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AIR FORCE

HUMAN RESOURCES

MAINTENANCE TRAINING SYSTEM:
6883 CONVERTER/FLIGHT CONTROL TEST STATION

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The Technical Training Division of the Air Force Human Resources Laboratory is investigating the application of simulation technology to maintenance training. The primary objectives of the project entitled "6883 Converter/Flight Control Test Station Maintenance Training System (MTS)" were (a) design, build, test, and install a prototype, simulator-based system to train test station operators and maintainers, and (b) provide the Air Force with a research tool for evaluating the practicality, cost- and training-effectiveness of simulated equipment for intermediate-level maintenance training. This report describes the design features and operation of the system. The 6883 MTS should provide much needed simulator effectiveness data. The technical achievements of the program are applicable to the procurement of future simulation-based training systems.

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SUMMARY

PROBLEM

Given today's sophisticated weapon systems, automatic test equipment (ATE) is a necessity in intermediate-level (I-level) maintenance shops. However, training personnel to operate and maintain the equipment has posed problems for training. In particular, use of operational ATE as training devices has the following shortcomings: (a) low availability of the equipment due primarily to low maintenance priority, (b) limited "hands-on" practice due to safety considerations, and (c) lack of trouble-shooting practice due to inability to insert a controlled set of equipment faults.

As a potential solution to these problems, the Technical Training Division of the Air Force Human Resources Laboratory is investigating the application of simulation technology to maintenance training. The primary objectives of the project entitled "6883 Converter/Flight Control Test Station Maintenance Training System" (6883 MTS), were: a) design, build, test, and install a prototype, simulator-based system to train test station operators and maintainers; and b) provide the Air Force with a research tool for evaluating the practicality, cost- and training-effectiveness of simulated equipment for I-level maintenance training.

APPROACH

The general approach adopted for developing the 6883 MTS included: a) formation of a multidisciplinary team, including training specialists, engineers, human factors psychologists, and system programmers; b) extensive involvement of Air Force instructors and subject matter experts; c) development, through a "front-end" analysis, of a detailed functional specification for use in engineering design; d) incorporation of distributed processing architecture for expansion capability; and e) use of modular software to maximize general application.

The first step in the design of the 6883 MTS was a front-end analysis; this was conducted to determine the simulation, training, and functional features to be incorporated in the training system. The essential steps involved were to determine the a) trainer mission, b) training objectives, c) training requirements and instructional features, and d) simulation requirements. The resultant functional specification provided a statement of system performance capabilities against which a detailed engineering design was developed.

Psychological rather than engineering fidelity was the key to developing a training system where the student performs (simulated) maintenance tasks monitored in an automated, closed-loop. The 6883 MTS evaluates the action and returns appropriate feedback and/or results.

Cost benefit was realized by systematically producing only those aspects of the operational job environment necessary for positive transfer of training from simulated to operational equipment.

RESULTS

Several alternative detailed designs could have satisfied the functional specification. The selected approach emphasized use of proven, off-the-shelf hardware and software elements wherever possible, development of cost-effective simulation techniques, and development of modular software to maximize general application.

Specifically, the approach was organized around a six-element system concept: 1) simulated hardware, 2) student console, 3) instructor console, 4) computer hardware, 5) system software, and 6) instructional features. At the core of this system concept is the instructional program, which emphasizes prompt feedback, flexibility in sequencing lesson material, student performance output log, and self-pacing capabilities, among other techniques incorporated to maximize efficient transfer of training.

CONCLUSIONS

The feasibility of a simulation-based, intermediate-level maintenance training system was realized when the Air Force project engineer on 23 June 1978 accepted a prototype system. Successful operation of the 6883 MTS should provide much needed data on simulator training effectiveness. The technology achievements represented by the 6883 MTS program are applicable to the procurement of future simulation-based training systems.

ACKNOWLEDGEMENTS

In a program as large as this one, there are many people to thank. Without the expert, subject-matter of MSGTs David Kassing and Lester Kilpatrick, both of the Air Training Command, the 6883 Maintenance Training System would still be just an idea. The leadership and guidance of Maj Dennis Downing, of the Technical Training Division, Air Force Human Resources Laboratory, and of Drs. James Gardner, Lorenz Schrenk, and Lee Miller, all of Honeywell, Inc., were vital to the program's success. Engineering design and production were the result of hard work by Carl Graf, Michael Lyons, Lewis Ritchie, Peter Dukich, and Kurt Graffunder of Honeywell, Inc. Finally, we are indebted to the timely assistance and dedication of Honeywell employees Mark Kartarik and Shirley Mosher.

