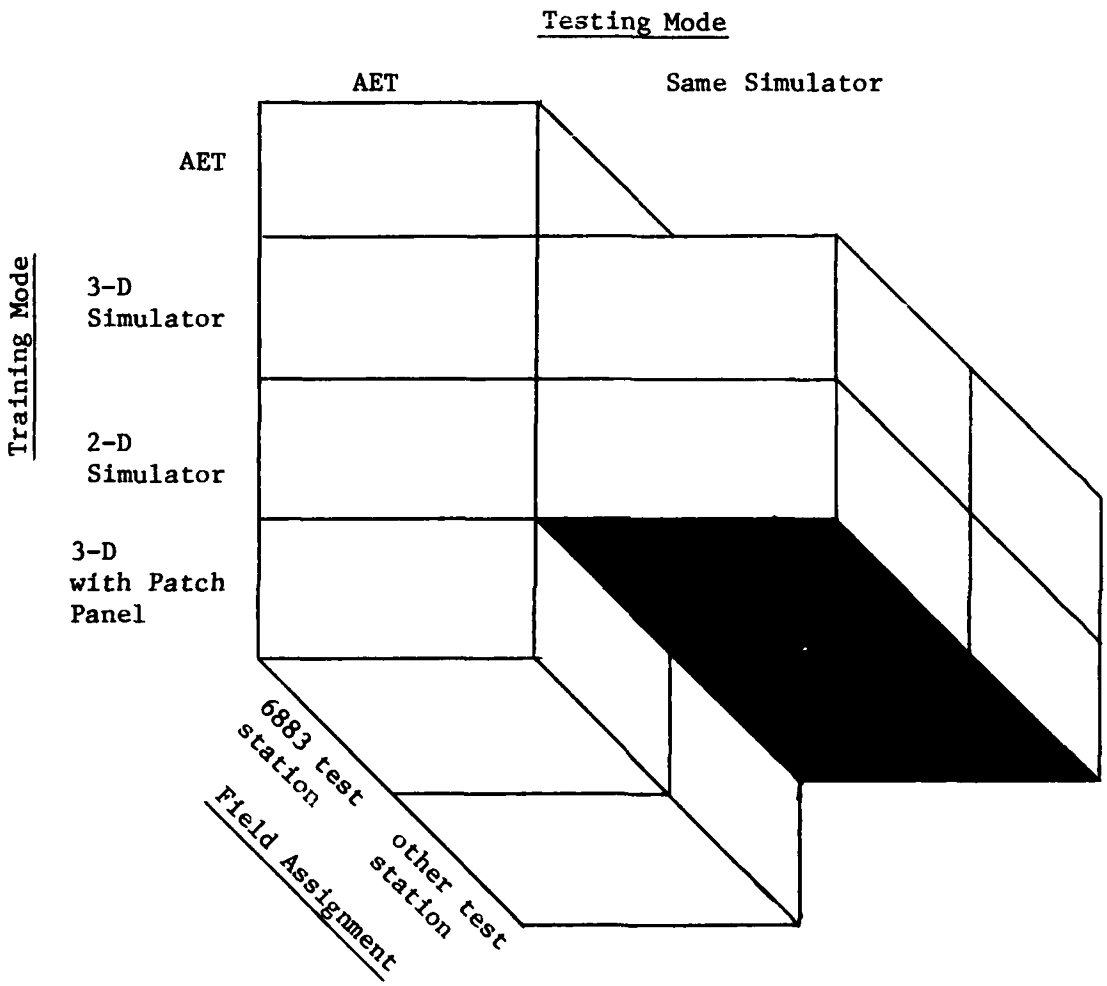


Figure 4. Research design used for comparing field performance.

Cost Analysis

The comparison of costs associated with using the 6883 AET, the 6883 3-D simulator and the 6883 2-D simulator for training was based on the model shown in Figure 5. The model consists of a matrix of six major cost categories and two components of life cycle costs. The model is simply the "ingredients approach" discussed by Levin (1975) in which cost elements are identified and evaluated consistent with the ATC acquisition and training environment. The cost elements associated with each cost category are evaluated either as Investment Costs (one-time costs) or as Recurring Annual Costs, consistent with the AFHRL perspective on economic analysis (Department of Defense, n.d.; Williams, 1977).

	Life Cycle Costs	
Cost Categories[1]	Investment Year	Operating Years 1 to 15
Facilities		
Equipment		
Instructional Materials/Training		
Personnel		
Students		
Miscellaneous		

Figure 5. Major categories used in the cost comparison model.

[1]Line items associated with each major cost category are presented in Chapter V.

The model used to establish the life cycle cost comparison also provides the framework for evaluating alternative simulator implementation strategies, particularly those involving proposed changes in such factors as student flow, course length, and time to complete specific instructional blocks. In this sense, the model is general.

To assess cost effectiveness, the three training devices were assumed to provide equal training effectiveness. Given this assumption, the life cycle cost comparison among trainers indicates which trainer exhibits the least total cost of ownership. This is a useful approach since it establishes baseline cost data and is consistent with the original simulator design objective of developing a functional replacement for the 6883 AET (Miller & Gardner, 1975). The cost analysis discussion addresses the validity of the equal effectiveness assumption in light of factors (e.g., equipment availability, Specialty Training Standards [STS]) which were found to influence training effectiveness.

Hypotheses to be Tested

This evaluation plan was designed to address the following hypotheses:

- Practical training on the 6883 3-D and 2-D simulators and the 6883 AET results in equivalent performance on the standard ATC block tests for subsequent training.

- Airmen trained on the 6883 3-D and 2-D simulators and the AET are equally accurate in solving troubleshooting problems.

- Airmen trained on the 6883 3-D and 2-D simulators and the AET are equally efficient in solving troubleshooting problems.

- Airmen trained on the 6883 3-D and 2-D simulators and the AET operate the AET with equal proficiency.

- Airmen trained on the 6883 3-D and 2-D simulators and the AET are equally familiar and comfortable in operating the AET without supervision.

- Airmen trained on the 6883 3-D and 2-D simulators and AET will acquire equivalent job-related experience.

- Airmen trained on the 6883 3-D and 2-D simulators and the AET will be equally capable of operating the AET in the field.

- Airmen trained on the 6883 3-D and 2-D simulators and the AET are equally capable of operating assigned test stations, other than the 6883 station, in the field.

III. THE EVALUATION ENVIRONMENT

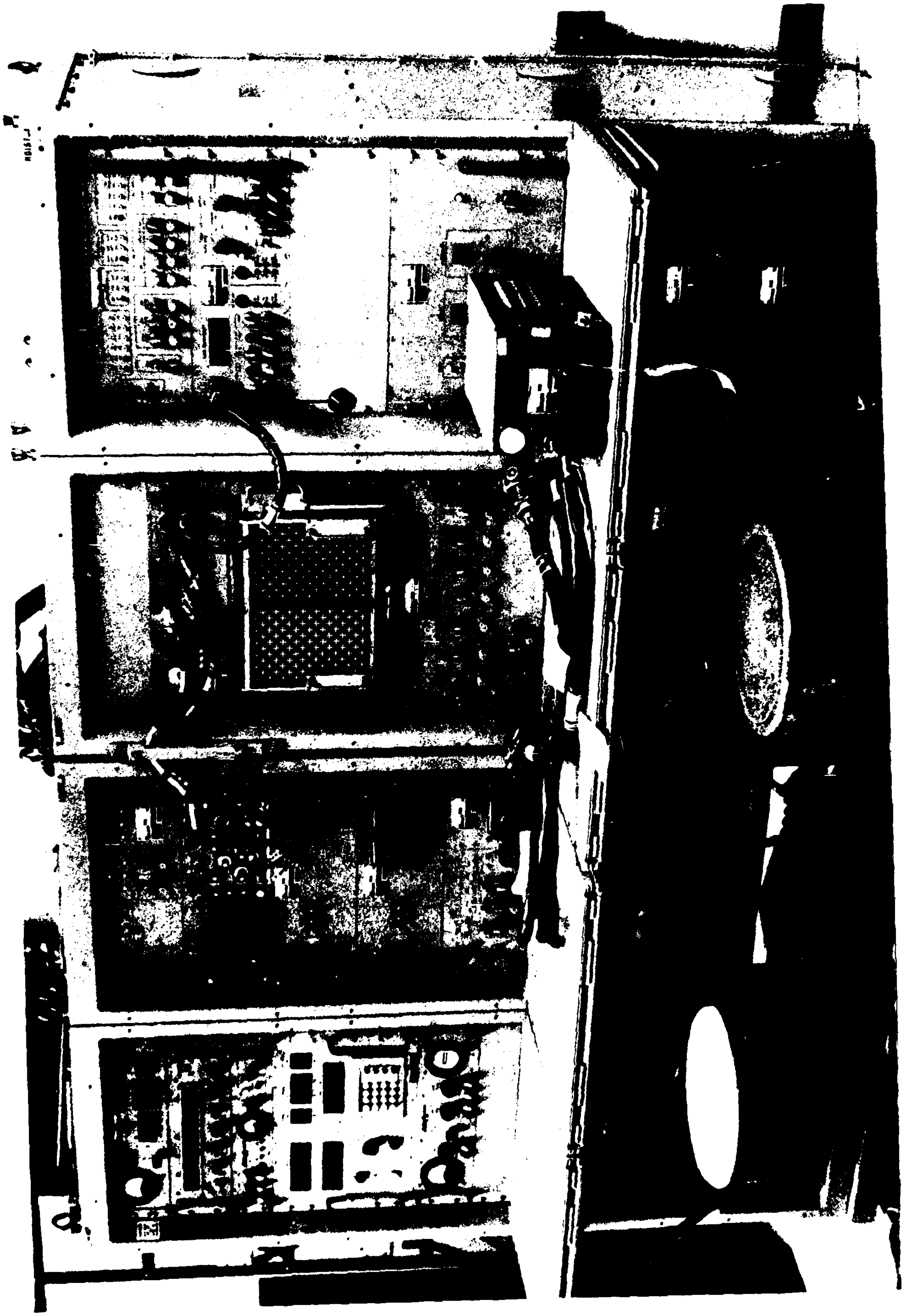
Throughout the project period, an ongoing analysis of the F-111 avionics maintenance training and field environments was conducted. This assessment included the collection and review of course-related documents, interviews with instructors and students, and direct observation of the 6883 classroom proceedings as well as other test station training blocks. Due to changes in several elements of training during the project period, it was necessary periodically to review and reanalyze course-related activities. The review of the classroom and field environments identified a number of factors which had a direct impact on the implementation and management of the evaluation effort. The most important of these factors were:

- training objectives
- training program format
- operational status of the 6883 3-D and 2-D simulators
- reliability of training equipment
- availability of equipment cost data
- student assignment and flow
- assignment and OJT

The impact of each of these factors on the evaluation is discussed in this chapter following a review of the equipment configurations and uses.

The 6883 Converter/Flight Control AET

The AET is a large (96" x 72" x 30") unit consisting of four interlocked bays (see Figure 6). Each bay consists of removable drawers, or TRUs, which allow the test station to function in a manner simulating the operation of the F-111 aircraft. To this AET are attached, through cables and adapters, LRUs which are electronic black boxes removed from aircraft because of suspected malfunctions. The AET, by simulating the aircraft electronic operation, permits troubleshooting of the LRU in a workshop environment. One of the key troubleshooting components is the switching complex, including the patch panel. Comprised of 1632 pins, the patch panel permits technicians to pinpoint malfunctions in the electronic flow between the



TRUs and the LRUs. It is this AET which has served as the model for the development of the 3-D and 2-D simulators.

The 6883 3-D Simulator

The 3-D simulator was designed and developed to appear and operate as the 6883 AET while achieving a consistency of training (high equipment reliability with standardized malfunction simulations), an increased level of safety, and reduced noise levels. The 3-D simulator lacks an operational patch panel, due to the costs estimated for developing a high fidelity unit.

The final configuration of the 6883 3-D simulator (Figure 7) includes (a) two computers (one a master, the second a slave which directly powers the simulator); (b) an instructor console for both monitoring student performance and inputting original programming; (c) a student console with a slide projector and screen (for providing information in addition to the technical order information) and a keyboard for student responses to questions displayed on a CRT; (d) a four bay, 3-D stand alone trainer with limited internal wiring of selected TRUs; (e) mock-up LRUs with simulated cables and adapters; and (f) a printer for recording student performance. All of these components are required in normal training conditions.

The 6883 2-D Simulator

The 2-D trainer is configured differently from the AET or 6883 3-D simulator (Figure 8). It consists of (a) a master console with keyboard and slide screen; (b) a student action panel on which students can identify an action to be taken upon a defective component; (c) a hard copy printer for monitoring student performance; (d) a flat panel mock-up of the 6883 AET; and (e) an LRU panel (located on the work tray of bay 4) which simulates the actions of all relevant 6883 LRUs in one unit and uses simplified adapters and cables. In addition, the 2-D simulator system includes three part-task trainers, peripheral to the flat panel components, which provide training on an oscilloscope, a patch panel and the logic of the electronics system. These three part-task trainers can be used independently of the flat panel trainer. The 2-D simulator was designed to have less physical fidelity to the AET than the 3-D unit but greater operational fidelity. That is, while there is a noticeable lack of detail in certain 2-D components such as cables and LRUs, the 2-D device does provide complete patch panel training.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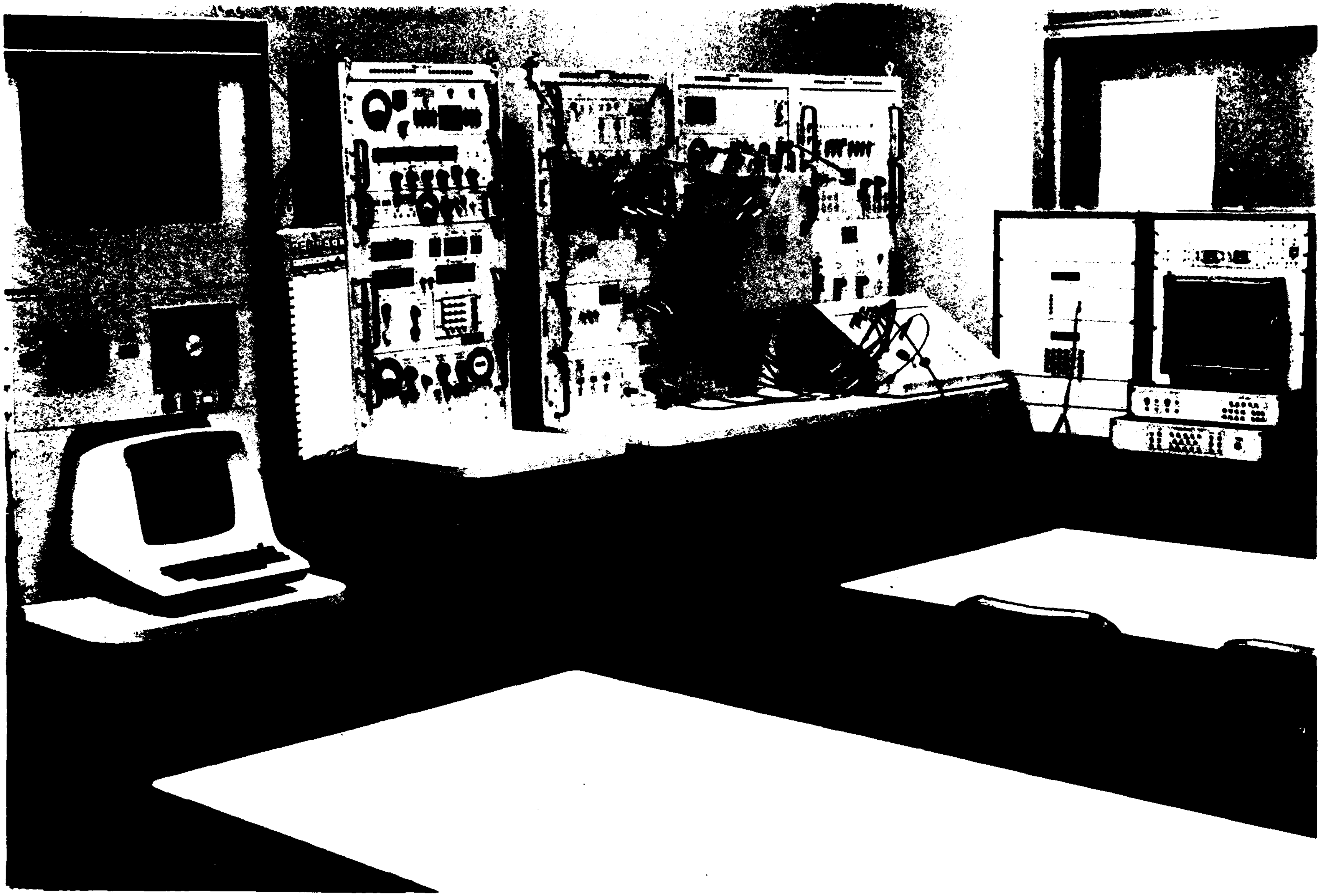

Figure 8. The 6883 2-D simulator.

Training Objectives

Training on the 6883 Converter/Flight Control Systems Test Station occurs as part of a 23-week intermediate level F-111 avionics maintenance course. The objectives of this course, the training format and the associated STS, have been in a continuous state of change.

Most recently, a number of factors have contributed to the need to modify course objectives and content. Perhaps the most important factor is the evolution of the F-111 aircraft itself. As more sophisticated F-111 models have been developed, course content has been modified to include instruction in the operation and maintenance of new test stations capable of testing the new aircraft systems. Prior to 1978, students were trained as test station operators (course ABR326X1B; 9 days of 6883 theory and practical training) or as test station maintenance personnel (course ABR326XOB; 5 days of 6883 theory and practical training). In 1978, these career options were integrated into a single career path, and a new STS was developed to reflect course modifications. In this combined course (Interim Course ABR326X1D), theory and practical training on the 6883 test station were reduced to a total of 8 days. More recently, still another Plan of Instruction (POI) was developed in accordance with STS ABR326X4A which became effective in April 1979. This course includes expansion of skills required for 3-level training.

The specifications for the 6883 3-D simulator were developed when operation and maintenance training were alternative career choices. On the other hand, specifications for the 6883 2-D simulator were developed during the Interim course (ABR326X1F) which combined the operator and maintainer components. The approach used to analyze course documentation and the use of the 6883 actual test station in training, then, was to compare training objectives at three discrete points in time. Specifically, the comparison was among instructional objectives used when (a) maintenance and operation of the 6883 test station were separate courses, (b) instructional objectives of the 1978 combined Interim course (ABR326X1F) were in place, and (c) the training objectives used for course ABR326X4A were in place, which was during this evaluation effort. Briefly stated, the analysis of training objectives revealed that the impact of these changes in objectives on the evaluation effort could be isolated. While many objectives remained the same over time, some objectives (e.g., training on the Yaw Computer LRU) that were used to define the simulator capabilities were eliminated due to the significant reduction in training time available. Since these training exercises were no longer used, it was not appropriate to include the associated simulator capabilities in any tests of student performance, and the evaluation design reflects this decision.

While course objectives did change over time, the relevant STS requirements did not substantially change. This finding suggested that the specialty standards are general enough to allow for interpretation, depending on the perspective of the instructional staff. That is, training and field personnel could easily assume that somewhat different skills are associated with specific requirements, such as "troubleshooting." The impact of this variability on the evaluation effort was more significant than any specific changes which took place in objectives. Clearly, the lack of specific criteria for adequate performance poses potential problems for an evaluation that attempts to assess training effectiveness.