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SECTION I

INTRODUCTION

OBJECTIVES

This study is part of a larger program of the Technical Training Division of the Air Force Human Resources Laboratory (AFHRL/TT) to evaluate the potential application of simulation technology to maintenance training for the Air Training Command (ATC). The primary objectives of this project were to a) design, fabricate, and test a simulator for the 6883 Converter/Flight Controls Test Station; b) establish a research test bed for investigating the major variables that impact the design of training equipment for intermediate-level maintenance (I-level, or "shop" maintenance); and c) evaluate the effectiveness of simulation technology for training Air Force technicians for a wide variety of checkout and troubleshooting procedures involved in the operation and maintenance of the 6883 Converter/Flight Controls Test Station.

BACKGROUND

The 6883 Converter/Flight Controls Test Station is part of the aerospace ground equipment comprising the F-111D avionics I-level maintenance shop. Two courses related to I-level maintenance of F-111D avionics are taught at Lowry Technical Training Center (LTTC), Lowry Air Force Base, Colorado. Course 3ABR32631D-002 trains individuals to operate the various test stations in the F-111D shop, including the 6883, and to test, inspect, troubleshoot, and repair faulty line replaceable units (LRUs) from the aircraft. Trainees also learn to perform limited tests of the test station to ensure that it is functioning properly. Course 3ABR32630B-000/001/002 trains individuals to perform detailed tests; to inspect, troubleshoot, and repair malfunctioning test stations; and to perform periodic preventative maintenance on the test stations.

Both courses are organized as multiple blocks of theory and hands-on application of theory taught in a prescribed sequence. A few blocks are related specifically to operation and maintenance of the 6883 test station. Other blocks include 10 to 12 weeks of basic electronics, generalized automatic test equipment theory, and instruction on specific operation or maintenance procedures dealing with F-111D avionics test stations other than the 6883.

Currently, I-level maintenance training is conducted on actual equipment. This approach has obvious value in that procurement is easily accomplished (no special training equipment design is required) and the realism provided has significant motivational value for both instructors and students. However, several major problems have arisen that limit the training value of actual equipment which generally is not designed to be used in a training environment. One primary disadvantage of using actual equipment for I-level training is the cost of acquisition and maintenance. Acquisition costs of such hardware often exceed several million dollars. Another disadvantage of using actual equipment comes from the nature of most I-level jobs: In order to train a student to become familiar with a specific procedure, the actual equipment must be run through highly procedural, time-consuming exercises that require little operator participation.

Other shortcomings of the actual equipment approach to training are:

- Extremely low reliability of the actual equipment, resulting in low availability of the device for training purposes,
- High risk of severe injury to trainees,
- High risk of costly, student-induced damage to the equipment,
- Limited range of equipment faults and emergency conditions to which trainees can be exposed, and
- Feedback delivery which necessitates instructor's continued presence.

These problems limit hands-on procedures training and troubleshooting practice. The 6883 Maintenance Training System (MTS) was designed to alleviate the above problems by providing a much less costly, and more forgiving, training environment that emphasizes job tasks requiring manual assistance and troubleshooting knowledge.

The 6883 MTS incorporates a simulated 6883 test station (6883 simulator), three simulated LRUs, and simulation of four associated interface adapters. The system is designed to support the 6883-related portions of courses 3ABR32631D-002 and 3ABR32630B-000/001-002 without affecting the content or format of remaining course blocks. It is designed to permit hands-on practice of the checkout, troubleshooting, and repair procedures performed by level-3 apprentices in the maintenance of the 6883 test station and associated LRUs. It is not intended to replace classroom instruction on the theory of operating the 6883 test station or related LRUs.

DESIGN APPROACH

The design of the 6883 MTS was based on a job task analysis conducted by AFHRL/TT with the assistance of ATC instructors who were familiar with the operation and maintenance of the 6883 test station. This task analysis was subsequently incorporated into an AFHRL/TT-developed functional specification for the 6883 MTS (Miller and Gardner, 1975). A detailed description of the task analysis and methodology for developing the functional specification is contained in that report. The above functional specification was used as the primary contractual document for the work described in this report.

The general approach adopted for the development of the 6883 MTS included: a) formation of a multidisciplinary team, including training specialists, engineers, human factors psychologists, and system programmers; b) extensive involvement of Air Force instructors and subject matter experts; c) refinement, through a "front-end" analysis, of the functional specification for use in engineering design; d) incorporation of distributed processing architecture for expansion capability; and e) use of modular software to maximize general application.