A portable troubleshooting device to be used as an independent performance test both at the end of training and during field follow up was considered, but not developed due to budgetary constraints. The problem was circumvented in this study by considering only comparative training effectiveness and ignoring the more basic and possibly more important issue of training adequacy. This study addressed the question, "How do simulator trained students perform as compared to AET trained students?" rather than "Does simulator training adequately prepare technicians for field duty?" Although an assessment of the overall adequacy of training was considered beyond the scope of this project, it is highly recommended that "adequacy of training" be a primary consideration in the development of Air Force training policy and in future simulator evaluation efforts.

Training Program Format

The comparative analysis of course content over the project period indicated that most of the objectives of the former maintenance and operations courses had been retained, although the presentation had been greatly modified in time allocation and format. It was originally proposed to rely heavily on existing test instruments to collect relevant data. Further, it was proposed to emphasize training on the 6883 2-D simulator since previous research (see Cicchinelli et al., 1980) on the AET and 6883 3-D simulator equipment would be available to serve as baseline data. However, changes in the 6883 block test instruments and changes in both training time and format (after completion of the Phase II AET and 3-D simulator study but prior to initiation of the 2-D simulator study) precluded use of the previous work as baseline data. In short, there were no standard Air Force test instruments nor previous comparative evaluation data available that could be used to compare the performance of a baseline group of trainees with those trained on either the 6883 3-D or 2-D simulators.

Prior to the Phase III data collection period, theory and practical training on the 6883 test station (5 days and 3 days, respectively) were considered separate blocks of instruction. However, in an effort to take advantage of the training equipment as a visual complement of the instructional material, the practical portion of the training program was combined with the theory portion to form a 9 day 6883 instructional block. Hands-on use of the AET, or the 3-D simulator or 2-D simulator, was directly incorporated into the theory instruction. The 6883 Block POI in effect during the study period included 27 hours of practical instruction, although instructors estimate that approximately 3 days of practical experience is provided to each class.

Availability of Cost Data

The essential question explored in the Cost Analysis effort concerns the costs of ownership and maintenance of alternative training devices. As might be expected, some difficulty in establishing costs of ownership was related to data access and reliability. Disaggregated estimates of the development costs of the simulator hardware, software, and courseware available from the manufacturers are not releasable for publication. Thus, for the purposes of this report, the acquisition costs of simulator hardware, software, and courseware have been lumped together and treated as "sunk" costs. These sunk costs have been included in the assessment of the life cycle costs of the respective systems as Investment Costs (see Chapter V).

The contracted cost for developing and manufacturing the 6883 simulators does not reflect the total expenditure for development and production of the devices because corporate and independent research and development (R&D) funds were used in years prior to the contract awards to develop certain aspects of the technology used. Estimates of the dollar value of these somewhat indirect costs were not available from the manufacturers. The manufacturers believe that the actual costs incurred in development and production of the first 6883 simulators are not useful as an estimate of the costs of producing additional simulators. For example, the 3-D 6883 simulator was considered to be a research device incorporating features inconsistent with production models and current computer technology. In the case of the 3-D simulator, the control system was designed to be expandable so that a minimum of four satellite test station simulators comparable to the 6883 could be operated simultaneously from the same instructor station. Thus, it was considered important to be able to estimate the incremental cost of hardware and software development associated with the additional computer that provides master control for simultaneous operation of the satellite simulators. However, such detailed cost data were not available from the manufacturer.

Finally, difficulty was encountered in regard to estimating the AET costs. ATC maintains two Burroughs D84 computer processors and related peripherals to actually "run" automatic fault isolation tests on 10 test stations (including the 6883) used in F-111 training. Developing life cycle cost information on these Central Processor and Controller (CENPAC) computers for purposes of allocating costs to the operation of the 6883 test station was seen to be a project at least equal in scope to the cost analysis of the 6883 test station and without benefit of complete production and installation cost data. Therefore, the effort was not undertaken.

These problems highlight difficulties associated with attempting a cost analysis of subsystem components in the absence of a total system analysis. Although the 6883 AET and the simulators are discrete elements in the training system, it is not known how representative they are of other system components. To illustrate this point, consider that the cost of maintenance for the 6883 AET was based on maintenance records. For purposes of comparison with the simulators, there is no way of judging whether these costs are representative of the other test stations. Similar problems of representativeness arise with respect to the costs of courseware development.

To summarize, the cost analysis should be understood as an effort to document the cost experiences for alternative training devices. Since available cost data lack the detail needed for generalizations about the cost of simulation at the training system level, a fixed effects analysis of specific training devices is provided in this report.

Student Flow

Another important aspect of the evaluation environment is the number of students passing through the training program in a specified time period. Table 1 presents the numbers of students per class that participated in this study and the training/testing modes. It was not uncommon to have a lapse of a few weeks between classes. The flow of student subjects, while anticipated to be heavy, was characteristically low. As a result, though very few students were lost to the study, it was possible to evaluate the performances of only 129 students during the period August 1980 through October 1981.

Table 1

Schedule for DRI Testing, July 1980 - October 1981

Class #	Shift	# Students	Training Mode	Testing Mode
800411*	B	6	3-D	3-D
800418*	C	6	AET	AET
800425	B	6	3-D	3-D
800516	A	4	AET	AET
800516	B	6	3-D	3-D
800523	A	5	AET	AET
800606	B	5	3-D	3-D
800623	A	3	AET	AET
800630	B	5 (6)	3-D	AET
800708	A	3 (5)	AET	AET
800729	B	4 (5)	3-D	AET
800812	A	5	3-D	AET
800820+	B	4 (5)	2-D	---
800826	A	3	AET	AET
800911	A	4	3-D	3-D
801006	B	6	AET	AET
801031	C	4	2-D	AET
801110	A	6	AET	AET
801208	B	5	AET	AET
810126	A	4 (5)	2-D	2-D
810202	B	4	2-D	2-D
810126	C	6	2-D	2-D
810224	A	5	2-D	2-D
810316	B	4	2-D	2-D
810323	C	4	2-D	2-D
810414++	A	0 (6)	2-D/3-D	2-D
810427	B	5	2-D	2-D
810507	C	8	3-D/PPT	2-D
810519	A	5	3-D/PPT	3-D
810616	C	6	2-D	3-D
810529	B	4	2-D	3-D

NOTES: Numbers in parentheses indicate class size prior to attrition or washbacks.

*Denotes classes used for pilot testing.

+Class received training as part of 2-D shakedown procedure and was required to provide questionnaire data only.

++Class lost to study due to equipment failure in mid-training.

Assignment and OJT in the Field

Once trainees are assigned to the field, they enter OJT. Field training is relatively informal and is designed to develop the skills needed to operate and maintain the assigned test station.

Field site visits conducted during the course of the project revealed that the number of technicians available and their technical competency upon arrival determined the extent and type of OJT received. Due to the individualized approach to providing training in the field, it was not possible to use the extent and type of OJT required as an indicator of training effectiveness. A second method of assessing field performance was considered. This approach involved recording the number and cost of replacement parts requested and used by new technicians to perform test station and LRU repairs. However, the implementation of this indirect measure of training effectiveness was not feasible due to the complexities of obtaining such data in the field. In short, it was difficult to isolate clear measures of long-range impact of simulator training.

It was anticipated that the performance of simulator-trained personnel and AET trained personnel would be compared after specified intervals of time in the field. The effects of OJT were expected to be present and constant in both groups; therefore, any differences in performance could be attributed to the mode of training. Clearly, with variable amounts of OJT, this assumption was not valid. In fact, if the proposed time series sampling framework was used, differences in performance due to training would be reduced as time in the field increased. Therefore, in order to obtain some measure of the long-range impact of simulator training on performance, it was necessary to devise a method of estimating job proficiency prior to field assignment, and to collect subjective ratings of field performance from supervisors shortly after the field placement (within about 4 weeks).

From discussions with the ATC staff and field personnel, it became apparent that field assignments are made in view of the immediate demand for specific automatic test station operators. Thus, at best only a small, undetermined number of airmen trained to operate the 6883 test station was expected to be assigned to the 6883 or to the highly similar 6873 test stations in the field. Although the nature of the field assignments remained a design variable, it was clear from the outset that extremely disparate sample sizes for students assigned to 6883 and other test stations would be obtained. In fact, as discussed more fully in Chapter V, only 10 students out of 129 were assigned to the 6883 or 6873 test stations at any time during the first 4 weeks of assignment to duty stations.

IV. METHODOLOGY

This chapter provides a discussion of all data collection instruments developed to assess both classroom and field performance as well as costs. The techniques used for data collection and data management are also outlined.

Assignment to Treatment Groups

A total sample of 129 F-111 avionics maintenance trainees participated in this study. Twelve additional students served as pilot subjects during revision of the performance measures and one class of six students was eliminated from the evaluation because training included the use of both the 2-D and 3-D simulators. A complete schedule of 6883 classes participating in this effort was provided in Chapter III (rf. Table 1).

The modified experimental design, as discussed in Chapter II, included five cells within the training mode by testing mode matrix to which students were to be assigned. However, due to constraints imposed on the implementation of that design, assignments to treatment groups consistent with that design were not always possible. Rather than eliminate students from the experiment, complete preassessment, performance, and follow-up data were collected regardless of eventual modes of training and testing. The resulting distribution of students is shown in Table 2. Note that sample sizes approach or exceed the expected 15 to 20 students for only four of the five groups proposed for the modified design.

While it was intended that classes be randomly assigned to treatment groups, actual assignments were primarily determined by equipment availability. Specifically, Figure 9 shows that the availability of the actual equipment was generally limited to the early stages of the data collection period, whereas, the use of the 2-D simulator was restricted to later stages since it was subject to a formative evaluation until February 25, 1981. This inability to provide random assignment raised a number of questions concerning possible bias in treatment groups. Although these issues are fully considered in the analysis, previous work suggested that factors such as sex, aptitude, and prior ATC achievement do not pose significant bias problems for the evaluation of 6883 performance (Cicchinelli et al., 1980). However, control measures, such as the pre-assessment measures, were employed to measure the impacts of any nonrandom assignment upon performance criteria.

Data Collection Period

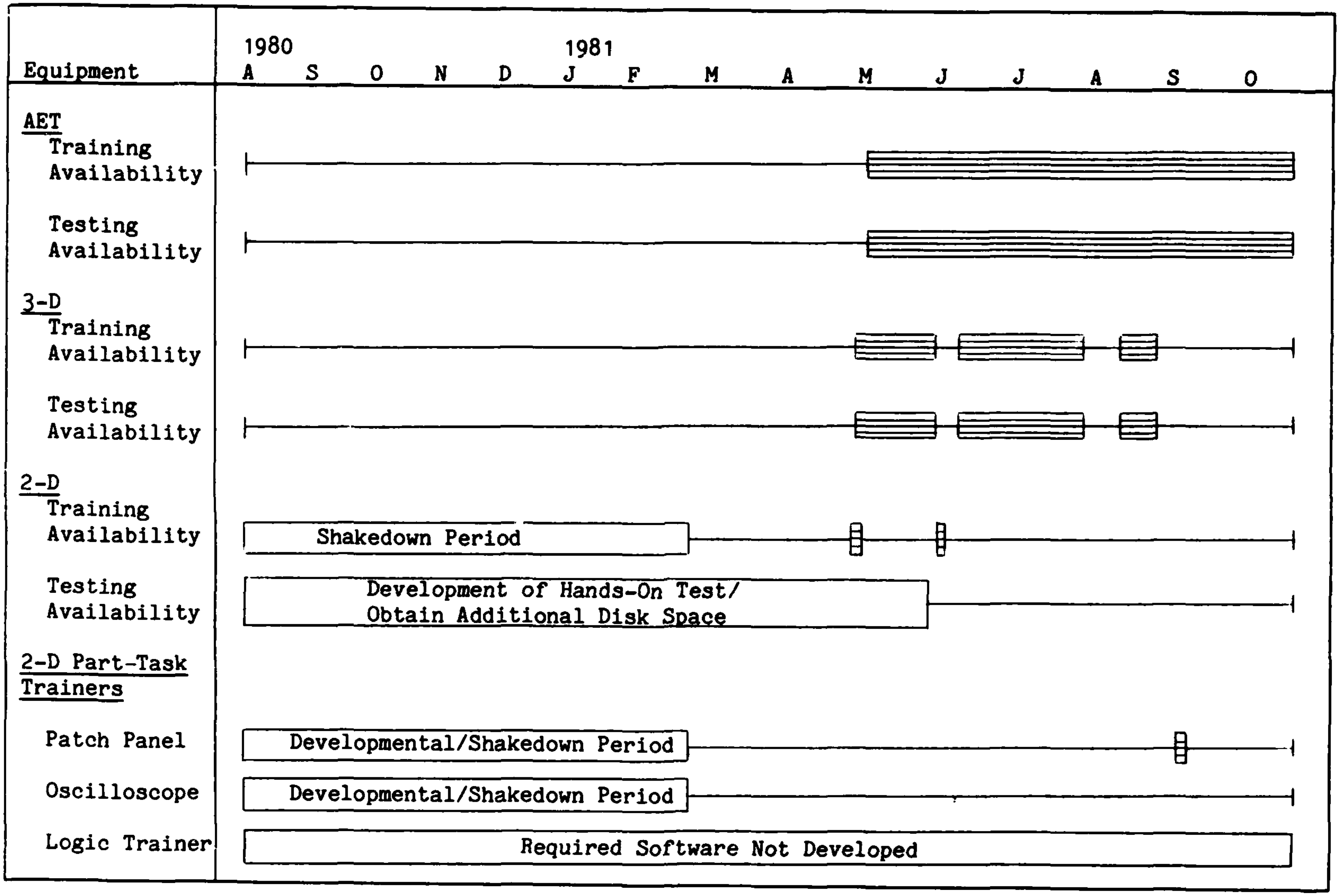

Figure 9. Equipment availability for training/testing during the data collection period.

Key:
Operational
Not available due to malfunction
Not available due to reason shown

Table 2

Distribution of Students Across 6883 Training and Testing Modes

	Testing Mode			
Training Mode	AET	3-D	2-D	Overall
AET	35*	-	-	35
3-D Simulator	14*	26*+	8++	48
2-D Simulator	4*	10	32*	46
All Devices	53	36	40	129

*Denotes cells consistent with modified experimental design.
+Includes five students with patch panel training on the Part-Task Trainer rather than on AET.
++All patch panel training accomplished on the Part Task Trainer.

In addition to explaining the need for nonrandom assignment of subjects, the data shown in Figure 9 also graphically illustrate why it was not possible to assign a sufficient number of subjects to the 2-D/AET experimental groups. Further, during the limited period between February 25 and May 7, 1981, when both the 2-D and AET equipment were simultaneously available, student flow was extremely low (e.g., no classes in March).

Data Collection

Consistent with the components of the evaluation design discussed earlier in this report, four general types of information were collected: (a) student background data, (b) classroom-related data, (c) field-related data, and (d) cost-related data. Procedures for data collection were carefully designed to minimize, as much as possible, disruptions of normal Air Force routines.

Student Background Data

A variety of aptitude and achievement measures were collected to examine the equivalence of treatment groups. Student records provided the majority of this background information including ASVAB and Air Force Qualifications Test (AFQT) results as well as block scores from prior ATC training.

Previous research by Cicchinelli et al. (1980) found no substantial or reliable relationships between standard Air Force aptitude measures (ASVAB and AFQT) and student performance in the 6883 instructional block. Because ASVAB and AFQT scores are used in part to determine career training assignments, such tests cannot also be expected to be sensitive to differences within a particular course of training. For the present evaluation, therefore, three additional aptitude tests were selected for administration to 6883 students: the Delta Concealed Figures Test, the Delta Reading Vocabulary Test,[2] and Form A of the Ship Destination Test.[2] Preassessment was conducted in a group setting at the beginning of each 6883 block and required approximately 45 minutes to complete.

Classroom-Related Data

As a result of a cooperative agreement between ATC and AFHRL, one day at the end of the Converter/Flight Control block of instruction was made available to DRI for data collection. This temporary departure from the normal training schedule, effective for the duration of this project, allowed data to be collected without altering the usual 6883 training protocol. Allocating a day for testing immediately following the 6883 training was extremely helpful to this evaluation effort for a number of reasons. First, the logistics of integrating the data collection into ongoing training were simplified. Second, the use of the actual or simulated 6883 test stations occurred as it normally would if there had been no evaluation effort. Third, the availability of testing time immediately following 6883 training eliminated the possibility that observed performance would be affected by intervening training. Finally, collecting performance data from each student at the same point in the training sequence ensured that all students had similar levels of training at the time of testing. Clearly, the cooperation of ATC in this matter was essential to the evaluation effort and their assistance is much appreciated.

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[2]These tests are protected by copyright laws. Additional information concerning specific test items can be obtained from the Air Force Human Resources Laboratory, Lowry Air Force Base, Denver, Colorado.

The following sections provide a brief discussion of the major data collection instruments developed and other sources of classroom data.

Hands-On Troubleshooting Test (HOTT). For purposes of this evaluation, maintenance skills were largely measured in terms of electronic troubleshooting. This emphasis on troubleshooting performance testing was suggested by field personnel at both Plattsburgh and Cannon AFBs. Twenty-four avionics personnel, having at least 2 years of field experience, were asked to rate the relevance of the 6883-related STS standards to job performance. Troubleshooting test station malfunctions was considered the most important job skill. Respondents also rated the ability to analyze a specific problem logically as a critical skill. Understanding the operation of the test station, its component TRUs, and associated signal flow was considered necessary to effectively troubleshoot the station and LRUs. The mean ratings of all STS standards by field personnel were presented in an earlier report (Cicchinelli et al., 1980, rf. Chapter IV, Table 2).

The HOTT was designed so that it could be administered on the AET or either the 2-D or 3-D simulator. The primary focus of this test was on troubleshooting skills; the problem selected involved the identification and correction of two related malfunctions, one in an LRU and another in the test station. The test was designed to examine the ability of a student to perceive that test station and its associated LRUs as an integrated system. The two-step nature of the malfunction was chosen to examine the procedural and logical processes of troubleshooting under circumstances that were more representative of actual on-the-job malfunctions than of 6883 training exercises. Since the test was dissimilar to the lessons available on both the 2-D and 3-D simulators as well as to the faults typically encountered on the AET, the task was new to all students.

The HOTT was administered and individually scored by DRI personnel.[3] Each test item constitutes a discrete step that a student had to complete in order to identify the malfunction. In addition to recording the completion (or noncompletion) of the required steps, the nature of all errors committed was noted on the scoring form. An analysis of these errors was conducted to isolate any differences among students trained on the 6883 2-D simulator, 3-D simulator, or AET. Time to complete various portions of the HOTT was also recorded. However, due to large differences in machine response times, variability in the need for student prompting, and a change in the LRU

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[3]Information concerning this performance test can be obtained from the Air Force Human Resources Laboratory, Lowry Air Force Base, Denver, Colorado.

model used for testing, this measure was subsequently found to be inappropriate for purposes of comparing student performance. The amount of information provided via prompts was controlled as strictly as possible through the standardization of test administration procedures. However, it was difficult to ensure that consistent information via prompts was always provided. Since few technicians use the same logic tree to solve a problem, information that is useful to one person may be unenlightening to others (Shriver & Foley, 1974).