This approach was organized around a six-element system concept: 1) simulated hardware, 2) student console, 3) instructor console 4) computer hardware, 5) system software, and 6) instructional features.

The contractor's front-end analysis was based on the AFHRL/TT functional specification and was conducted to determine in detail the simulation, training, and functional features to be incorporated into the training system. The essential steps involved were to determine the a) trainer mission, b) training objectives, c) training requirements and instructional features, and d) simulation requirements. The resultant performance specification stated system requirements and capabilities against which a detailed engineering design was developed. Several alternative detailed designs could have satisfied the performance specification. The selected approach emphasized use of proven, off-the-shelf hardware and software elements wherever possible, development of cost-effective simulation techniques, and development of modular software to promote flexibility. The system and its elements are described in Section II.

SECTION II

SYSTEM DESIGN AND PRODUCTION

SYSTEM DESIGN FEATURES AND DESCRIPTION

This section provides a general description of the basic system configuration and its elements and a detailed discussion of the design features of each element. Also included is a training scenario for a typical lesson.

System Architecture

Configuration--The 6883 MTS is a dual-computer system which drives simulations of the 6883 test station and associated LRUs through appropriate interface hardware. Student actions on the simulated equipment are sensed by the computer through the same interfaces. Appropriate student guidance and feedback are provided by a CRT/keyboard and random access slide projector. Student performance is recorded by the computer system and is output to the instructor's CRT/keyboard in summarized form. These same performance data can be output to a cassette tape and line printer for recordkeeping. A training system hardware block diagram is shown in Figure 1.

More specifically, the 6883 MTS computer system architecture is a multiprocessor, distributed system providing expansion capabilities. One Honeywell-716 computer (H716) functions as a classroom controller, operating

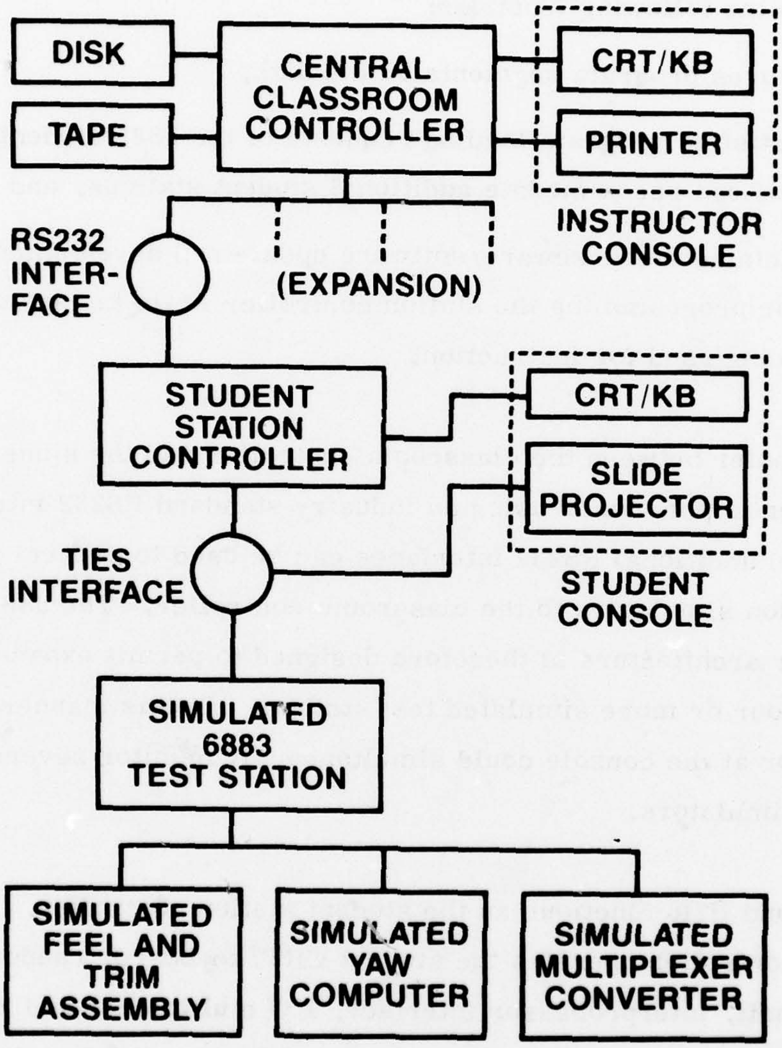


Figure 1. 6883 Maintenance Training System Hardware Block Diagram

the instructor station CRT/keyboard, high-speed printer, disk, tape drives, and interprocessor interface. In addition, the classroom controller performs the following functions:

- Stores program segments on the disk,
- Satisfies program loading requests of the 6883 student station and can accommodate additional student stations, and
- Acts as a courseware/software update and development device for programming the station controller while the system is not being used for instruction.