Paper-and-Pencil Troubleshooting Test (PPTT). Because of the importance of troubleshooting skills, a paper-and-pencil measure was developed in cooperation with Air Force subject matter experts to augment the hands-on test.[4] The PPTT consisted of eight discrete electronic signal flow problems of one or more parts which required students to use their TO schematics and logical skills training. Since this test was developed subsequent to the initial data collection efforts, it was available for administration to only 119 of the 129 students in the study.

Student and instructor interviews. All students participating in the study were asked to complete a brief written survey concerning their opinions and attitudes about the use of simulators in training. The survey instrument is shown in Section A-1 of Appendix A. A written format was selected so that complete and consistent data could be collected in a fashion that allowed the greatest flexibility within the test day schedule.

The ATC Instructor Questionnaire was administered in October 1981 to nine instructors in the F-111 training program at Lowry AFB. Only those instructors who had taught the 6883 block during the course of the evaluation were asked to respond. Questions regarding the general use of simulators in training and about the 2-D and 3-D simulators in particular were included. This questionnaire is provided in Section A-2 of Appendix A.

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[4]Information concerning this performance test can be obtained from the Human Resources Laboratory, Lowry Air Force Base, Denver, Colorado.

Course content and equipment malfunction. To determine the nature of AET use in training, course-related documents were collected and reviewed, instructors and students were interviewed, and direct observations of classroom proceedings were conducted prior to the performance evaluation phase. Additionally, the specific training received by students on the 6883 AET and both simulators was recorded. The training received was categorized according to the TRUs of the AET or simulators addressed in the lesson, the LRUs which were included in the training period, and the complexity of the training as defined by ATC instructors and software developers.

Equipment malfunctions for all three trainers were also recorded. This was accomplished by reviewing maintenance department records for the AET and 2-D and 3-D simulators. In addition, appropriate instructors were interviewed to corroborate the written records for all three trainers. Equipment malfunction data were collected on all malfunctions which in any way interrupted or interfered with the training of the avionics technicians. Since all trainers are "scheduled" to be available for training each day, equipment downtime (i.e., unavailability for classroom use), regardless of the availability of "substitute" trainers, was logged. This information served a dual purpose: to track any effects of malfunctions on training and to provide information for cost analysis.

Data were also collected regarding training deviations for students during the period of their 6883 training. Reasons for deviations range from adverse weather conditions to events authorized by the Base Commander to equipment breakdowns. Training deviations are given to students who have not received all of the required training time in a particular block.

Predicting Job Proficiency

One initial objective of this research was to assess the possible impact of simulator training on actual job performance. As discussed in earlier reports (Cicchinelli et al, 1980), differences in job performance as a function of training equipment would be obscured by the variable nature of OJT. To circumvent this problem, the aid of Air Force field supervisors was enlisted to develop a paper-and-pencil test to serve as a predictor of future job performance. This instrument was administered on the test day immediately following 6883 training.

To insure the validity of the Projected Job Proficiency Test (PJPT), criteria of job proficiency were established. Questions were solicited from field supervisors which would reflect levels of knowledge expected of newly trained personnel. A total of 75 items were received.

From these items and questions obtained from Lowry AFB instructors, an initial 70-item pencil-and-paper test of job proficiency was developed. An item analysis previously conducted on 115 students in earlier research (Phase II) resulted in revisions to the instrument. The final form of the PJPT included 35 items and was more objective and reliable than the original version.[5] This instrument required only 50 minutes to complete.

Field-Related Data

Subsequent to permanent field assignment, all technicians who participated in this evaluation project and their field supervisors completed follow up questionnaires. Since former students could be assigned to any one of three work shifts and were sometimes on temporary leave for medical or educational reasons, locating them was itself a difficult task. Supervisory field personnel were instrumental in this aspect of the data collection effort. They assumed the responsibility of distributing the questionnaires and forwarding all information to DRI. Generally, the technicians and their supervisors completed the questionnaires at their assigned stations. Approximately 15 minutes of each person's time was required.

Field technician survey. By means of an interview questionnaire, technicians who had participated in the evaluation program and were subsequently assigned to the field were asked to rate the adequacy of their ATC F-111 training and its relationship to their field work. Those technicians who had contact with either simulator during training were asked specifically to rate the adequacy of simulator training. Section A-3 of Appendix A includes this questionnaire.

Field supervisor survey. Technicians in OJT are assigned supervisors who assist them in becoming familiar with the responsibilities of field assignments and who rate their performances during the OJT period. The supervisors may work at the assigned test station with the technicians or may only be available to answer questions on an as-needed basis. Personnel limitations require that one supervisor be responsible for more than one technician in most cases. These supervisors were asked to rate the performances of technicians in areas of housekeeping, use of testing equipment, knowledge of LRU and TRU circuit flow and operation, and troubleshooting initiative. There was a total of 23 items on which each technician was rated.

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[5]Information concerning this performance test can be obtained from the Human Resources Laboratory, Lowry Air Force Base, Denver, Colorado.

Field follow up data were collected once a technician had been involved with OJT for approximately 1 month. Based on previous work, it was decided that training effects would be further diluted by practical field experience if a longer lag time was selected. The supervisor rating form is included as Section A-4 of Appendix A.

Cost-Related Data

A comparison of 6883 2-D simulator, 3-D simulator, and AET life cycle costs, under the assumption of equal training effectiveness, was conducted to determine which trainer was most cost effective. Since the 6883 simulators are among the first such devices introduced into the intermediate level maintenance training environment, this analysis also served as a point of reference for a discussion of simulation options available in Air Force maintenance training.

The question of which trainer is most cost effective can be complicated when different training equipment utilization patterns for the simulators and AET produce differences in training effectiveness. For example, the most costly equipment alternative might still be the most cost effective because the equipment, together with its utilization strategy, produces proportionately greater training effectiveness.

These complications were not encountered in the evaluation because the total training environment was not disturbed by the introduction of the simulators. That is, with the introduction of the simulators, no new training strategy was imposed which could have been expected to result in differences in training effectiveness. Thus, the comparison of only the life cycle costs of the three trainers is a realistic way to establish which is most cost effective.[6]

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[6]It should be noted that the term "cost effectiveness" is used here in a limited sense: which of two or more equivalent training systems has the least total cost of ownership. The notion of cost effectiveness of simulation in training is a broad concept that presumes (a) equal effectiveness of both simulators and AETs and (b) that student performance can be gauged by objective performance criteria associated with student task performance on the actual equipment. In this context, cost effectiveness analysis of simulation training would include a determination of the marginal utility of the simulators, that is, at what point does greater use of a simulator no longer reduce training costs for the simulator-AET combination? Orlansky and String (1977) develop this important topic in their review of Cost-Effectiveness of Flight Simulators for Military Training. This issue is not engaged in the present cost analysis because the amount of training could not be systematically varied (for institutional reasons), nor could student performance of troubleshooting tasks be ascertained using existing Air Force performance criteria. This assessment is not intended to be a criticism; rather it is a comment on the maturity of simulation development for the maintenance training field.

Life cycle cost comparison. The approach taken to the development of the life cycle cost comparison considers that each simulator is a replacement alternative to the AET. The respective cost streams for each of the trainers were calculated for a projected 15-year life. Since the comparison used 1978 as the reference year, AET costs incurred prior to 1978 and simulator costs incurred subsequent to 1978 were adjusted according to the annual inflation rate to establish investment costs in 1978 dollars. Operating costs were discounted at 10 percent annually to establish net present value (NPV) in 1978 dollars.[7]

Figure 10 displays the framework for cost comparison and the major categories for which input data were acquired. The Facilities category refers to the cost of space necessary to house the training device. The Equipment category is composed of four subcategories: (a) Cost of Hardware, including original software, (b) Specifications and

Cost Categories	AET	2-D Simulator	3-D Simulator
Facilities			
Equipment			
Instructional Materials			
Personnel			
Students			
Miscellaneous			
TOTAL (construction $)			
NPV (1978)			
Cost Effectiveness ($ per student-hour)			

Figure 10. Life cycle cost comparison framework.

[7]This discount rate is consistent with Office of Management and Budget (OMB) Guidelines (Circular A94).

Acquisitions Management, which includes personnel time for developing contract specifications, contract award and monitoring, (c) Support and Installation, which includes personnel costs incurred after delivery of the device for set-up, debugging, and formative evaluation (excluding on-site manufacturer costs), and (d) Sustaining Investment, which includes the costs of maintenance (spares and personnel time for repair). The Instructional Materials category includes the cost of lessonware revision and the development of additional software/ lessonware needed. The Personnel category includes the costs incurred for administration and instruction, and the Student category refers to student wages and support. Finally, the Miscellaneous category was included to account for supplies regularly used in laboratory training.

Related cost models. Two studies concerned with the cost of training systems have been particularly useful in this work. The Naval Training Analysis and Evaluation Group (TAEG) developed a cost model (Braby, Henry, Parrish, & Swope, 1978) which included methods for evaluating the elements in each cost category shown above. A computer program for calculating total training cost was also provided. The TAEG model and its cost element estimation procedures would have been used in this work except for two drawbacks: (a) the model contains insufficient detail concerning the equipment acquisition life cycle phase that was considered important here, and (b) the emphasis given the TAEG model was one of predicting costs of alternative systems for the purpose of cost acquisition minimization, not for predicting total costs of system ownership.

The AFHRL Logistics Research and Training Division, Wright-Patterson AFB, completed a life cycle cost estimation for F-16 simulated and AET maintenance training systems in which the Braby model was used as a starting point (Eggemeier, 1979; Eggemeier & Klein, 1979, 1981). In addition, a logistics support cost (LSC) model was incorporated to estimate elements in the equipment cost category. The latter model was originally developed for the Simulator Systems Program Office (Sim SPO) to estimate costs for aircrew simulators. The principal value of the LSC model is that it can be used to estimate certain cost elements based on functional relationships derived from historical acquisition data. This technique was helpful in the present study for estimating sustaining investment costs associated with the 6883 AET operation. In addition, the F-16 analysis also provided guidance in estimating elements in other cost categories.

The cost model presented in this study is perhaps best thought of as a method for organizing and tabulating cost elements ("ingredients") for which historical data are available. The sources of the historical data for the AET station used in this cost comparison included the 3450th Technical Training Group, Avionics Branch and the Logistics Support Group (Lowry AFB). The sources of data for the simulators include the AFHRL technical monitors for the simulator contracts and the manufacturer of the 3-D simulator.

Data Management

After students completed the F-111 training program, training and performance data were collected, coding forms were completed and the data were entered into a computer file for subsequent analysis. All data except field follow up data for the last 31 students were collected for each student. Due to the approximately 12 week time period between completion of the 6883 block of training and 1 month at the field assignment, these data were not available for this analysis.

The data collected regarding training deviations, training received, unscheduled maintenance, and personal interviews were also organized for analysis. When the evaluation period was concluded, the impact of these various factors on training and performance was assessed.

V. RESULTS AND DISCUSSION

The primary focuses of this cost and training effectiveness evaluation were: (a) to examine classroom and field performance as a function of training mode (AET, 2-D simulator, or 3-D simulator), (b) to compare and contrast the characteristic operation of each trainer, and (c) to assess the costs of using the alternative types of training equipment. This chapter provides a discussion of all evaluation findings related to these three objectives as well as the results of all supporting analyses undertaken. Because of the stringent selection criteria used for entry into avionics technician training, students were fairly homogeneous with respect to both inherent abilities and achievements in the overall ATC program of instruction. Furthermore, marked differences in subsequent performance could not be expected after as brief a training manipulation as in the present case. Thus, any tests developed to isolate training differences had to be particularly sensitive to differences in the training equipment.

Analysis of Troubleshooting Performance

A central issue to be addressed by this investigation was whether 2-D simulator, 3-D simulator, and AET training would result in equal levels of student performance on troubleshooting problems as might be encountered in the field. As discussed in Chapter IV, three separate measures of 6883 training effectiveness were employed. The primary measure was a timed, serial, 26-item practical test (HOTT) of each student's ability to troubleshoot malfunctions. This test was supplemented by the PPTT and Air Force-administered 6883 block test results.

These data will be considered in the sections that follow. Because the precision of performance measurement was a primary concern, and because nonrandom assignment of students to training modes may have resulted in biased experimental groups, an analysis of covariance (ANCOVA) framework was considered most appropriate for the evaluation of performance-related data. The procedures used to identify suitable covariates for these analyses are described in Appendix B along with a summary of all pretraining variables considered in this analysis.

Hands-On Troubleshooting as a Function of Training

Table 3 summarizes student performance on the HOTT as a function of training and testing modes. While all 129 students may have completed a particular test item, only 126 overall test scores are shown. This is due to the method of scoring the test. For those students who were able, for whatever reasons, to isolate the cause of the malfunction (the blown fuse) without completing all of the intermediate steps, no overall score was recorded. Instead, data for those items completed were included insofar as they were in correct sequential order.

Two hypotheses were of particular interest with respect to hands-on troubleshooting abilities:

1. Students trained on the 3-D simulator, the 2-D simulator, and the 6883 AET are equally accurate in solving troubleshooting problems.

2. Students trained on the 3-D simulator, the 2-D simulator, and the 6883 AET operate the AET with equal proficiency.

Table 3

Mean Hands-On Troubleshooting Test Scores by Training and Testing Modes

		Testing Mode		
Training Mode		AET	3-D	2-D
AET	N	34		
	$\overline{X}$	21.50	-	-
	σ	2.16		
3-D Simulator	N	14	26	8
	$\overline{X}$	22.57	21.58	21.00
	σ	1.79	2.19	2.83
2-D Simulator	N	4	10	30
	$\overline{X}$	24.25	21.60	22.30
	σ	0.96	1.84	1.73

To test the first hypothesis, a one-way ANCOVA was performed using only data from those treatment groups where training and testing were accomplished on the same piece of equipment. It was assumed that these three groups--AET/AET, 3-D/3-D, and 2-D/2-D--provided the most appropriate comparison in lieu of a full factorial design since all students were equally familiar with the testing equipment. Furthermore, this approach avoided making the assumptions necessary to collapse across testing modes, while including 70 percent of the available student data. Scores from the Delta Concealed Figures Test, the General Aptitude Test, and the Common Automatic Test Equipment (CATE) instructional block served as covariates for this and subsequent analyses performed on the HOTT results. The analysis revealed no significant differences as a function of 6883 training mode ($F(2,77) = 1.95$, $p = .15$).

The second hypothesis required a comparison of the AET tested treatment groups as a function of training. Unfortunately, only one class of four students could be tested on the AET following 2-D training; thus, a direct test of this hypothesis was not possible. However, the rationale can be developed that the 2-D and 3-D simulators should be considered as "AET equivalent" for purposes of testing. First, previous research by Cicchinelli et al. (1980) found no effect of testing mode (3-D simulator vs. AET) on the accuracy of student troubleshooting performance. Second. both simulators are fairly high fidelity replicas of the 6883 test station and thus are reasonable alternatives to the AET. Third, the present data showed no difference among the 3-D simulator-trained students as a function of testing mode (F $(2,39) = 1.05$, $p = .36$). And fourth, an ANCOVA comparison of troubleshooting scores for 2-D simulator-trained students who were tested on either the 2-D or 3-D equipment also showed no significant main effect of testing (F $(1,35) = 1.15$, $p = .29$). The 2-D/AET condition was not included as a treatment level in this latter analysis because so few observations were available. In summary, it seemed unlikely that troubleshooting test results were affected by the device used for test administration. For these reasons, it was assumed that all testing modes might be combined in order to examine "AET equivalent" testing.

Turning once again to hypothesis #2, AET, 2-D, and 3-D testing modes were combined, and data from the resulting three training groups were analyzed in the usual ANCOVA framework. A marginally significant effect of training mode was found with this approach (F $(2,112) = 2.79$, $p = .07$). Subsequent tests of orthogonal contrasts showed that while there was no difference in performance between 2-D and 3-D trained students (F $(1,112) < 1$), simulator and AET trained students did differ reliably (F $(1,112) = 4.95$, $p = .03$). It should be stressed that two important and somewhat dubious assumptions have been made in arriving at this finding. First, it was assumed that the testing mode had no effect on 2-D trained student performance, based only on data from two of the three testing levels. And second, it was assumed that there was no interaction between training and testing. A violation of either assumption was possible and could account for this marginal difference in performance.

Training/Testing and Specific Troubleshooting Test Items

Using Cronbach's method, the reliability of the HOTT was computed and found to be low ($\alpha = .37$), suggesting that a variety of skills were contributing to each total score. For this reason, and because meaningful differences in overall scores had not been shown as a function of training, a more detailed analysis of the data was performed. Error rates for each of the 26 items were computed and are presented in Table 4 according to student training modes.

Table 4

Mean Error Rates for Hands-On Troubleshooting Test Items as a Function of 6883 Training Modes

	Training Mode		
Item #	AET	3-D	2-D
1	.09	.15	.22
2	.03	.15	.04
3	.03	.06	.00
4	.03	.06	.00
5	.14	.13	.15
6	.00	.04	.00
7	.06	.02	.00
8	.03	.02	.00
9	.09	.00	.00
10	.03	.10	.04
11	.09	.06	.11
12	.03	.08	.13
13	.03	.08	.07
14	.17	.10	.15
15	.03	.04	.09
16	.03	.06	.00
17	.23	.15	.04
18	.09	.13	.13
19	.59	.40	.42
20	.41	.56	.36
21	.18	.23	.05
22	.18	.33	.18
23	.62	.58	.43
24	.76	.50	.75
25	.12	.04	.09
26	.24	.27	.16

A review of the data shown in Table 4 suggests the following observations:

- Safety errors (item #1) were slightly more common among simulator-trained students than among those trained on the AET. Furthermore, while 81 percent of the simulator-trained students were assigned to a simulator for hands-on testing, they accounted for 94 percent of the errors made by simulator-trained students. Thus, it appears that an error on item #1 is more likely with simulator training and testing. This finding suggests that students may have failed to perceive the simulators as actual test stations. Special efforts should be directed toward ensuring that safety is not compromised by this apparent difference in student attitudes.

- Students had particular difficulty with items #19 and #20--recognizing the need to rerun a test that has failed by returning to the previous "0-ending" test number. It was expected, based on DRI's class observations, that AET trained students would be more likely to recognize the need to repeat a test that has failed (item #19) but less likely to choose the correct method (item #20). This followed from the observations that AET test failures are quite common, and they are generally addressed by selecting the "repeat" mode option which was not a correct procedure for the hands-on test. Both groups of simulator-trained students were expected to make more errors on the "need to repeat test" item, since this step is not stressed by the training lessons. Surprisingly, the error rate results were at odds with both of these predictions. AET trained students were somewhat less likely to recognize the need to repeat the test that failed and 3-D-trained students were least likely to select the proper repeat procedure.

- Item #21 dealt with suggesting replacement of the faulty component (Yaw Board TB3). The fact that 2-D students performed slightly better than 3-D or AET groups on this item may be due to the nature of the student action panel used for 2-D student-simulator interactions. The single "Repair or Replace" option is a common solution to 2-D lessons.

- In general, as items #23 and #24 reflect, decoding the fault isolation proved to be a difficult task for all students. While the simulator training modes, and 3-D in particular, showed a slight edge in performance on these items, the difference is not likely to be reliable.

Overall, the differences observed in item error rates as a function of training mode were minimal. This finding is consistent with the analyses of total scores discussed previously.

Supplemental 6883 Performance Measures

Two additional measures of 6883 performance were recorded--the Air Force-administered 6883 end-of-block test and the PPTT. Table 5 presents the mean scores for each as a function of the three training modes. Following the statistical approach outlined in Appendix B, covariates were selected for each measure. For 6883 block scores,

Table 5

Supplemental 6883 Performance Measures
as a Function of Training Mode

		Measures	
Training Mode		6883 Block Score	PPTT Score
AET	N	35	31
	$\bar{X}$	85.26	19.29
	σ	8.70	6.65
3-D Simulator	N	48	42
	$\bar{X}$	84.00	18.67
	σ	9.64	7.90
2-D Simulator	N	46	46
	$\bar{X}$	83.39	19.78
	σ	10.57	7.52

these covariates consisted of Administrative Aptitude Scores and scores from the Electronic Fundamentals and CENPAC instructional blocks. For the PPTT, scores from the Electronic Fundamentals block as well as Electronic and Mechanical Aptitude Test results were selected as covariates. Separate ANCOVAs revealed no significant differences among training conditions for either the 6883 block scores (F (2,111) < 1) or the written troubleshooting scores (F (2,102) = 1.12, p = .33).

In sum, students trained on the simulators and those trained on the AET did not differ appreciably with respect to overall troubleshooting abilities as measured by both practical and written tests. Furthermore, when students were compared across an "AET equivalent" testing mode, all three training modes exhibited similar levels of troubleshooting proficiency.

Estimation of Field Preparedness

Two methods were used to assess the impact of training mode on student acquisition of field-relevant skills. One analysis dealt with the results of the PJPT which was administered to all students at the conclusion of the 6883 instructional block. As discussed previously in this report, the PJPT was specifically developed for this purpose (rf. Chapter IV). Since subsequent instructional blocks included training components similar to those in OJT, student performance in those blocks also indicated field preparedness. Therefore, the second analysis examined the results of Air Force-administered achievement tests for these later blocks.

Projected Job Proficiency as a Function of Training Mode

The PJPT was a paper-and-pencil test that included 35 four-alternative choice items, each contributing equally to a total score. The mean PJPT scores were 20.8, 21.0, and 20.6 for AET, 3-D, and 2-D trained students, respectively. Not surprisingly, these values did not differ appreciably when subjected to an ANCOVA (F (2,119) < 1) in which scores from the Electronic Fundamentals and DATAC blocks and the Ship Destination Test served as covariates. Thus, the hypothesis was supported that the 3-D simulator, the 2-D simulator, and the AET provide equivalent job-related experiences.

Subsequent Classroom Performance as a Function of 6883 Training

Another facet of assessing possible training effects on job-related abilities was the analysis of subsequent instructional block scores. It was anticipated that practical blocks would be particularly sensitive to simulator versus actual training experiences in the 6883 block and also most similar to the eventual field training situation. Four of the nine subsequent training blocks involved hands-on training, but no training differences could be found since all students received a grade of "satisfactory" in each.

Since practical instruction blocks offered no useful data, performance in subsequent theory instruction blocks was examined as an alternate means of assessment. Table 6 presents the mean block scores for the five theoretical courses as a function of 6883 training mode. A series of univariate analyses of covariance were performed in order to assess the possible effects of 6883 training on subsequent block scores. Covariates were again selected according to the procedures outlined in Appendix B, and varied somewhat for each measure as shown in Table 6. Only in the case of the Attitude and Rate TS block was there even a marginally significant effect of training on performance. However, while a minor difference was detected, the overall data suggest that students perform equally well on subsequent instructional blocks whether trained on the 3-D simulator, the 2-D simulator, or the AET.

User Acceptance

User acceptance of the 3-D and 2-D simulators was assessed through the administration of student interviews and instructor interviews. Students were given interview forms at the completion of DRI end-of-block testing; thus student acceptance was based on responses of all 129 students who participated in this evaluation effort. Instructor acceptance was examined on the basis of interview forms given to nine instructors who were involved in delivering 6883 training during the project period. The amount of contact time with either or both of the simulators varies considerably among instructors. This was primarily due to the existence of a Special Projects Group composed of three F-111 instructors who were responsible for conducting all 6883 simulator-based training. AET instruction was provided by several additional instructors who were given fewer opportunities to operate or observe the simulators.

Student Interviews

'verall, students did not differ greatly in their impressions of the 6883 instructional block as a function of training mode. Interview items were rated on a 5-point scale, where 5 corresponded to a highly positive response. The mean ratings, shown in parentheses,

Table 6

Instructional Block Performance
Subsequent to 6883 Training

Instructional Block		6883 Training Mode AET	3-D Simulator	2-D Simulator	ANCOVA* F-Ratio
Computer Test Station (TS)	N	27	29	23	
	$\bar{X}$	92.8	90.5	89.6	1.56
	σ	6.3	6.9	6.2	(p=.22)
Attitude and Rate TS	N	27	29	23	
	$\bar{X}$	85.1	84.0	89.4	2.42
	σ	9.4	8.7	6.5	(p=.10)
Display TS	N	8	19	23	
	$\bar{X}$	87.3	88.0	84.5	< 1
	σ	12.5	8.8	8.8	
Video TS	N	35	48	46	
	$\bar{X}$	80.7	82.4	79.5	1.13
	σ	11.0	9.0	13.5	(p=.33)
Radar-Transmitter Modulator TS	N	35	48	41	
	$\bar{X}$	89.5	87.8	90.5	< 1
	σ	6.2	9.3	7.7	

*Selected covariates were as follows:

Computer TS--Sex, Electronic Fundamentals, Navigation Block Scores
Attitude and Rate TS--CENPAC Block and Ships Destination Scores
Display TS--Electronic Fundamentals, Logic, and AGE Principles Block Scores
Video TS--Navigation and Electronic Systems Block Scores
Radar-Transmitter Modulator TS--Concealed Figures Test, CATE, and CENPAC Block Scores

suggested that students were only slightly more comfortable operating either of the simulators (3.6) than operating the actual equipment (3.4). Students trained on the 2-D simulator estimated that more of their time was spent on troubleshooting exercises (3.0) than did students in either the 3-D or AET training groups (2.7 and 2.6 respectively). While all students believed strongly that more troubleshooting experience was necessary, this belief was somewhat more evident for 3-D trained students (4.7) than for students taught with the 2-D simulator (4.4) or AET (4.1). Students trained on the 3-D simulator also felt less prepared for their field assignments in terms of troubleshooting experience (2.1) than did students in the 2-D or AET training modes (2.4, 2.5). Overall, students were very supportive of their instructors, regardless of the equipment used for training (4.2). A complete summary of student interview results is provided in Section A-5 of Appendix A as a function of the primary equipment used for 6883 training.

Instructor Interviews

The instructors were asked to use a 5-point scale to rate simulator training in general on several factors (e.g., Is it a good idea?; Can it provide AET equivalent training?; Is it more reliable than AET training?) based on their experiences with the two simulators used in this study. Only one statement received a below average (2.4) rating: that simulators could replace actual equipment in training. This finding was not surprising since previous studies have shown instructors strongly believe in the necessity of AETs for training (e.g., Fink & Shriver, 1978). Statements which drew strong support from the instructors included (a) simulation can provide adequate training at a cost savings (4.0), (b) simulators can provide more variety of training than can AETs (4.2), and (c) simulators are more reliable than actual equipment (4.6).

When asked to rate 13 elements which are considered important in simulator design, six were given especially high marks by the instructors. These were (a) software should be suitable to the course objectives (4.7), (b) instructors should have input or control over software development (4.8), (c) the Air Force should have control over the design of the simulator (4.4), (d) the equipment must have operational reliability (4.9), (e) the equipment must be easy to maintain (4.6), and (f) the software must include a broad variety of lessons (4.1). The least important element of the 13 was the inclusion of a student performance monitoring capability (3.1). It should be noted that the AET does not have such a capability, and, although the two simulators are able to track student performance, this capability was used sparingly during the evaluation period by instructors.

Instructors were also asked to rate a number of statements that might apply to both the 2-D and 3-D simulators. A comparison of mean rating results as a function of equipment showed that instructors agreed (a) the 2-D hardware was slightly more simplistic (2.9) than was the 3-D hardware (2.0), (b) the 3-D simulator was more likely to be conceived of as similar to the AET by students (3.1) than was the 2-D simulator (2.1), and (c) when compared to the AET, the 3-D was a somewhat better trainer (2.8) than was the 2-D (2.1).

The impact of the introduction of simulators on the training regime was also investigated by asking the instructors to what extent their experiences with the simulators affected their approach to teaching. Of the nine respondents, four reported they had identified weaknesses in the training materials and had requested changes be made in these materials, and four reported placing more emphasis on certain portions of the course material. Complete results from the instructor interview are provided in Section A-6 of Appendix A.

The instructor survey was also designed to determine preference regarding future use of the three trainers in the classroom. Due to a poorly constructed survey item, however, it was determined that the responses concerning future use were confounded by prior experience with the various trainers. Thus, the average response score for this item was not included in the analysis. Since this issue was considered to be of significant importance to the evaluation, a separate interview was conducted with the same instructors to determine trainer preferences. Instructor preference was overwhelmingly in favor of the AET. Of eight respondents, six ranked the AET as their first choice, with the remaining two responses being split between the simulators. The 2-D simulator was ranked as the last choice (i.e., third) by five respondents, followed by the 3-D simulator by three respondents, and the AET was ranked as the last preference by only one respondent. Among the reasons given for these choices of trainers, the one-to-one relationship between the AET and the expected field experience was most often cited, despite recognition of the poor record of reliability of the AET. The choice of the 3-D over the 2-D simulator also reflects an instructor preference for high physical fidelity, which they perceive to reside with the 3-D simulator rather than with the 2-D simulator.

Assessment of Field Performance

To determine whether technicians trained on simulators and on AETs were equally capable of operating F-111 automatic test stations in the field, subjective ratings of each technician's performance were collected from the technicians themselves and from their supervisors. However, because of the 12 week time lag between the completion of

6883 training and the administration of field follow up questionnaires, not all students who had participated in the performance evaluation phase were available for follow up prior to the finalization of this report. The abilities of those students assigned to 6883 and the highly similar 6873 equipment were of particular interest, although actual assignments to these stations were quite low. Only 10 of the 98 technicians who responded to the field survey were assigned to 6883 or 6873 test stations. For this reason, it was not possible to reliably assess the impressions of these few technicians as a function of each of the three 6883 training modes they might have encountered. The results discussed in the following sections, therefore, are based on the entire sample of 98 technicians and their supervisors regardless of equipment assignments.

Technician Follow Up Survey

Mean ratings for selected items from the technician survey are presented in parentheses throughout this discussion. All ratings are based on a 5-point scale where 5 indicates a highly positive response. A complete summary of these data is provided in Section A-7 of Appendix A. It should be noted at the outset that the respondents generally believed that 6883 training had been relatively unimportant for their current field assignments (2.3); this finding reflects the previous comments regarding equipment assignments and supports the earlier conclusion that significant training effects would not be anticipated based on the brief 6883 training manipulation.

The results showed that all technicians were reasonably comfortable operating actual field equipment and that this was perhaps more true for 3-D trained personnel (4.1) than those trained with 2-D (3.8) or AET (3.8) equipment. When asked about their ability to cable LRUs and adapters to the test stations, the AET and 3-D trained technicians felt slightly more confident (3.1, 2.9) than did those who used the 2-D simulator (2.6). Technicians also believed that they were somewhat better trained in the use of common test equipment if they had AET training (4.0) than if they had simulator-based training (3.7 for 3-D and 3.6 for 2-D).

With respect to how well technicians felt they had been prepared for field work in terms of troubleshooting skills, the responses were quite consistent with the earlier student interview results. Overall, the technicians rated ATC troubleshooting training as adequate; less so for 3-D training (2.4) than for other training modes (2.7).

Those technicians who had been trained on one of the simulators were asked four questions pertaining to their experience with simulated training. Technicians trained on the 2-D reported receiving more enjoyment from their experience than did 3-D trained technicians (3.5 vs 3.2); however, 3-D and 2-D trained technicians were equally likely to rate the simulator with which they had had experience as an adequate simulator of actual test station operation conditions (3.3 for 3-D and 3.2 for 2-D). Neither group was supportive of the idea that simulators were better training instruments than were AETs (2.2 for 3-D and 2.4 for 2-D) or that simulators should be used more frequently during ATC training (2.8 for 3-D and 3.0 for 2-D).

Supervisor Survey

The results of the supervisor survey revealed no substantial performance differences among technicians who had received various modes of 6883 training. In general, the ratings were high, indicating that supervisory personnel are satisfied with the abilities of electronic maintenance technicians currently being trained by ATC. Section A-8 of Appendix A summarizes the mean ratings given for selected survey questions.

Contextual Analysis of Training Environments

Analyses of several contextual elements were included in this evaluation effort. These elements were grouped into three general areas: system capabilities, system support requirements and operating characteristics, and equipment reliability.

System Capabilities

Each of the three systems evaluated (the normal operational configurations of the AET, the 3-D simulator and the 2-D simulator with part-task trainers) has different capabilities defining operation and training utility (Table 7). Some of the comparisons of particular interest were (a) the ability to insert equipment malfunctions, (b) the capability for providing troubleshooting experience, (c) the amount of student contact time with the trainer, (d) safety, and (e) ease of maintenance and modification. In three of these categories, the 2-D system was rated most favorably; in two of these areas the 3-D and 2-D were rated equally capable. The AET was rated low in several capabilities areas and was considered relatively difficult to maintain and modify.

The capabilities identified and compared in Table 7 do not, of course, establish which system was most effective for training

Table 7

Comparison of Device Characteristics and Training Capabilities

	Training Device		
Factor	AET	3-D Simulator	2-D Simulator*
Capabilities			
Malfunction Insertion	Very Limited	Unlimited+	Unlimited+
Troubleshooting	Very Limited**	Limited++	Unlimited+
Part-Task Training	Low	Very Low	High
Self-Paced Learning	Low	High	High
Student Contact	Low	Low	High
Student Performance Monitoring	No	Yes	Yes
Support Requirements and Operating Characteristics			
Mobility	Low	Very Low	High
Operating Noise Level	High	High	Low
Safety	Low	High	High
Power Requirements	115v, 60 Hz 115v, 400 Hz	120 VAC	120 VAC
Operational Responsiveness to Keyboard Input	Fast	Slow	Very Slow
Physical Representativeness to AET	---	High	Moderate
Operational Representative-ness to AET	---	Moderate	Moderate
Ease of Maintenance	Poor	Fair	Good
Spare Parts Requirement	Very High	Moderate	Low
System Modifications	Difficult	Easy	Easy
System Support Equipment	Extensive	Minor	Minor

*Includes Part-Task Trainers
**Restricted to unscheduled malfunctions

+Restricted only by lessonware development limitations
++Nonexistence of patch panel

purposes. Performance analyses and user acceptance, previously presented, and cost elements discussed in the next section were the key elements in system comparability.

System Requirements and Characteristics

The three 6883 training devices differed considerably with respect to support requirements and operating characteristics. Table 7 provides a summary comparison of the three training devices in relation to these factors. Some of the more prominent environmental differences are discussed in the following sections.

Housing. To meet the combined theoretical and practical objectives of training, all 6883 training equipment was originally housed in rooms that included tables and chairs as well as the training device. During the first half of the project period, the three units (AET, 3-D, and 2-D) were housed in similarly configured rooms with each unit in its own room. The AET room included a large air conditioning unit (floor-mounted) whereas the two simulator rooms had window-mounted air conditioning units. Subsequently, all three units were moved to a new building with central air conditioning. The AET and 3-D simulator were housed in the same room in this new facility. The room was quite large, approximately 40' by 25', with a linoleum floor and no chalkboards. The 2-D simulator room was smaller (30' by 18') in size but included features such as a carpeted floor, a chalkboard, and a more permanent arrangement of tables and chairs for instruction.

In reality, the specific housing requirements for the three trainers are minimal. All trainers require air conditioning to maintain optimum operating temperatures. Space requirements for the trainers can be met by standard classroom-size areas, assuming the CENPAC computers continue to be housed in quarters separate from the AET, as is currently the case. Additional space, furnishings, or facilities serve primarily to enhance the human and instructional environment (e.g., carpeting, chalkboard).

Support. To operate each of the three devices, certain support requirements must be met. For the AET, these include high electrical power inputs, air conditioning, adjunct CENPAC computers (which serve all operating test stations), and a substantial number of spare electronic parts. The 3-D and 2-D simulators require only standard 120 volts AC wall outlet power for operation. The computers which operate these simulators are exclusive to the units and the simulator systems have need for few replacement parts. Air conditioning is provided to each classroom via a central system.

Safety. Because of the high power requirements of the AET, safety was an important consideration in the training environment. Potential safety problems are aggravated by the existence of several TRU and LRU connectors, jacks, and other points of possible electrical power output from the AET. Both simulator systems, with their lower power requirements and fewer potential contact points, reduce the safety problems considerably.

Noise Levels. The noise level of an operating test station is a significant environmental factor for two primary reasons: the volume and frequency of the noise level is often physically irritating, and the noise level interferes with instructor-student communication. Special efforts were made, therefore, to record actual operational noise levels for each device in order to substantiate these observations. The results are provided in Table 8. The high level of noise attributed to the operating AET is due to the fact that, in its normal operation, the 6883 AET requires the operation of a blower unit in addition to air conditioning required to dissipate heat from the TRUs and LRUs. The 3-D system is also, though to a lesser degree than the AET, a noisy system in operation. This is due to the existence of two computers, blower units in the computer racks, and required air conditioning. The 2-D simulator itself generates virtually no noise; however, the 2-D system also requires an air conditioning system to maintain operational temperatures. Nonetheless, the 2-D operational environment is measurably quieter than the operational environments of the AET or the 3-D system.

Table 8 shows (a) the values recorded with equipment and background noise together and (b) the adjusted values which reflect equipment-only noise. This adjustment, using a standard logarithmic formula, was necessitated by the fact that background noise could not be eliminated from the environment. For the specific formula used to determine the equipment-only values, see Appendix C. In normal classroom usage, air conditioning (the primary source of background noise) for each training device is required to maintain operable temperature levels. Thus, the values in the upper portion of the table reflect normal classroom noise levels.

Since the 2-D simulator is operated in a classroom environment that includes carpeting, tables, chairs, and other sound-absorbing elements, additional readings were taken in this classroom environment. As shown in Table 8, the overall unadjusted noise level was 66 dBa at 5 feet, with a background noise level of only 62.5 dBa. The adjusted noise level in this environment was 63.4 dBa.

The accuracy of the readings, within ±1 dBa, is sufficient to ascertain that all are within Occupational Safety and Health Agency guidelines for nondamaging noise levels for an eight hour period.