Data transfer between the classroom controller and the student station controller is performed using an industry standard RS232 interface. Three (or more) additional RS232 interfaces can be used to connect additional test station simulators to the classroom controller. The 6883 system computer architecture is therefore designed to permit expansion to a total of four or more simulated test stations. In this manner, a single instructor at the console could simultaneously monitor several different station simulators.

The second H716 functions as the student station controller. The student station controller operates the student CRT/keyboard, random access display unit, interprocessor interface, I/O multiplexer and test station, and LRU simulated hardware. A trainer interface electronics system (TIES) provides an input/output multiplexing capability for sensing student actions and for driving displays and indicators on the simulated equipment. A random-access MAST slide projector is computer-controlled through this multiplexer. The student station controller is designed to provide the following functions:

- Operate all digital/analog conversion hardware,
- Drive all displays/indicators on the simulation hardware,
- Process all student actions at both the CRT/keyboard and the simulation hardware,
- Receive additional program data segments from the classroom controller,
- Deliver all automated instruction,
- Provide student performance data to the classroom controller for display to the instructor, and
- Cooperate with the system controller to perform simulator self-diagnostic procedures.

Trainer Layout--The 6883 MTS installation layout is designed to be efficient and easy to operate (Figure 2).

The instructor console, consisting of the instructor CRT/keyboard and high-speed line printer, is located at the center left of the room. This arrangement affords the instructor an unobstructed line-of-sight to the student console and 6883 simulator at the rear of the room. Easy access to the classroom and the student station controller is possible with this arrangement, thus facilitating disk changes, tape changes, and H716 front-panel entries. Location of the instructor console in close proximity to the computer systems reduces the required cable lengths and decreases the probability of electromagnetic interference.

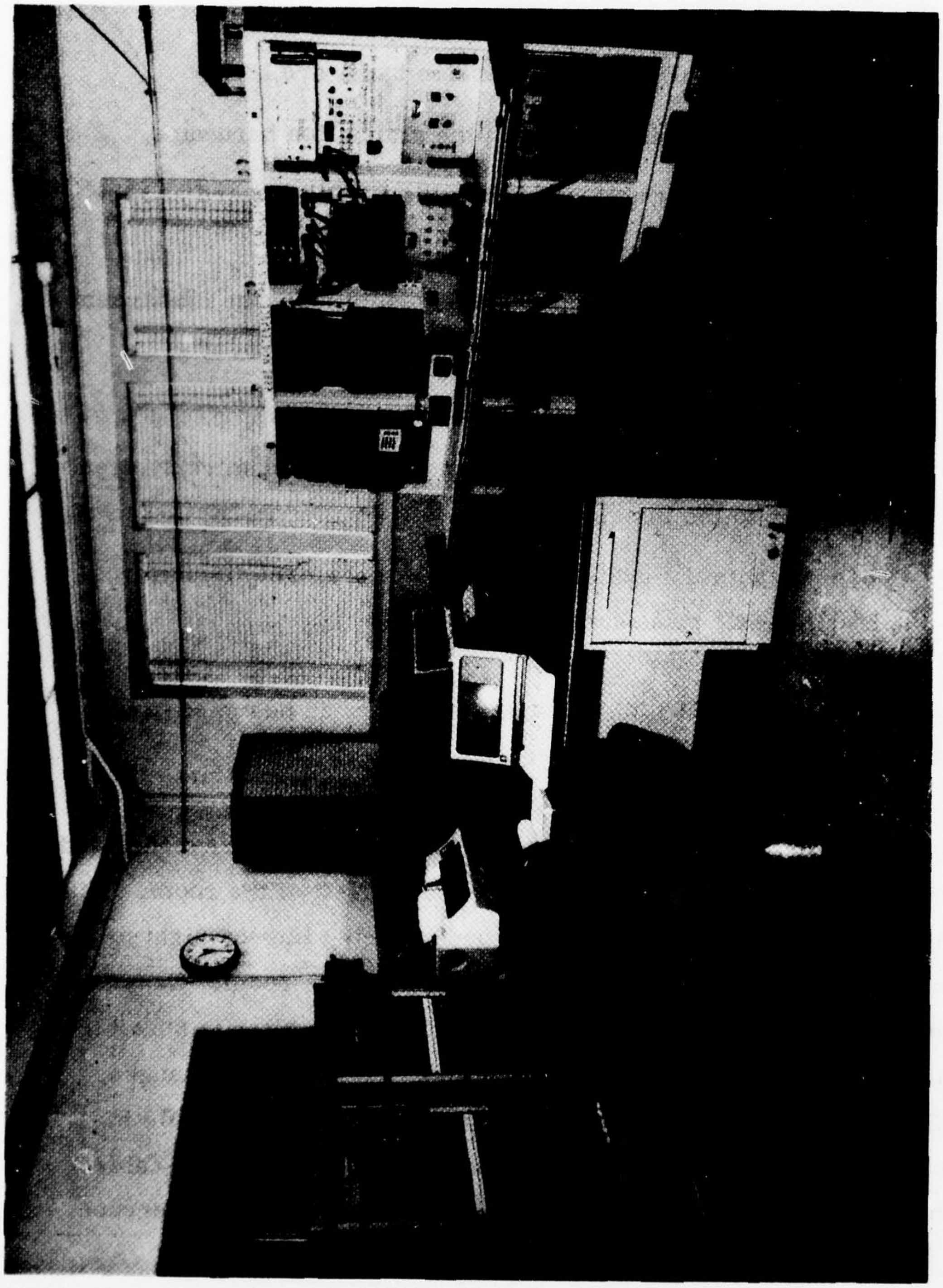


Figure 2. 6883 Maintenance Training System Installation Layout

The student console, consisting of a CRT/keyboard and slide projector, is located in the left rear quadrant of the room adjacent to the 6883 simulator. Most student actions at the student console will take place at the CRT/keyboard, while most actions on the 6883 simulator will involve the data transfer and control (DATAC) panel in the far left equipment bay. The room layout positions the student CRT/keyboard and DATAC panel in close proximity to simplify trainer operation. The arrangement permits cabling to the student console along the left wall, thus reducing cable lengths and possible electromagnetic interference.

The 6883 simulator is located in the right rear of the room away from the wall to allow rear access to all equipment bays. This arrangement minimizes cable walk-overs and requires minimum cable lengths to the student station controller. All simulated LRUs will rest on the front shelf of the 6883 simulator and will interface with the 6883 simulator through a simulated adapter unit mounted on the simulated patch panel in the third bay of the test station.

The student station controller and the classroom controller are located in the left front quadrant of the room. They are positioned away from the wall to permit rear access to electronic equipment.

System Elements

Instructor Station--The instructor station consists of a classroom controller and an instructor console as shown in Figure 3. The heart of the classroom controller is a standard, commercially available H716