Table 8

Noise Level Readings for the Three 6883 Training Devices (in dBa)[1]

Distance from Equipment	Equipment			
	AET	3-D	2-D	2-D[2]
Equipment and Background Noise[3]				
Near (1 ft.)	77.50	73.90	67.00	-
Intermediate (5 ft.)	77.83	73.00	66.00	66.00
Distant (10 ft.)	75.83	71.50	65.88	-
Equipment Noise Only				
Near (1 ft.)	77.2	73.2	62.7	-
Intermediate (5 ft.)	77.6	72.3	59.1	63.4
Distant (10 ft.)	75.4	70.4	58.6	-

[1]All readings, unless otherwise stated, were taken in the laboratory room which normally houses the AET and 3-D trainers.

[2]Readings in the classroom housing the 2-D where a background noise level of 62.5 dBa was measured. Readings were taken at one distance since movement toward and away from the unit produced no significant fluctuations in the meter reading

[3]Background noise was measured at 65 dBa

Environmental Protection Agency standards suggest that to conduct training using a normal voice with the sound levels measured in the normal classroom environments experienced in this study, the instructor could be no more than .5 foot (for the higher measurement of the AET environment) to 2 feet (for the lower measurement of the 2-D environment) from the students. Using a raised voice (or a "classroom" voice), appropriate distances would be 1 foot (AET) to 3 feet (2-D). Tables indicating interference levels for various dBa levels and distances are included in Appendix C.

Equipment Reliability

A fundamental issue involved in the evaluation of simulated training devices is training equipment reliability. Equipment reliability has potential impacts on both performance and cost and, in large part, defines the format of the training approach used with actual test station equipment. Unlike the approach with preprogrammed malfunctions on the simulators, the acquisition of practical experience on the actual equipment is dependent on pre-existing or unexpected equipment failures. This is particularly true of the troubleshooting aspects of training. In extreme cases (which were observed during this evaluation), this dependency results in very limited training. For example, when all TRUs and LRUs operate without malfunction, it is not possible to demonstrate troubleshooting techniques. At other times when a specific TRU failure causes the test station to be inoperative, no training is possible, or extensive attention to one portion of the test station results.

The observed reliability of the 6883 test station, the 3-D simulator and the 2-D simulator during the data collection period is graphically depicted in Figure 11. It can be seen that the AET was inoperable for a 6 month period. The primary cause of the downtime on the AET was the relocation of F-111 Test Stations to a new training facility. Not only was the AET unavailable for use during the period of the move, but once the device was in place, it became apparent that the new electrical system was insufficient for proper AET operation. While the AET had been experiencing serious malfunctions prior to the move and it was possible to make limited repairs without station power, maintenance efforts were severely restricted until the building power problems were solved. Ill-timed preventive maintenance also caused some difficulty for assessing reliability of the AET. Specifically, an LRU cable which was necessary for both AET training and the contractor's hands-on testing was sent off-base for refurbishment during the same general time. This action further contributed to the unavailability of the equipment for training.

Evaluation Project Data Collection Period

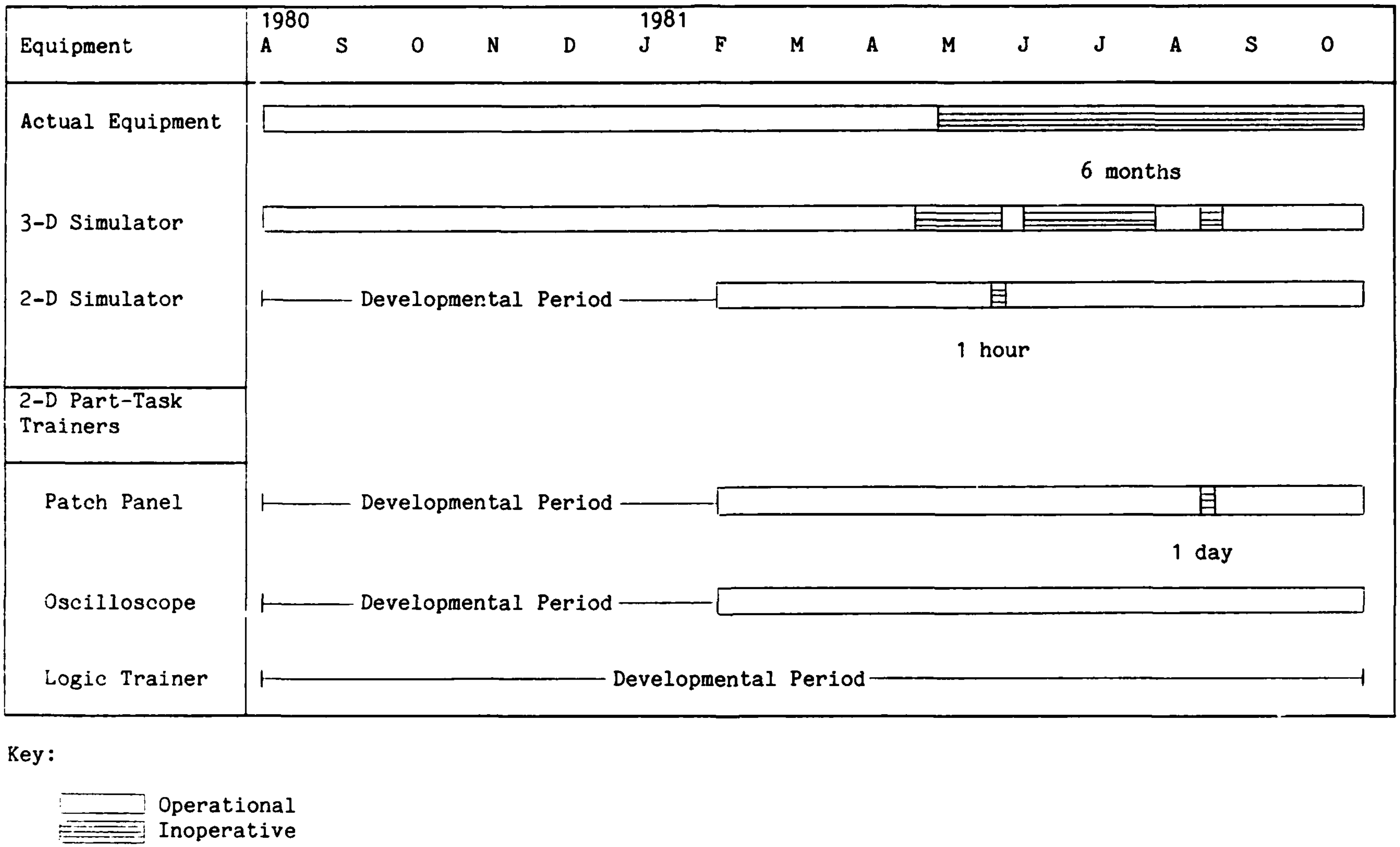

Figure 11. Equipment reliability during the data collection period.

The 3-D simulator experienced three periods of downtime primarily due to interface problems between the two computers associated with the 3-D simulator system. One of these periods occurred directly after, and most likely as a result of, the relocation of the 3-D simulator to the new training facility. Other periods occurred before the equipment move and near the end of the evaluation period.

The 2-D simulator experienced no significant downtime and was moved to the new facility without apparent complications. The Patch Panel Trainer experienced only 1 day of downtime. Since the other part-task trainers were either inoperable (i.e., Logic Trainer) or rarely used (i.e., Oscilloscope Trainer), their reliability remains to be demonstrated. The results of this analysis suggest that the two simulators, and especially the 2-D simulator, were highly reliable trainers in comparison to the AET.

The reliability of the trainers influenced the evaluation effort in at least two ways. First, the frequency and duration of individual equipment failures shown in Figure 11 were sufficient to cause disruption of project training assignments and data collection. The major impact of malfunctions on the evaluation design was on the assignment of trainees to experimental groups. Thus, flexibility in the evaluation design was essential to allow for unexpected changes in the training schedule and to minimize the potential loss of performance data. Second, only minimal training time was lost due to the availability of the three training instruments. For example, all AETs associated with F-111 electronics maintenance training were unavailable for training or testing during the data collection period associated with the power source problems. Only the 6883 block of instruction did not require issuance of "training deviations," since at least one of the simulators was operational throughout that period.

The existence of alternative training devices can significantly affect the assessment of equipment reliability in the training environment. For example, in the present study, there appeared to be little motivation to effect immediate repairs on a particular device since there was always at least one suitable alternative device available for training purposes. Thus, even when parts were available to effect repairs on a malfunctioning trainer, the availability of an alternative device lessened the motivation to complete those repairs.

Alternative methods are available for determining equipment reliability. For example, downtime can be defined as the time to make repairs, excluding the time spent waiting on parts. This approach eliminates the problems of specifying all factors contributing to downtime, but does not accurately reflect the duration of downtime periods. A better measure may be the operating time between repairs. This measure is unrealistic, however, when applied to ATC since its low priority for replacement parts can result in periods of test station inoperability exceeding 1 year, thus creating the possibility of recording few or no periods of equipment operation during an evaluation study. A measure combining time to repair and time awaiting parts is more realistic. While this measure can also be artifically inflated due to the low priority on parts, it was used in this study since these two elements best typify the real training environment and serve as indicators of system maintainability (i.e., frequency and duration of malfunctions, and availability of spares).

Cost Analysis

Table 9 shows the major factors of the life cycle cost comparison among training devices. Recurring and nonrecurring costs have been combined to provide profiles of costs in constant 1978 dollars. The NPV of each cost stream projected for 15-year life cycles and discounted at 10 percent is also shown, along with the estimated training costs per student-hour of instruction.

As can be seen from Table 9, the differences in total costs can be attributed almost entirely to differences in the costs of purchasing and sustaining the equipment. Personnel and instructional materials costs are quite comparable across the three training devices. Facilities and student costs are identical for each trainer since equal training interventions were assumed. Alternative cost scenarios are clearly possible, however, in which student costs would be expected to vary as a function of training provided. The final entries of Table 9 show the average cost per student hour of instruction based on the total NPV of each device. Both simulators show a substantial savings over the average cost associated with AET training.

Tables 10, 11, and 12 show individual estimates for cost elements that comprise each category, together with explanatory information for the AET, the 3-D simulator and 2-D simulator, respectively. The tables are structured so that the 1978 Investment Costs can be considered as sunk costs; from this perspective, the costs in constant dollars of operating the AET and the simulators for 15-year life cycles are $3,366,150 (AET), $1,588,020 (3-D) and $1,294,410 (2-D). The life cycle cost comparison, which clearly favors the simulators, and the 2-D simulator in particular, establishes that simulation is an important option for maintenance training. The following examination of some of the cost assumptions inherent in this comparison further supports this finding.

Table 9

The Life Cycle Cost Comparison

Cost Categories	Training Device: AET	3-D Simulator	2-D Simulator
Facilities	$ 110,650	$ 110,650	$ 110,650
Equipment	4,767,140	1,594,330	1,046,380
Instr. Materials	27,890	26,000	29,580
Personnel	72,530	94,250	72,530
Students	357,770	357,770	357,770
TOTAL	$5,335,980	$2,183,000	$1,616,910
NPV 1978	$3,760,680	$1,501,090	$1,060,430
$ per student-hour*	$58	$23	$16

*Based on 15 years x 30 classes/year x 6 students/class x 3 days x 8 hours/day = 64,800 student-hours.

Table 10

Life Cycle Costs (Thousands of Dollars)
for AET Simulator--Constant 1978 Dollars

Cost Category	Cost Element	Inv Cost	Operating Years (15) 1	2	3	4-15	Total	Comments (rf. Appendix D)
Facilities	Replacement cost of space		7.34	7.34	7.34	7.34	110.15	450 sq ft @ $16.32/ft (A)
	Supplemental furnishings	0.5						Estimated (B)
Equipment	6883 test station and LRUs	1,954.33						Inflated 79.5% from '72-'78
	Acquisition management	15.00						Est @ .75% of AET cost (C)
	Sustaining investment		0.0	195.4	195.4	195.4	2,736.02	Est @ 10% of AET cost (D)
	Maintenance (672 hrs/yr)		3.62	3.62	3.62	3.62	54.29	0.323 person-years (E-5) (E)
	Operating costs (power)		0.50	0.50	0.50	0.50	7.5	
Instructional Materials	TOs and software	0						Included in equip costs (F)
	Update laboratory exercises		1.86	1.86	1.86	1.86	27.89	0.16 person-years (E-5) (G)
Personnel	Laboratory Instructor		3.73	3.73	3.73	3.73	56.01	0.33 person-years (E-5) (H)
	Overhead burden		1.10	1.10	1.10	1.10	16.52	Prorated mgt and adm (I)
Students	Wages (180 students/yr-- 3 days)		15.20	15.20	15.20	15.20	227.89	Equiv to 2.077 yr (E-2)
	Permanent change in station		0.1	0.1	0.1	0.1	1.5	$23,300 over 23 weeks
	Miscellaneous support cost		8.55	8.55	8.55	8.55	128.38	2.077 yrs @ $79.25/wk (J)
Miscellaneous	Not estimated							No supplies regularly used in 6883 laboratory training
TOTALS		1,969.83	42.0	237.4	237.4	237.4	3,366.15	

Total cost in constant dollars = $5,335,980
Net present value (1978) = $3,760,680

Table 11

Life Cycle Costs (Thousands of Dollars)
for 3-D Simulator--Constant 1978 Dollars

Cost Category	Cost Element	Inv Cost	Operating Years (15) 1	2	3	4-15	Total	Comments (rf. Appendix D)
Facilities	Replacement cost of space		7.34	7.34	7.34	7.34	110.15	450 sq ft @ $16.32/ft (A)
	Supplemental furnishings	0.5						Estimated (B)
Equipment	6883 simulator, software and courseware	548.00						Contract value
	Specification and acqui- sition management	45.68						Est based on project rds (K)
	Support and installation		19.84	31.18	0	0	51.02	Est based on project rds (L)
	Sustaining investment		34.5	57.5	65.33	65.33	941.33	Eng change, maint, records (M)
	Air conditioning and inst	0.8						
	Operating costs (power)		0.5	0.5	0.5	0.5	7.5	
Instructional Materials	Software revision (lessons)		7.86	15.71	0.0	0.0	23.57	Full-time E-7 for 18 months
	Overhead burden		0.8	1.63	0.0	0.0	2.43	
Personnel	Laboratory instructor		5.60	11.20	11.20	3.73	72.75	Full-time E-5 for first 2½ yrs
	Overhead burden		2.10	3.10	3.10	1.10	21.50	Then, .33 yrs of E-5 level (H)
Students	Wages (180 students/yr--3 days		15.20	15.20	15.20	15.20	227.89	Equiv to 2.077 yrs (E-3)
	Permanent change in station		0.1	0.1	0.1	0.1	1.5	$23,300 over 23 weeks
	Miscellaneous support costs		8.55	8.55	8.55	8.55	128.38	2.077 yrs at $79.25/wk (J)
Miscellaneous	Not estimated							No supplies regularly used in 6883 simulation training
TOTALS		594.98	102.39	152.01	111.32	101.85	1,588.02	

Total cost in constant dollars = $2,183.00
Net present value (1978) = $1,501.09

Table 12

Life Cycle Costs (Thousands of Dollars) for 2-D Simulator--Constant 1978 Dollars

Cost Category	Cost Element	Inv Cost	Operating Years (15) 1	2	3	4-15	Total	Comments (rf. Appendix D)
Facilities	Replacement cost of space		7.34	7.34	7.34	7.34	110.15	450 sq ft @ $16.32/ft (A)
	Supplemental furnishings	0.5						Estimated (B)
Equipment	6883 simulator, software and courseware	313.90						Contract value deflated 25.5% (N)
	Specification and acquisition management	7.3						Est based on project records (O)
	Support and installation		18.65	4.02	0.0	0.0	22.67	(P)
	Sustaining investment		33.55	47.19	47.19	47.19	694.21	Eng change, maint, records (Q)
	Air conditioning	0.8						
	Operating costs (power)		0.5	0.5	0.5	0.5	7.5	
Instructional Materials	Software revision		17.37	6.57	0.0	0.0	23.94	Full-time E-7 for 16 mos and ¼-time E-3 for 18 mos
	Overhead burden		3.99	1.65	0.0	0.0	5.64	(I)
Personnel	Laboratory instructor		3.73	3.73	3.73	3.73	56.01	.33 yrs of E-5 level (H)
	Overhead burden		1.10	1.10	1.10	1.10	16.52	(I)
Students	Wages (180 students/yr--3 days		15.20	15.20	15.20	15.20	227.89	Equiv to 2.077 yrs (E-3)
	Permanent change in station		0.1	0.1	0.1	0.1	1.5	$23,300 over 23 weeks
	Miscellaneous support costs		8.55	8.55	8.55	8.55	128.38	2.077 yrs @ $79.25/wk (J)
Miscellaneous	Not estimated							No supplies regularly used in 6883 simulation training
TOTALS		322.5	110.08	95.95	83.71	83.71	1,294.41	

Total cost in constant dollars = $1,616,910
Net present value (1978) = $1,060,430

Cost Considerations

A major issue involved in planning this analysis was that the acquistion cost of each simulator system was estimated by project administrators to be higher than is represented by the actual contract cost. Only now can this concern be put into proper perspective, and the question can be asked, "What is the impact on the cost effectiveness ratio if the actual acquisition cost of the simulator is perhaps double the contract price?" In an NPV calculation, the acquisition costs are **not** discounted; thus, the effect of doubling the contract price is not obscured by the discounting process. For example, if the actual cost of the 3-D simulator were doubled, increasing the NPV of the simulator to $2,049,090, the cost per student-hour of instruction would increase only 39 percent ($32/hour), just over one-half of the cost found for the AET. Similarly, if the actual cost of the 2-D simulator were doubled, the NPV would be $1,374,330. The cost per student-hour would increase only 26 percent ($21/hour), still only about one-third the cost found for the AET.

Further, the LSC model developed by the Sim SPO provides additional insight into the relationship between system cost and the Sustaining Investment cost component, which involves test station spares, spare components, and inventory management. This model, used to assess costs of the F-16 simulator, indicated that the initial system acquisition and support costs ($4,919,000 and $4,965,000, respectively) were approximately equal to the 15-year life cycle costs projected for "Sustaining Investment" (Eggemeier, 1979, Table 6). This relationship is important because it reflects the lower cost of spares associated with simulators based on actual cost experience with one-of-a-kind systems. Table 11 presents an estimate for Sustaining Investment over the life cycle of the 6883 3-D simulator. The $941,330 projected is relatively consistent with an estimate of about $1,100,000 for system and support costs of the simulator (double the contract value). Table 12 shows that the projected Sustaining Investment of $694,210 for the 2-D simulator is also consistent with an estimated $640,000 (double the contract value) for system and support costs (see, however, Note Q, Appendix D).

In considering the policy implications of a 2.5 to 1 ratio in the cost effectiveness of the 3-D simulator and a 3.6 to 1 ratio for the 2-D simulator as each is compared to the AET (rf. Table 9), it is important to understand that the estimate for the AET is extremely conservative. It was noted earlier that the costs of the CENPAC computers were not allocated to the AET. Examination of Table 10 shows that no cost element was included in the equipment category that reflects the cost of installation and start-up of the AET. In contrast, installation and start-up costs for the simulators were fully allocated as shown in Tables 11 and 12. Start-up costs for the 3-D simulator were unexpectedly high due to problems encountered in bringing the simulator on-line.

The particular value of the cost comparison lies in the notion that with cost experience data derived from actual trainer alternatives, there is an obvious cost of ownership preference for simulators. Table 9 also shows that the 2-D simulator is somewhat more cost effective than is the 3-D simulator. Although there was a cost savings in developing the specifications for the 2-D simulator due to the existence of the 3-D simulator, the major difference lies in Acquisition Costs and Sustaining Investment costs.