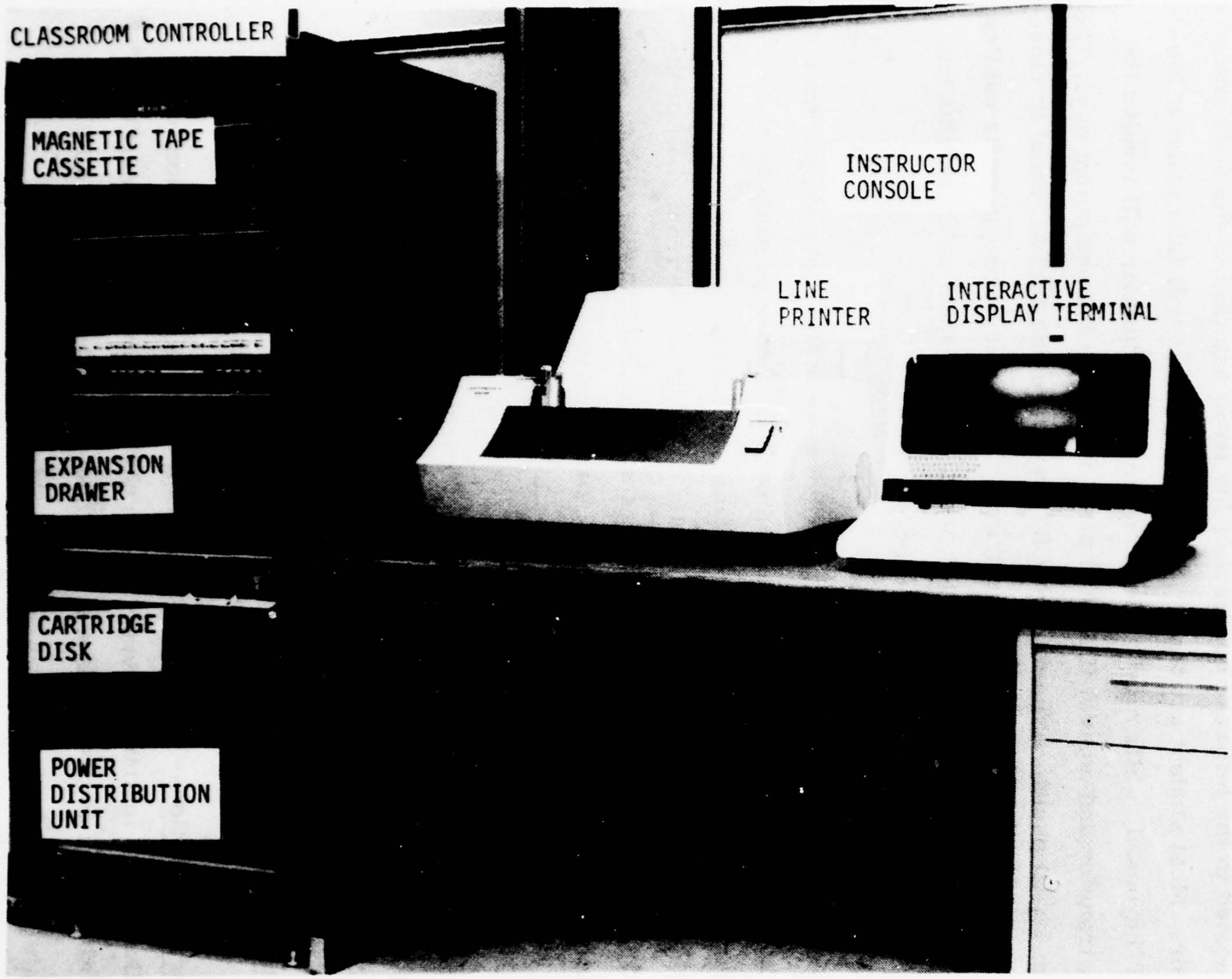


Figure 3. Instructor Station Module

minicomputer with 32,768 words of internal memory. Other off-the-shelf equipment used within the classroom controller are a Honeywell 9030 expansion drawer, a Honeywell 5400 cassette magnetic tape with the 5401 expansion feature (two cassette tape operation), a Honeywell 4768 dual cartridge disk, and a Honeywell 9400 power distribution unit.

The instructor console consists of a Hewlett-Packard Model (HP) 2640B interactive display terminal (CRT), a Centronics Model 102AL line printer, and a desk and chair.

Instructor Station Controller--The H716 as applied to the 6883 MTS meets or exceeds all system requirements and is intended to provide the user with the capability to modify software easily as training requirements evolve.

Characteristics of the H716 computer include:

- Flexible minicomputer architecture,
- Comprehensive instruction repertoire which includes hardware multiply/divide capability,
- High-speed, banked core memory which is power-fail protected,
- Optional memory expansion to 100 percent more than the memory size specified for the 6883 simulation,
- Flexible I/O structure which is compatible with the industry standard RS232 interface,
- Honeywell standard disk and magnetic tape cassette peripheral element controllers, and

- Console control panel for direct manual interaction with the computer system to update system software or to examine the contents of any memory address or program accessible register.

Line Printer--The Centronics 102AL is a medium-speed, serial printer which meets trainer system requirements for speed (330 characters/second) and quiet operation (Figure 4). It is designed for printing programs (both software and courseware) and student performance data and for diagnostic maintenance support.

A speed of 125 lines per minute is achieved with bidirectional printing. Two print heads, operating in unison, print 132 character lines with each head traveling only one-half the width of the paper. Both heads then print in reverse on the next line resulting in no carriage return. The line printed is visible at all times for immediate reading. The 102AL contains an automatic motor control on/off feature which eliminates standby noise and uses unique timing characteristics to control printing and associated operations. The printer is automatically powered up when data are received, with no delay time required before printing is initiated.

CRT Display/Keyboard--The CRT shown in Figure 5 is designed to meet the needs of the 6883 instructor. The application requires the display of textual materials with an alphanumeric keyboard capability to permit trainer system interactions. Specific display system requirements include:

- Alphanumerics and graphics display capability
- Individual pages modifiable without disturbing the remaining pages

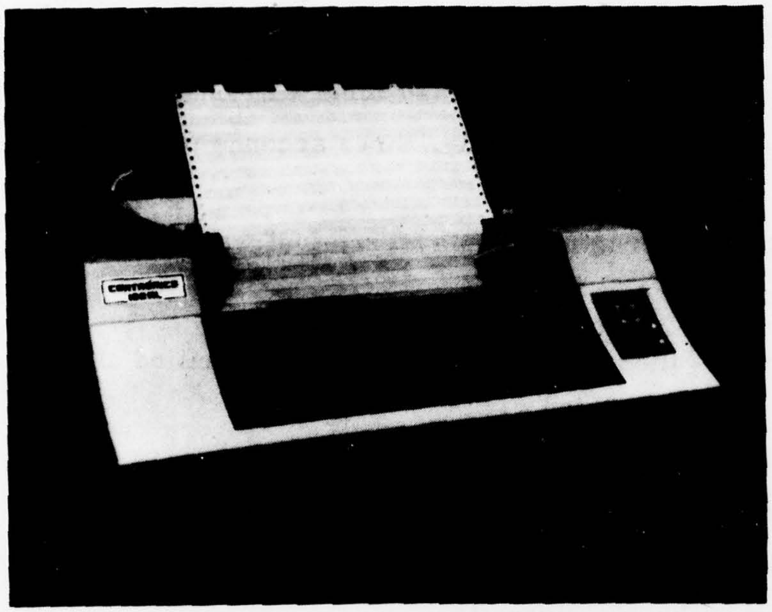


Figure 4. Line Printer

Figure 5. Interactive Display Terminal/Instructor Station

- Control by instructor and/or computer input
- Each new complete page (20 lines x 64 characters) is available in five seconds; typically, three seconds per full page is realized.

The HP 2640 B Interactive Display Terminal was selected for the 6883 MTS because it

- Exceeds the minimum requirements specified above
- Meets all existing training needs
- Is compatible with the RS232 equivalent interface
- Is a standard off-the-shelf commercially available unit which is used without modification
- Provides growth capability for evolving trainer system requirements

The display's alphanumeric keyboard with auxiliary function keys allows manual entries of commands and data to the simulator. It is used for a) trainer system initialization and control, b) development and maintenance of training software/courseware, and c) control of system diagnostic and fault isolation procedures.

Student Station--In the 6883 MTS, the student station is the center of training activities. The student station elements--student station controller, the student console (CRT/keyboard and slide projector), the simulated 6883 test station, and simulated LRUs--interact to provide the student with computer-generated responses which mimic operational equipment analog (meters) and discrete (lamp and digital panel meter) signal responses. Messages displayed on the interactive CRT terminal supplement simulated operational equipment responses and guide the student through the correct interpretation of technical material. Figure 6 shows the student station controller, interactive display terminal, and slide projection system.

Student Station Controller--The student station controller Figure 6, consists of a TIE system which provides the interface medium for both the simulated 6883 test station and the random-access slide projector. In addition, the controller cabinet contains a H716 mainframe with 16,384 words of internal memory, a Honeywell 9030 expansion drawer, a Honeywell 9400 power distribution unit, and an emergency power control panel. The student station computer mainframe and expansion drawer equipment are identical to the classroom controller computer equipment except for mainframe memory capacity and the interface card complement within the expansion drawer.

The TIE System--The TIE system controls the communications traffic between the computer and the simulation hardware. The trainer control adapter (TCA) card, which is connected to the computer I/O bus, is the direct interface to the computer. When a computer direction or data command is initiated, it is received by the TCA card, analyzed, and passed on to the multiplexer for execution. In some cases, instructions received by the TCA call for execution of a routine in the computer memory; in these instances, the TCA generates a call to the computer for the appropriate routine. TCA instructions to the multiplexer are routed through the interface card with the appropriate address for either the TCO (output to the simulator) or TCI (input from