It is important to make comparisons between the two 6883 simulators cautiously, however. First, both devices are prototypes and each was designed to test the feasibility of a different configuration. The cost of the 3-D simulator was most certainly higher due to intent to drive four independent, complete student stations. Elimination of this device specification would have reduced costs considerably since only one computer system would have been needed. Similarly, the part-task trainer approach employed in the design of the 2-D simulator provides an opportunity to train four students simultaneously on different aspects of the 6883 system. To date, however, two of the task trainers have not been consistently employed by instructors in the classroom. Even though student performance, as measured by the tests utilized in the present study, is equivalent on all three training devices, it is not clear that the three trainers provide equivalent training opportunities. It must be noted that the simulators were incorporated into the existing curriculum and no strategies were employed to maximize the training capabilities of either simulator device. Any comparison of the costs between simulators must be based on the assumption of training equivalency to the AET and untapped training device capabilities. Indeed, a study of the unique capabilities of each device is recommended.

Alternative Simulator Applications

A cost effectiveness advantage has been determined for the 6883 simulators under the assumption of equal training effectiveness and identical patterns of trainer use. This determination has particular significance if, in fact, the simulator does provide student training to the same level as achieved on the AET. As already discussed, while no major performance differences were observed, it is not true that the content of training and use patterns were identical for all groups studied.

Figure 12 illustrates the relative training capabilities of alternative training devices. The diagram indicates that the 6883

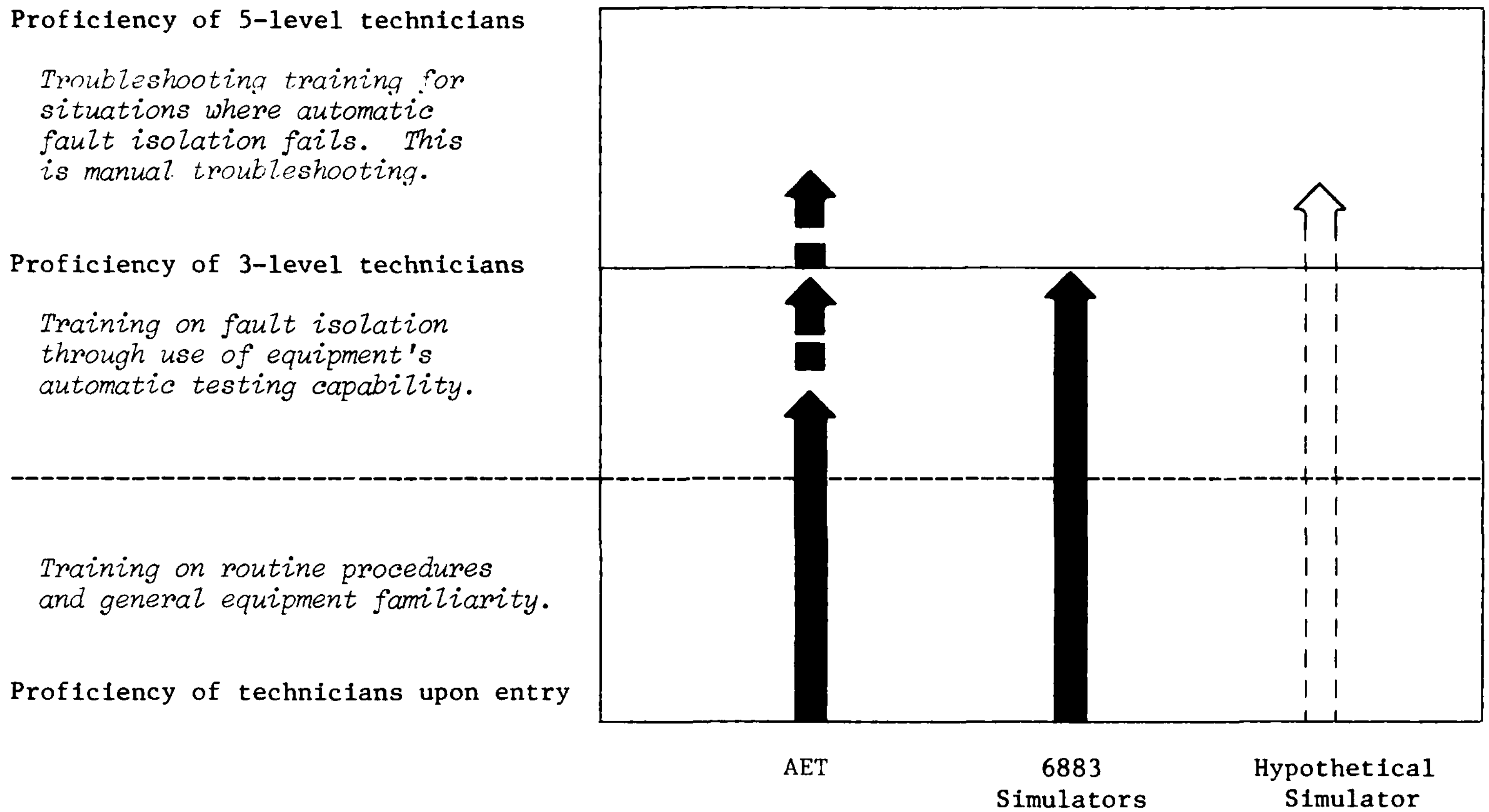

Figure 12. Training capability of equipment in relation to the implicit hierarchy of training objectives.

simulators effectively train procedures and troubleshooting through the automatic testing features of the device to a level consistent with the STS for 3-level personnel. The broken line associated with the AET indicates that the AET trains to the 3-level less well because of the unpredictable nature of equipment performance during each training session (the uniformity of training issue). Although the simulators can train consistently to the 3-level, the AET can do something that cannot be done on the simulators; provide hands-on troubleshooting experience when the fault cannot be corrected through automatic testing procedures. The diagram shows that if the technical school is to provide experience in the manual troubleshooting domain (regardless of how well such requirements are reflected in the STS), then AETs are essential to the training. The two 6883 simulators have not filled this gap in training requirements, although another type of simulator that provides manual troubleshooting training might be developed. With this hierarchy of training objectives in mind, the cost model can be used to examine alternative simulation interventions in maintenance training.

A generic test station simulator. A review of the operating status of the 10 test stations used in F-111 maintenance training suggested (a) that manual troubleshooting experience cannot always be included in practical exercise sessions due to variations in test station availability and (b) that simulators patterned after the 6883 could be useful to deliver training related to procedure and automatic fault isolation. From this assessment, it could be argued that test stations with the best records of operational status are in a real sense now being used as generic test stations--to the extent that experience with procedures and fault isolation must be transferable to other (nonoperating) test stations.

Consider the possibility of using a generic test station simulator as a means of providing training in troubleshooting procedures, assuming that these procedures employ only automatic testing for fault isolation. The pattern of use suggested for this generic simulator is one in which lessons are tailored to meet the full range of F-111 maintenance training needs. That is, the available set of lessons can be used to replace training, in a generic sense, that would have been provided on actual equipment, if it was operative. Used in this way the generic simulator would eliminate the need for AET training on some of the 10 trainers now used in the course.

The cost effectiveness of such a generic simulator can be examined in a straightforward way. A cost savings will not necessarily be realized because the simulator represents an additional equipment cost. In fact, increased training costs will be incurred because the pattern of simulator use suggested does not disturb the life cycle cost estimate for the AETs. In a life cycle cost analysis of the AET training system, however, if the costs associated with student and instructor time are aggregated for all procedural and fault isolation training time lost due to AET status, then it is conceivable that the benefits of the generic simulator will exceed costs. If, for example, as few as 120 hours per student are lost out of approximately 930 hours required for the course (13%), then a simulator would be justified on the basis of its cost/benefit ratio over the 15-year life cycle since increased training effectiveness would offset the higher training costs.

Combined test station/simulator complements. A second approach to using simulators in F-111 maintenance training might be to develop a full complement of simulators, one for each of the AETs. The simulators could be used to train procedures and automatic fault isolation while the AETs would be used to provide equipment familiarity and "manual" troubleshooting experience. The cost effectiveness of this approach cannot be adequately evaluated without more information on the life cycle cost of the current training system and some estimate of how the 6883 AET actually compares with other test stations. Nevertheless, it is unlikely that the combination of reduced training time and AET maintenance costs, together with increased manual troubleshooting skills, would ever result in a cost/benefit ratio less than one. The only major source of cost saving that has the potential of offsetting the simulator investment is to return some of the AETs (and LRUs) to inventory to serve as spares for the flight line. Based on the cost effectiveness ratio found for the 6883 simulators, it would be necessary to return perhaps four or five AETs to F-111 weapon system inventory; training for those blocks of instruction affected would then be accomplished on simulators. Without attempting to generalize further, this option may be worthy of consideration by ATC given the existing AET operational status.

Replace AETs with simulators. This final approach to employing simulators in maintenance training is potentially the most revolutionary one because it suggests new patterns in simulator use and simulator development. It proposes that all of the AETs are returned to inventory and that no attempt be made to train manual troubleshooting skills on actual equipment within the residence phase of F-111 maintenance training. Manual troubleshooting principles could, of course, be taught using advanced simulators. There are many difficulties inherent in this approach, principally because implementation would require changes both in the residential and OJT environments, as well as changes in training policy. For example, the residence training environment would need to be modified to optimize the effectiveness of simulators in teaching procedures and troubleshooting, and the OJT environment would need to be reorganized to insure that transfer of training to the actual equipment occurs.

One outcome of using simulators in this way might be a reduction in course duration--possibly to 16 weeks from 23 weeks--in view of the increased training potential associated with the simulators. It must be recognized that students' manual troubleshooting skills are not well developed in the training environment and that simulation technology could lead to a redefinition of the training process.

Evaluation of this approach to simulator training is not possible at this time because of the broad implications for OJT, Air Force Logistics Command, and ATC. It has been presented here only to show the range of options that might be considered in an attempt to establish cost effective training programs that maximize the potential of simulated equipment.

VI. GENERAL DISCUSSION

The results of this study indicate that (a) both the 3-D and 2-D simulators can provide training at least equivalent to that currently provided by the AET, (b) these simulators can be expected to yield a substantial cost savings when compared to the cost of actual equipment over a 15-year life cycle, (c) the simulators are more reliable and safer training devices than are AETs, and (d) the simulators can provide more consistent and controlled training across classes than can AETs, particularly with regard to troubleshooting training.

This study reflects the use of the simulators in an operational avionics maintenance course with all of its constraints. This section presents a discussion of the potential of simulators when employed to maximize several key elements of instruction in electronics maintenance training. Given the findings of this study, the question of future design and use of simulated devices in the training environment remains. Clearly, the decision to employ simulators is dependent on the training needs identified.

Need for More Reliable Trainers

If a primary concern of the Air Force is the reliability and safety of training equipment, then this study suggests that simulators are the clear choice. Both simulators were more consistently available for training and necessitated fewer training deviations than did AET training. Further, the reliability of the 2-D simulator was far superior to that of the 3-D simulator. Assuming that experience on maintenance test stations is an essential component of training, these high fidelity simulators serve as an excellent alternative to actual equipment. It is important to note, however, that the high level of physical and psychological fidelity incorporated into the 3-D and 2-D[8] simulators in this study makes them largely unsuitable for training in other instructional blocks. Thus, to realize the objectives of increased reliability and safety throughout the training course it would be necessary to develop a simulated version of each test station used for training. It is certainly questionable if such an approach could ultimately be considered cost effective, especially if the simulators are planned to supplement rather than replace AETs.

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[8]It is recognized that some components of the 2-D simulator were designed to be used as generic trainers. However, even these components of the simulator had considerable physical and psychological fidelity with those components of actual test stations.

Need for Less Expensive Training Devices

Clearly, the simulators were less expensive to purchase than actual equipment, and the increased reliability made them less expensive to maintain. Based on the cost data alone, it seems that simulators are the preferred training devices. Unfortunately, the interpretation of this cost information is meaningless without considering the overall context in which simulators will be used. If no actual equipment is available for training, then simulators would be the least expensive training devices to acquire. However, if actual equipment is considered essential to adequate training, and the same number of actual units would be purchased for this purpose regardless of a decision to employ simulators, then the cost of the simulators must be considered an added cost of training, not a replacement cost.

There is some evidence from this study that high fidelity simulators may be considered acceptable replacements for actual equipment by instructors. These devices are clearly among the more expensive simulated trainer options available. However, the potential for replacing actual equipment may easily offset their higher acquisition and maintenance costs, making high fidelity simulators the most cost effective alternative presently available. This is not to say that low fidelity simulators are not viable training devices. Rather, there is a greater need to demonstrate their training effectiveness in order to secure user acceptance.

In the event that the use of simulators would reduce the number of AETs required, the cost savings of simulators must be calculated by comparing additional copies of actual equipment with the cost of an initial simulator. Beyond the first simulator, cost savings could be determined by comparing the cost of additional copies of each device.

To use cost appropriately as a primary factor in decisions concerning future acquisitions, the value of the increased reliability and improved maintainability of the simulators should also be calculated.

Need for More Consistent Training

Closely related to the fact that the simulators are more reliable than actual equipment is the advantage of providing consistent training. Actual equipment, employed as trainers, often introduce digressions into the training regime due to malfunctions. When this equipment becomes inoperative, the instructor must either troubleshoot the test station as a class demonstration or go on to teach other aspects of the course which do not require operational equipment. Should a decision be made to troubleshoot the equipment "on stage," a number of risks are involved. First, the malfunction may be unrelated to the material being taught. Second, the problem may be quite complex and thus require that all the time allocated for student "hands-on" experience be spent observing the instructor. While this experience can be instructional, it often is not, since the instructor's objective becomes repairing the test station rather than teaching troubleshooting skills to the class. Third, using naturally occurring malfunctions as instructional experiences can be both frustrating and embarrassing for an instructor, especially when the problem cannot be resolved in the available class time. Finally, when repairing the test station requires ordering parts, the equipment often remains unavailable for further training for long periods of time.

The simulators, on the other hand, provide a pool of known malfunction problems which can be used to teach various aspects of the equipment in a planned and structured manner. Lesson difficulty can be controlled and the instructor can more easily focus on assessing student troubleshooting skills. In short, the simulators offer an opportunity to integrate carefully appropriate "hands-on" experience into selected informational blocks of instruction.

Need for Increased Student Contact Time

It is accepted that hands-on experience is a better training methodology than is lecture or observation. The AET is limited in its ability to provide all students in a class with sufficient equipment contact time. Further, due to cost and space constraints it is not feasible to acquire multiple operational test stations for training purposes. The simulators, however, do offer an opportunity to provide more than one or two students with hands-on experience simultaneously. The 3-D simulator was configured to allow up to four student stations to be operated from a single instructor station. The 2-D simulator was designed as four stand-alone components and thus is theoretically capable of having four student stations operate simultaneously.

Although these capabilities do exist, no additional student stations have been added to the 3-D simulator. And, while four components of the 2-D simulator are available for training, two of the components have not been used to any significant extent by the instructors. These two components are task specific and do not directly relate to the operation of the 6883 test station. While the generic aspect of these components should be an asset to instruction, according to informal comments by instructors these components are considered too simplistic to be of any real training value. (See also instructor interview results, Chapter V.)

In sum, then, simulators do offer the potential for increasing student contact time with equipment in a cost effective manner. In the case of the 3-D simulator, duplicate student stations could be used. While this approach is somewhat more expensive than the "part-task trainer" approach, it does insure that each student has access to all training protocols (i.e., a complete test station unit). The part-task trainer approach employed by the 2-D simulator is the more cost effective alternative but requires considerable care in the design stage. For example, the division of tasks among components must be made in view of task complexity, training time required on each task, task relevancy to specific instructional blocks, and user acceptance. If these factors are not adequately addressed, it is likely that some system components will not be incorporated effectively into the training regime, and the objective of increasing student contact time with the equipment will not be realized.

Need for Improved Training

If a primary objective of the Air Force is to improve the quality of training delivered, then this study must be considered inconclusive. The present evaluation demonstrates that equivalent 6883 training can be delivered using either a simulator or the AET. It is also reasonable to assume that simulators may offer some training options that are not available with AETs. However, when simulators are operated in the existing training environment and used as an alternative to AETs, their potential training advantages cannot be realized or measured. To properly determine if simulators are more effective trainers than those currently employed, it is necessary to design a study capable of testing one or more of the following hypotheses:

- Given equal training time on a simulator or AET, simulator-trained airmen perform better than AET trained airmen.

- Simulator-trained airmen can be trained to perform at a specified level of competence in less time than airmen trained on the AET.

- Simulators can increase the amount of hands-on training time per student within the same training regime currently used.

The first hypothesis is the one tested in the present study. However, the finding of equivalent training effectiveness cannot be considered conclusive for two reasons. First, the amount of training actually delivered in the 6883 test station block of instruction is very limited when viewed in the context of the total course. Second, due to variations in instructor teaching styles, class sizes, and equipment availability, it is difficult to assume that equal training was provided to all classes. An adequate test of the first hypothesis (given equal training time, simulator trained airmen perform better than AET trained students) would require an increase in the amount of the intervention (i.e., use of the simulator) and careful control of the material presented. Further, the performance test used must be validated in the field and shown to discriminate among various levels of performance or ability, since the relationship between school performance and field performance is unknown (Orlansky & String, 1979).

The second hypothesis (equivalent performance in less time using simulators) has clear implications for cost effectiveness as well as training effectiveness. A carefully designed study which addresses this hypothesis could also investigate the amount of simulator training required to attain specified performance levels.

The third hypothesis is itself based on the assumption that more hands-on training will result in better performance. Given this assumption, support for the hypothesis would demonstrate that simulators are more effective trainers because more airmen can be adequately trained in a specified amount of time. A test of this hypothesis would, of course, require that the option of adding three student stations to the 3-D simulator be exercised. In the case of the 2-D simulator it would be necessary to devise a training protocol which enabled airmen to receive equivalent training by rotating through the four part-task trainers.

Summary

The preceding discussion illustrates that simulators might be expected to fill a variety of needs in the Air Force training environments. They can be more reliable in operation, less expensive to acquire and maintain, more consistent in delivery of training, and allow more student contact time than actual equipment. However, to provide insight effectively into the potential training and cost advantages of simulators over AETs the purpose(s) of introducing simulators into the training environment must be clearly articulated and the role of the simulator must be clearly defined.

As the number of objectives identified for simulator training increases, the evaluation design will become more complex. Thus, the strength of any study conducted will be directly affected by the amount of control afforded evaluators over key instructional variables (e.g., duration of training, content of training, use of equipment). The incorporation of simulators into the existing curricula, without investigating the potential of such devices to go beyond that framework, will always leave the true value of such devices in doubt.

Despite the numerous environmental constraints on the present study, it is clear that simulators do provide a cost effective alternative to AETs. Further, when introduced into existing curricula, simulators provide training equivalent to that obtained by using AETs. This information alone, however, is insufficient to make knowledgeable decisions regarding the use of simulators in electronic maintenance training. To make such decisions, it is essential that more complete, evaluator controlled experimentation, designed according to clearly defined objectives and roles, be undertaken.

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APPENDIX A

DATA COLLECTION INSTRUMENTS

Section A-1	Student Interview
Section A-2	Instructor Interview
Section A-3	Field Technician Survey
Section A-4	Field Supervisor Survey
Section A-5	Results of Student Interview
Section A-6	Results of Instructor Interview
Section A-7	Results of Technician Field Follow-up Survey
Section A-8	Results of Supervisor Field Follow-up Survey

SECTION A-1

STUDENT INTERVIEW

NAME ______________________________

CLASS # ____________________________ DATE ______________________

For each of the questions below, please circle the number that best expresses your opinion on a scale from 1 to 5, where 1 = Not at all, and 5 = Very much. This information is for use by Denver Research Institute only, and will be kept strictly confidential.

	Not at All				Very Much
1. Did you have sufficient training time on the equipment in the 6883 block?	1	2	3	4	5
2. Was your time on the equipment well utilized?	1	2	3	4	5
3. Was there variety in the training on the 6883 equipment?	1	2	3	4	5
4. Do you have a good understanding of how to operate the 6883 equipment?	1	2	3	4	5
5. Do you feel comfortable operating the equipment?	1	2	3	4	5
6. To what extent did 6883 equipment malfunctions hinder your training?	1	2	3	4	5
7. To what extent did 6883 equipment malfunctions benefit your training?	1	2	3	4	5
8. How much of your training time on the 6883 equipment was spent on troubleshooting?	1	2	3	4	5
9. Would you like to have had more troubleshooting experience?	1	2	3	4	5
10. Do you feel that you have had adequate troubleshooting experience for your field assignment?	1	2	3	4	5

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11. Was your training instructor helpful in explaining the 6883 equipment and its use? 1 2 3 4 5

12. Do you have any comments or suggestions about your 6883 training, the equipment used, or DRI tests used?

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SECTION A-2

6883 TRAINING SIMULATOR EVALUATION PROJECT
INSTRUCTOR QUESTIONNAIRE

About how long (in months) have you been an instructor at Lowry AFB?

____

Approximately how many times in the past year have you taught the following blocks?

Converter-Flight Control ______________________________

Other blocks ____________________________________

If you have had field experience with Test Stations, please indicate the length of such experience and whether your experience involved TS operation, TS maintenance, or both ______________________________

____

In the next section, we would like you to rate how much you would agree with each of the following statements on a five (5)-point scale, where 1=disagree strongly and 5=agree strongly.

From your general knowledge of and experience with simulated training, do you feel that simulated training:

	disagree strongly				agree strongly
a. is a good idea	1	2	3	4	5
b. can be more effective than actual equipment	1	2	3	4	5
c. can provide equivalent training with actual equipment	1	2	3	4	5
d. must be highly similar to actual equipment to be useful	1	2	3	4	5
e. can provide adequate training at a cost savings	1	2	3	4	5
f. allows for more complexity of training	1	2	3	4	5
g. is more reliable than actual equipment	1	2	3	4	5
h. teaches safety training better than actual equipment	1	2	3	4	5
i. provides more variety of training than actual equipment	1	2	3	4	5
j. is something you would use as an integral part of your teaching program	1	2	3	4	5
k. can replace actual equipment for	1	2	3	4	5
"hands-on" training	1	2	3	4	5

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Please rate how important you feel each of the following factors is in evaluating a simulated training device:

		unimportant				very important
a.	complexity of the equipment	1	2	3	4	5
b.	capability of the software to meet STS and Air Force objectives	1	2	3	4	5
c.	a lower cost of hardware and operating expenditures compared to actual equipment	1	2	3	4	5
d.	a high degree of similarity of the simulated equipment to the actual equipment	1	2	3	4	5
e.	a savings in the amount of time required for training	1	2	3	4	5
f.	the degree of control of AF personnel over the design of the equipment	1	2	3	4	5
g.	the capability of AF personnel to modify existing or create new lessons for the simulated trainer	1	2	3	4	5
h.	mobility of the equipment, for versatility of use in the classroom	1	2	3	4	5
i.	reliability of performance of the equipment	1	2	3	4	5
j.	ease of maintenance of the equipment	1	2	3	4	5
k.	ability to more closely monitor student performance on the equipment	1	2	3	4	5
l.	variety of material covered in lessons compared to actual equipment	1	2	3	4	5
m.	ease of use for training staff in presenting training materials.	1	2	3	4	5

Please indicate the amount of experience you have had with the 3-D 6383 Training Simulator and the 2-D Training Simulator by checking the appropriate statements below:

For 3-D		For 2-D
______	have heard about it, but never actually used it	______
______	have seen a demonstration of it	______
______	have had limited use of it, as a reference for teaching	______
______	have used it as a regular part of my teaching	______
______	have been involved with writing lessons for use on it	______
______	have been involved with the design and development of the unit	______
______	am a member of the Special Projects staff	______

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page 2 of 4

From your experience with the 3-D 6883 Training Simulator, to what extent would you agree with the following statements:

		disagree strongly				agree strongly
a.	the hardware is too simple for it to be an effective training instrument	1	2	3	4	5
b.	the software (lessons) is well-designed for instruction purposes	1	2	3	4	5
c.	the lessons meet STS and course objectives	1	2	3	4	5
d.	students appear to regard the simulator as an actual Test Station	1	2	3	4	5
e.	the simulator is a better training instrument than the Test Station	1	2	3	4	5
f.	I have used/will use the Honeywell simulated trainer as an integral part of my teaching program	1	2	3	4	5

From your experience with the 2-D 6883 Training Simulator, to what extent would you agree with the following statements:

		disagree strongly				agree strongly
a.	the hardware is too simple for it to be an effective training instrument	1	2	3	4	5
b.	the software (lessons) is well-designed for instruction purposes	1	2	3	4	5
c.	the lessons meet STS and course objectives	1	2	3	4	5
d.	students appear to regard the simulator as an actual Test Station	1	2	3	4	5
e.	the simulator is a better training instrument than the Test Station	1	2	3	4	5
f.	I have used/will use the Burtek simulated trainer as an integral part of my teaching program	1	2	3	4	5

Do you have any additional comments to make regarding the 3-D 6883 Training Simulator, its design and use?

____

____

____

____

____

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Do you have any additional comments to make regarding the 2-D 6883 Training Simulator, its design and use?

____

____

____

____

____

What involvement have you had with the Denver Research Institute's evaluation of the simulated trainers? Please check any applicable statements.

a. ______ proctored the two-hour written test package
b. ______ proctored the practical performance test
c. ______ assisted with the design of the tests
d. ______ was interviewed regarding my teaching methods and course material
e. ______ had no involvement with the DRI evaluation program or development of materials. (If no involvement, skip next section.)

To what extent would you say your involvement with the DRI evaluation has influenced your approach to teaching? Check any appropriate statements.

a. ______ I have become aware of weaknesses in my methods of presenting block material.
b. ______ I have become aware of weaknesses in the course material.
c. ______ I have put more emphasis on certain areas of the course material.
d. ______ I have made changes in the Plan of Instruction (POI) for the block(s) I teach.
e. ______ I have requested changes in the course material for the block(s) I teach.
f. ______ I have not been influenced in my methods of teaching by the the DRI evaluation.
g. ______ I have not seen any reason to alter course materials due to the DRI evaluation.

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SECTION A-3

DRI F-111 TRAINING SIMULATOR EVALUATION PROJECT

AVIONICS TECHNICIAN SELF-RATING FORM

This form is to be used to assess the field performance of the technician named in the box on the right. The information contained on this form will in no way be used to affect the technician's personal or work records, or enhance or impede his/her career. This form becomes the sole property of the Denver Research Institute and HRL under the terms of Contract No. F33615-78-C-0018. This information is being collected to monitor the field performance of those technicians whose training performance was monitored at Lowry AFB during their ATC training assignment.

TO BE COMPLETED BY DRI			
Technician Last Name:			
Personal Security Number:			
Current AFB Assignment:			
Technician Time in Field:			
Training	AET	3-D	2-D
Testing	AET	3-D	2-D

BACKGROUND DATA

1. What is your current Test Station (TS) assignment? ____________________

2. What previous TS assignments have you had since you have been in the field?

   ____

3. During the 6883 Test Station (Converter Flight Control Systems) block of your ATC training at Lowry AFB, were you trained or tested on a Training Simulator?

   (Circle the correct answer):

   a. Yes, trained on Simulator
   b. Yes, tested on Simulator
   c. Yes, trained and tested on Simulator
   d. No, no contact with Simulators
   e. Don't know

On the following pages, we would appreciate your help on this evaluation project. Please answer the questions, to the best of your ability, using the graduated scale. The questions relate to your current working situation and your ATC training at Lowry AFB. Circle the point on the scale which most accurately reflects your situation or opinion.

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CURRENT FIELD ASSIGNMENT	4. How many hours of your eight-hour shift do you spend actually operating the TS, not including observation time?	0-1 2-3 4-5 6-7 8 or more
	5. In operating the TS, how many others work at the TS with you?	none 1 2 3 4 or more
	6. How much individual attention do you receive on the TS during OJT?	none some a lot
	7. How comfortable do you feel operating the TS to which you are currently assigned?	not at all somewhat very much
	8. How adequate are the TOs for trouble-shooting the TS and LRUs?	not at all somewhat very adequate
	9. To what extent does OJT address your training needs usually?	not at all somewhat very much
	10. To what extent does your current field assignment meet your personal/career objectives?	not at all somewhat very much
	11. How relevant was your ATC training to your current field assignment?	not at all somewhat very much
PREVIOUS TRAINING	12. Did your ATC training adequately teach you cabling (of LRUs or adapters)?	not at all somewhat very adequate
	13. Did your ATC training adequately teach you use of common test equipment (PSM-6, etc.)?	not at all somewhat very adequate
	14. How adequate was your ATC trouble-shooting training for preparing you for your current assignment?	not at all somewhat very much
	15. How important was the Converter Flight Control (6883) block of your ATC training to your current assignment?	not at all somewhat very important
	16. To what extent does the training you missed at ATC (training for which you received deviations) affect your ability to operate the TS in your current assignment?	not at all somewhat very much

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PREVIOUS TRAINING

17. Did your ATC training give you adequate training on the use of the patch panel as a trouble-shooting instrument?

not at all — somewhat — very much

18. What aspects of your ATC training do you specifically use in your current field assignment? ______

19. What aspects of your ATC training do you use very little in your current field assignment? ______

20. What would you add to the overall ATC training program at Lowry AFB to better prepare avionics technicians for their field assignments?

______

The remaining questions on this questionnaire are directed to those technicians who received some training or testing on a Training Simulator at Lowry AFB. If you circled responses a, b, or c on question 3 of this questionnaire, please complete the questions to follow. If you circled responses d or e, you have completed the questionnaire and should return this form to your supervisor.

SIMULATOR SPECIFIC

21. To what extent did you enjoy interacting with the Training Simulator during ATC training at Lowry AFB?

not at all — some — very much

22. To what extent did the Training Simulator simulate actual TS operating conditions?

not at all — some — very much

23. Do you feel the Training Simulator was probably a better training instrument than the actual TS for ATC training?

not at all — some — very much

24. Do you think simulated training instruments should be used more frequently during ATC training?

not at all — some — very much

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SIMULATOR SPECIFIC

25. In what areas was the training simulator <u>deficient</u> or bothersome:

- _____ response time
- _____ cabling procedures
- _____ visual similarity to AET
- _____ operational similarity to AET
- _____ LRU operation
- _____ TS troublerhooting capability
- _____ noise level
- _____ sensitivity to dial settings, switch movement or solution selection
- _____ Other ______________________________

26. What did you like or dislike about the Training Simulator as a training instrument? ______________________________

You have completed the questionnaire. Please return this form to your field supervisor. Thank you for your assistance.

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page 4 of 4

SECTION A-4

DRI F-111 AVIONICS TECHNICIAN EVALUATION PROJECT

Supervisor Rating Form

This form is to be used to assess the field performance of the technician named in the box on the right. The information contained on this form will in no way be used to affect the technician's personal or work records, or enhance or impede his/her career status. This form becomes the sole property of DRI and HRL under the terms of Air Force Contract No. F33615-78-C-0018. This information is being collected to monitor the field performance of those technicians whose training performance was monitored at Lowry AFB during their ATC assignment.

TO BE COMPLETED BY DRI			
Technician Last Name: ______			
Personal Security Number: ______			
Current AFB Assignment: ______			
Technician Time in Field: ______			
Training	AET	3-D	2-D
Testing	AET	3-D	2-D

BACKGROUND DATA

1. Name of person rating technician: (include position, e.g., Br. Chief, Shop Chief, etc.)

______

2. Test station technician is currently operating (e.g., 6883, 6886, 6863, etc.):

______

3. Other test station's technician has operated during field duty: ______,

______, ______

4. Has technician been reassigned to duty other than TS operation?

Yes ______ No ______ if yes, what other duty and when?

______

Form SRF-A
page 1 of 3

IN the following section, please rate the technician's task performance on a scale of 1 to 5, where 1 signifies very poor or unsatisfactory performance, 2 signifies poor performance, 3 signifies satisfactory or fair performance, 4 signifies good performance, and 5 signifies very good or excellent performance. NA indicates this task is not applicable in rating the technician at this time.

		Very Poor		Fair		Very Good	
BASIC TRAINING COMPETENCY	5. Practices housekeeping consistent with the safety of personnel and equipment:	1	2	3	4	5	NA
	6. Applies safety precautions when maintaining/operating test station equipment (for example, removes all items of metal such as jewelry, watches, glasses, etc.):	1	2	3	4	5	NA
	7. Uses technical manuals as a source of information for performing maintenance and inspection:	1	2	3	4	5	NA
TEST STATION COMPETENCY	8. Understands purpose and function/operational concepts of test stations in general:	1	2	3	4	5	NA
	9. Understands purpose and function/operational concepts of CENPAC:	1	2	3	4	5	NA
	10. Understands purpose and function of Converter and Flight Controls test station in particular:	1	2	3	4	5	NA
	11. Understands theory/signal flow of particular LRUs associated with test station listed above:	1	2	3	4	5	NA
	12. Operates test station and shop standards to perform diagnostic testing:	1	2	3	4	5	NA
	13. Operates test station and shop standards to troubleshoot malfunctions:	1	2	3	4	5	NA
	14. Operates test station and shop standards to perform maintenance:	1	2	3	4	5	NA
	15. Understands use of patch panel as troubleshooting instrument:	1	2	3	4	5	NA
	16. Performs cabling of LRUs and adapters:	1	2	3	4	5	NA

Form SRF-A
page 2 of 3

ATTITUDE, INITIATIVE & SUPERVISION		Very Poor		Fair		Very Good	
TSC (cont.)	17. Uses common test equipment to perform troubleshooting and maintenance of TS and LRUs:	1	2	3	4	5	NA
	18. Coordinates work with other personnel:	1	2	3	4	5	NA
	19. Resolves technical problems assigned to him/her:	1	2	3	4	5	NA
	20. Works well without significant supervision:	1	2	3	4	5	NA
	21. Shows initiative in troubleshooting tasks:	1	2	3	4	5	NA
	22. Shows good work attitude toward assigned tasks:	1	2	3	4	5	NA
	23. How would you rate this technician compared to other technicians at the same (3,5,7 or 9) level of status?	1	2	3	4	5	NA

Form SRF-A
page 3 of 3

SECTION A-5

STUDENT INTERVIEW RESULTS

Questions	Training Mode		
	AET (n=40)*	3-D (n=53)*	2-D (n=45)*
Did you have sufficient training time on the equipment in the 6883 block?	3.6	3.2	3.5
Was your time on the equipment well utilized?	3.8	3.6	3.6
Was there variety in the training on the 6883 equipment?	3.4	3.3	3.4
Do you have a good understanding of how to operate the 6883 equipment?	3.3	3.2	3.5
Do you feel comfortable operating the equipment?	3.4	3.6	3.6
To what extent did 6883 equipment malfunctions <u>hinder</u> your training?	2.8	2.7	2.8
To what extent did 6883 equipment malfunctions <u>benefit</u> your training?	3.2	3.0	3.3
How much of your training time on the 6883 equipment was spent on troubleshooting?	2.6	2.7	3.0
Would you like to have had more troubleshooting experience?	4.1	4.7	4.4
Do you feel that you have had adequate troubleshooting experience for your field assignment?	2.4	2.1	2.5
Was your training instructor helpful in explaining the 6883 equipment and its use?	4.3	4.3	4.0

*Total=138. Interviews were conducted with all students participating in the program, although the performance results of only 129 of those students could be used in the analyses of performance.

SECTION A-6

INSTRUCTOR INTERVIEW RESULTS

From your general knowledge of an experience with simulated training, do you feel that simulated training:

	n=9
• is a good idea	3.8*
• can be more effective than actual equipment	3.6
• can provide equivalent training with actual equipment	3.0
• must be highly similar to actual equipment to be useful	3.3
• can provide adequate training at a cost savings	4.0
• allows for more complexity of training	3.8
• is more reliable than actual equipment	4.6
• teaches safety training better than actual equipment	3.4
• provides more variety of training than actual equipment	4.2
• is something you would use as an integral part of your teaching program	4.0
• can replace actual equipment for "hands-on" training	2.4

Please rate how important you feel each of the following factors is in evaluating a simulated training device:

	n=9
• complexity of the equipment	3.8
• capability of the software to meet STS and Air Force objectives	4.7
• a lower cost of hardware and operating expenditures compared to actual equipment	3.9

*1=disagree strongly; 5=agree strongly

• a high degree of similarity of the simulated equipment to the actual equipment	3.7
• a savings in the amount of time required for training	3.7
• the degree of control of AF personnel over the design of the equipment	4.4
• the capability of AF personnel to modify existing or create new lessons for the simulated trainer	4.8
• mobility of the equipment, for versatility of use in the classroom	3.3
• reliability of performance of the equipment	4.9
• ease of maintenance of the equipment	4.6
• ability to more closely monitor student performance on the equipment	3.1
• variety of material covered in lessons compared to actual equipment	4.1
• ease of use for training staff in presenting training materials	3.9

From your experience with the 3-D 6883 Training Simulator, to what extent would you agree with the following statements:

	n=9
• the hardware is too simple for it to be an effective training instrument	2.0
• the software (lessons) is well designed for instruction purposes	3.1
• the lessons meet STS and course objectives	3.9
• students appear to regard the simulator as an actual Test Station	3.1
• the simulator is a better training instrument than the Test Station	2.8
• I have used/will use the Honeywell simulated trainer as an integral part of my teaching program	*

---

*No average response is reported for this item due to the ambiguous wording of the question.

From your experience with the 2-D 6883 Training Simulator, to what extent would you agree with the following statements:

	n=9
• the hardware is too simple for it to be an effective training instrument	2.9
• the software (lessons) is well designed for instruction purposes	3.6
• the lessons meet STS and course objectives	3.6
• students appear to regard the simulator as an actual Test Station	2.1
• the simulator is a better training instrument than the Test Station	2.1
• I have used/will use the Burtek simulated trainer as an integral part of my teaching program	--*

To what extent would you say your involvement with the DRI evaluation has influenced your approach to teaching? Check any appropriate statements.

n=9

__3__ I have become aware of weaknesses in my methods of presenting block material.

__4__ I have become aware of weaknesses in the course material.

__4__ I have put more emphasis on certain areas of the course material.

__1__ I have made changes in the Plan of Instruction (POI) for the block(s) I teach.

__4__ I have requested changes in the course material for the block(s) I teach.

__1__ I have not been influenced in my methods of teaching by the DRI evaluation.

__1__ I have not seen any reason to alter course materials due to the DRI evaluation.

---

*Same as previous page.

SECTION A-7

TECHNICIAN FIELD FOLLOW-UP SURVEY RESULTS*

Selected Survey Questions	Training Mode		
	AET	3-D	2-D
How comfortable do you feel operating the TS to which you are currently assigned?	3.8 (n=34)**	4.1 (n=39)	3.8 (n=24)
How relevant was your ATC training to your current field assignment?	3.3 (n=34)	3.0 (n=38)	3.2 (n=24)
Did your ATC training adequately teach you cabling (of LRUs or adapters)?	3.1 (n=34)	2.9 (n=36)	2.6 (n=24)
Did your ATC training adequately teach you use of common test equipment (PSM-6, etc.)?	4.0 (n=34)	3.7 (n=39)	3.6 (n=24)
How adequate was your ATC trouble-shooting training for preparing you for your current assignment?	2.7 (n=34)	2.4 (n=39)	2.7 (n=24)
How important was the Converter/Flight Control (6883) block of your ATC training to your current assignment?	2.1 (n=34)	2.3 (n=39)	2.5 (n=23)
Did your ATC training give you adequate training on the use of the patch panel as a troubleshooting instrument?	3.0 (n=34)	2.9 (n=39)	2.5 (n=23)
To what extent did you enjoy interacting with the Training Simulator during ATC training at Lowry AFB?	NA	3.2 (n=38)	3.5 (n=23)
To what extent did the Training Simulator simulate actual TS operating conditions?	NA	3.3 (n=38)	3.2 (n=23)
Do you feel that Training Simulator was probably a better training instrument than the actual TS for ATC training?	NA	2.2 (n=38)	2.4 (n=23)
Do you think simulated training instruments should be used more frequently during ATC training?	NA	2.8 (n=38)	3.0 (n=23)

*scale: 1=not at all; 5=very much
**not all respondents answered all questions

SECTION A-8

SUPERVISOR FIELD FOLLOW-UP SURVEY RESULTS

Selected Survey Questions	Training Mode		
	AET	3-D	2-D
Applies safety precautions when maintaining/operating test station equipment (for example, removes all items of metal such as jewelry, watches, glasses, etc.):	4.6 (n=34)*	4.7 (n=40)	4.4 (n=24)
Understands purpose and function/operational concepts of test stations in general:	3.9 (n=34)	3.8 (n=41)	3.7 (n=23)
Operates test station and shop standards to perform diagnostic testing:	3.5 (n=27)	3.7 (n=36)	3.6 (n=22)
Operates test station and shop standards to troubleshoot malfunctions:	3.5 (n=29)	3.5 (n=36)	3.4 (n=22)
Operates test station and shop standards to perform maintenance:	3.5 (n=27)	3.6 (n=36)	3.6 (n=21)
Understands use of patch panel as troubleshooting instrument:	2.7 (n=17)	3.0 (n=18)	3.0 (n=15)
Performs cabling of LRUs and adapters:	3.9 (n=27)	4.0 (n=34)	4.0 (n=22)
How would you rate this technician compared to other technicians at the same (3, 5, 7 or 9) level of status?	4.4 (n=34)	4.4 (n=40)	4.2 (n=23)

*not all respondents answered all questions

APPENDIX B

NOTES ON PERFORMANCE DATA

DATA ANALYSIS NOTES

As noted in Chapter V, an analysis of covariance framework was adopted for this study. This approach was expected to satisfy two objectives: increase the precision of assessment and control for any pre-existing differences (bias) among experimental groups. The series of analyses outlined below were developed to select appropriate covariates for these purposes. Because bias was believed to pose the most serious problem for data analysis, this issue was considered first and then supplemented with information designed to increase precision. In brief, the procedure consisted of four steps: (a) the identification of pretraining measures, (b) test for bias in the assignment of students to training groups, (c) selection of indicators of bias, and (d) selection of supplementatl covariates. Each of these steps is described more fully in the following sections.

Pretraining Measures

A total of 17 qualitative and quantitative measures were collected from each student prior to their participation in the 6883 training evaluation. These variables included sex, standardized Air Force aptitude scores, DRI-administered preassessment test scores (rf. Chapter IV), and achievement scores from previous instructional blocks. Tables B-1 through B-4 summarize these variables as a function of eventual student training assignments.

Test for Bias

A primary concern in this study was whether there were any meaningful pre-existing differences among students assigned to the three 6883 training modes. Since such a large number of variables could be considered in this regard, typical univariate methods designed to isolate these differences would capitalize on chance. That is, 17 independent tests of bias might well lead to spurious results. On the other hand, it was believed that a single multivariate analysis including all 17 measures would result in a substantial reduction in the power of the test for bias. Thus, a two-phase approach was adopted to resolve these two problems. First, all 17 variables were included in a stepwise regression to predict assignment to training modes. In the final equation, only four variables were statistically significant ($p < .05$) predictors of training assignment. These were the Delta Concealed Figures test score, the AF Administrative Aptitude measure, and results from the Electronics Fundamentals and Logic instructional block tests. These four variables then were identified as likely indicators of bias in the assignment of students to training.

Table B-1

Males/Females by Training Assignment

Mode of Training	Students		
	Male	Female	Total
AET	30	4	34
3-D Simulator	40	8	48
2-D Simulator	40	6	46
TOTAL	110	18	128

NOTE: One observation was missing and not available from the student's record.

Table B-2

Aptitude Scores as a Function of
6883 Training Assignments

Aptitude Test		Training Mode		
		AET	3-D Simulator	2-D Simulator
General	N	30	47	46
	$\bar{X}$	82.0	78.8	75.2
	σ	11.6	16.1	12.6
Mechanical	N	30	47	46
	$\bar{X}$	80.7	76.0	75.0
	σ	15.4	17.5	16.2
Administrative	N	28	44	46
	$\bar{X}$	76.8	68.6	70.7
	σ	12.9	18.8	15.3
Electronics	N	28	44	46
	$\bar{X}$	85.7	84.8	83.2
	σ	6.3	8.3	7.5
AFQT	N	28	43	45
	$\bar{X}$	77.6	76.8	75.7
	σ	11.2	14.7	13.0

Table B-3

Preassessment Scores as a Function of 6883 Training Assignments

Preassessment Measure		Training Mode: AET	3-D Simulator	2-D Simulator
Delta Concealed Figures	N	35	46	46
	$\overline{X}$	5.60	4.59	5.85
	σ	3.28	3.21	2.53
Delta Reading Vocabulary	N	35	46	46
	$\overline{X}$	26.5	27.5	24.3
	σ	7.1	7.2	6.5
Ship Destination	N	35	45	46
	$\overline{X}$	35.5	34.9	36.8
	σ	9.0	9.4	7.5

Table B-4

Prior Block Achievement Scores as a Function of 6883 Training Assignments

Instructional Block		Training Mode: AET	3-D Simulator	2-D Simulator
Fundamentals of Electronics	N	35	47	46
	$\bar{X}$	89.8	87.0	87.4
	σ	6.6	6.2	6.0
Introduction to AGE Principles	N	35	48	46
	$\bar{X}$	89.6	88.6	85.5
	σ	8.1	8.6	9.0
CENPAC	N	35	48	46
	$\bar{X}$	83.1	83.4	84.0
	σ	9.7	10.7	9.0
DATAC	N	35	48	46
	$\bar{X}$	84.2	86.6	84.0
	σ	9.7	7.9	10.7
Data Logic Analysis	N	35	48	46
	$\bar{X}$	85.0	87.1	85.7
	σ	11.6	9.9	9.0
CATE	N	35	48	46
	$\bar{X}$	88.6	85.7	86.0
	σ	8.7	10.0	8.3
Navigation and Weapons	N	35	48	46
	$\bar{X}$	85.6	85.8	86.8
	σ	10.9	9.9	9.3
Electronic Systems	N	35	48	46
	$\bar{X}$	88.4	86.7	85.8
	σ	11.6	9.5	10.9

The second phase involved submitting these variables to a multivariate analysis of variance (MANOVA) to determine whether or not there were any pre-existing differences among the three training groups. This analysis revealed a significant bias effect (F (8,218) = 2.63, p = .01).

Selection of Bias Indicators

While the previous analysis suggested that some bias existed in experimental groups and which variables might be used to reflect that bias, a further step was necessary in order to finalize the selection of bias indicators. The question addressed at this point was: Are all four of these indicators necessary to appropriately reflect bias? An extension of the MANOVA procedure used in the previous section was used to answer this question. First, the dependent variable in the MANOVA with the greatest univariate F-ratio as a bias indicator was now considered as a covariate, thus removing its contribution from the main effect. Then, a multivariate analysis of covariance (MANCOVA) was performed. Because the main effect was still significant, another variable was shifted from the dependent variable list to the covariate list as before. After three variables had been treated as covariates in this manner, the main effect of the remaining variable (Administrative Aptitude) was not found to be significant. The other three variables (Delta Concealed Figures, Electronics Fundamentals, Logic) were then selected as final indicators of bias.

Supplemental Covariates

The gain in precision from the use of a covariance adjustment depends upon the degree of correlation between the covariate and the dependent variable. Thus, while bias indicators had been identified, a second objective was to select covariates that were strongly related to each measure of performance or indicator of subsequent job performance. Although similar principles were applied to each type of dependent variable, the analysis results have been presented in the following sections.

Performance measures. Three performance measures were recorded in this experiment: Hands-On Troubleshooting Test scores, Paper-and-Pencil Troubleshooting Test scores, and Converter/Flight Control (6883) block test scores. For each variable, covariates were selected by using a regression analysis in which all three indicators of bias were entered first into the regression equation. For example, an equation was computed for predicting Hands-On Test scores with Delta Concealed Figures, Electronics Fundamentals, and Logic scores entered first in a stepwise fashion. Additional variables, from the original set of 17 measures, were then added to the equation until a total of five variables were included. From these five, only those found to be significant predictors of performance were selected as final covariates for use in the ANCOVAs reported in Chapter V. It was possible that indicators of bias were not strongly related to Hands-On Test results and these were not included in subsequent analyses. In this example, only the Delta Concealed Figures variable was retained as a covariate from the bias indicators and two additional variables, General Aptitude Test scores and CATE instructional block scores, were selected to supplement the covariance approach.

Table B-5 shows the final covariates selected for use in each ANCOVA involving performance measures. In each case, indicators of bias were selected as covariates only if the relationship between the indicator and the dependent variable was sufficiently strong.

Job-related measures. This procedure to select covariates was also applied to two types of job related measures: the Projected Job Proficiency Test and subsequent block test results. The outcome of this procedure has also been included in Table B-5. A multivariate approach to subsequent block scores would have been preferred; however, such an analysis was not possible since students were not all assigned to the same instructional track.

Table B-5

List of Covariates Selected for Dependent Variables Used in This Study

Dependent Variable	Covariates Selected
Performance Measures	
Hands-On Troubleshooting	Delta Concealed Figures General Aptitude CATE Block
Paper-and-Pencil Troubleshooting	Electronics Fundamentals Electronic Aptitude Mechanical Aptitude
Converter/Flight Control Block	Administrative Aptitude Electronics Fundamentals CENPAC Block
Job-Related Measures	
Project Job Proficiency	Electronics Fundamentals DATAC Block Ship Destination
Computer Test Station Block	Electronics Fundamentals Sex Navigation Block
Attitude and Rate TS Block	CENPAC Block Ship Destination
Displays TS Block	Electronics Fundamentals Logic Block AGE Principles Block
Video TS Block	Navigation Block Electronics System
Radar-Transmitter Modulator TS Block	Delta Concealed Figures CATE Block CENPAC Block

APPENDIX C

NOISE LEVEL ANALYSIS NOTES

NOISE LEVEL ANALYSIS NOTES

Since it was not possible to remove the background noise (central air conditioning) from the training environments to obtain equipment-only noise level readings, calculations were made to subtract the background-only noise from the overall equipment and background noise levels. The standard logarithmic decibel scale formula used was:

$$SPL_{total} = SPL_1 + SPL_2$$

$$= 10 \log_{10} \left(10^{\frac{SPL_1}{10}} + 10^{\frac{SPL_2}{10}} \right)$$

Where SPL = sound pressure level or dBa

SPL_1 = equipment-only

SPL_2 = background noise

Working with the overall dBa readings and the background readings, equipment-only readings were obtained for each of the distance measurements for each of the training devices. For example, if:

SPL_{total} = 73.9 dBa

$SPL_{background}$ = 65 dBa

then:

$$SPL_{equipment\text{-}only} = 10 \log_{10} \frac{73.9}{10} - 10 \log_{10} \frac{65}{10}$$

$$= 10 \log_{10} (10^{7.39} - 10^{6.5})$$

$$= 10 \log_{10} (10^{1.39} - 10^{.5})\ 10^6$$

$$= 10 \log (24.5 - 3.16)\ 10^6$$

$$= 10\ (7.32)$$

$$= 73.2 \text{ dBa}$$

Table C-1 shows the relationship between addition or subtraction of noise levels. For example, if the difference between two given noise levels is 5 dBa, the total level of both noises combined is only

1.2 dBa higher than the larger of the two levels. Thus, in the example above, removing 65 dBa from an overall level of 73.9 dBa results in a difference of only .7 dBa for the equipment-only noise level.

Table C-1

Addition and Subtraction of Sound Pressure Levels
(Rank in Order from High to Low)

Excess in dB	Add to higher
0	3.0
1	2.6
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
9	0.6
10	0.4

The results of the noise level comparisons indicated, based on Table C-2, that instructor-student communication will be greatly influenced by the distance between them and will require various vocal intensities for effective communication.

Table C-2

Maximum Speech Interference Levels (in dBa) for Reliable Communication at Various Distances and Vocal Efforts

	Vocal Effort			
Distance (feet)	Normal	Raised	Loud	Shout
0.5	76	82	88	94
1	70	76	82	88
2	64	70	76	82
4	58	64	70	76
8	52	58	64	70
16	46	52	58	64
32	40	46	52	68

APPENDIX D

NOTES ON COST ANALYSIS

NOTES ON COST ANALYSIS

A. Replacement cost of space estimate was taken from the F-16 cost study (Table 8).* The estimate of $16.27/square foot represents the amount the building inventory at Lowry AFB would be reduced at the end of 1977 if a training facility were scrapped.

B. The supplemental furnishings estimate for laboratory space was based on the approximate cost of items used in the laboratories.

C. The acquisition cost estimates for the AET were guided by the estimates made for the F-16 trainer. The acquisition management cost for the 36th unit of production was .82 percent of the unit cost (Table 5).* Our estimate of .75 percent was more conservative because the technology of the F-111 is not as sophisticated as that of the F-16, even though the F-111 station represents the eleventh unit produced.

D. Sustaining Investment estimate was guided by the estimates made for the F-16 trainer which, in turn, were derived from Air Force Logistic Command experience. The Sustaining Investment required was found to be approximately 12.5 percent of the unit cost each year (Table 5).* Our estimate of $195,400 per year was 10 percent of the unit cost of the test station. The unit cost was inflated 79.5 percent to reflect wholesale commodity price changes from 1972 to 1978 (source: Economic Indicators, U.S. Government Printing Office, Washington, DC, 1979). No estimate was made for logistics costs associated with the spares inventory.

E. The personnel cost of maintenance on the 6883 AET was based on records of actual hours spent on repair from 1/1/79 to 7/30/79. (BLIS Report, Logistics Branch, Lowry AFB). The time spent during this period was assumed to be proportional to the yearly maintenance requirement. The grade level for costing purposes was estimated to be E-5 for the estimated 672 hours/year. A BLIS Report for this

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*The F-16 study refers to a draft technical report, "Life Cycle Cost Estimation of Simulated vs. Actual Equipment Maintenance Training for the F-16 Avionics Intermediate Shop." This report was prepared by the AFHRL Advanced Systems Division, Wright-Patterson AFB, Ohio (T. Eggemeier, March 1979). The report (unpaged) was a substantial resource for cost data appropriate to training at Lowry AFB, and the equipment cost model employed provided substantial insight for estimates related to acquisition management costs and the logistical costs including Sustaining Investment for weapons subsystems.

figure was not included in the table because when salary changes and adjustments to 1978 dollars are made, the result is not substantially different from the original estimate of $3,620/year. 1980 showed a total of 641.6 hours were spent on repair of the same equipment.

F. Since no student materials are required for 6883 laboratory work, this cost was assumed to be zero.

G. Updating laboratory exercises was assumed to require one-sixth of an instructor year. Updating represents such activities as installing "faults" in the AET to facilitate "manual" troubleshooting exercises.

H. Instructor contact time for practical training on the 6883 test station was estimated at 540 hours per year (based on approximately 6 hours a day of actual student-instructor classroom interaction; three days of instruction per class; 30 classes per year). The estimate was increased to one-third of a year (693 hours) to more accurately account for the fact that one full-time instructor would actually be assigned to teach 6883 theory and practice.

I. The overhead or burden associated with maintaining each involved instructor for a specified time period was estimated by apportioning the salary of the course manager (GS-12), the course supervisor (E-7), and the instructor's supervisor (E-6) to management and administration of 24 instructors for the same time period. (Salary schedule source: AFR-173-10, 1978).

J. Miscellaneous student support costs for students in residence at Lowry AFB were estimated at $79.25 per student per week; 540 student days represent 2.077 years, assuming 260 working days per year (2.077 x 52 x $79.25 = $8,550).

K. Estimate based on AFHRL project records: 1056.5 hours (military) and 2357.5 hours (civilian) prior to installation of the simulator; cost factors for military and civilian personnel for AFHRL were assumed to be $12/hour and $14/hour over the 18-month period.

L. Estimate based on AFHRL project records: 1482 hours (military) and 2374 hours (civilian) for support and installation. Same cost factors as used for (K), above.

M. Sustaining Investment for the 6883 3-D simulator was based on the cost of maintenance contracts in force from June 1978 until November 1979, and a contract being negotiated for 1980-1981.

N. 2-D contract value was $393,900. Deflated 25.5 percent to adjust December 1979 dollars to 1978 dollars for capital equipment (Source: Economic Indicators, U.S. Government Printing Office, Washington, DC, 1980).

O. Estimate for specification and acquisition management computed as one-quarter time for one year (520 hours civilian) at $14/hour. It should be noted that this time investment is substantially less than that for the 3-D simulator since specifications already developed formed a large part of the specifications for the 2-D simulator.

P. Estimate for support and installation of: 430 hours (military) figured at $12/hour was provided by the AFHRL 2-D project monitors. Additional time reported by the ATC special projects staff include: 6.75 months of E-7; 6.75 of E-5; and 4 months of E-3.

Q. Sustaining Investment for the 6883 2-D simulator was initially based on the cost of maintenance contracts in force from March - September 1981 ($40,600). This amount was deflated by 21 percent ($33,550) to reflect to 1978 wage levels. For subsequent years the 7-month contract was used to project a yearly maintenance cost of $57,100. This amount was also deflated by 21 percent ($47,190) to reflect 1978 wage levels. Note, however, that figures for actual expenditures provided by the AFHRL 2-D project monitor differed substantially from these estimates. Based on actual contract expenditures, sustaining cost figures were estimated to be only $5,200 in the investment year and $2,000 for subsequent years.