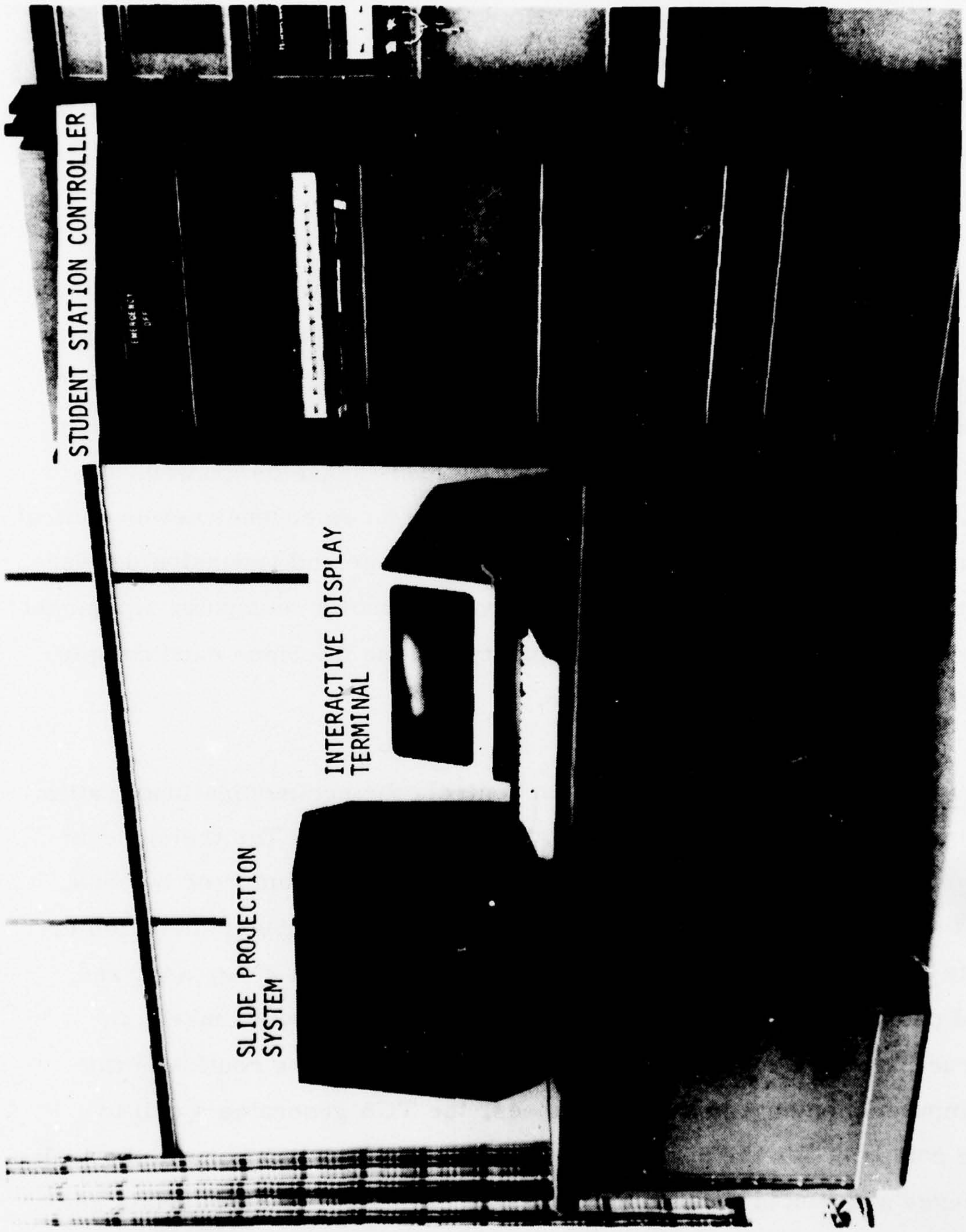


Figure 6. Student Station Module

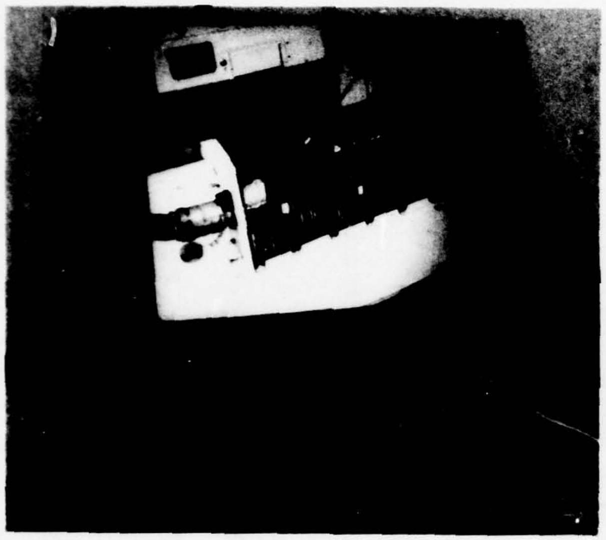
the simulator) cards. An output results in a change of simulator hardware condition (such as a display being turned on) which requires a specific student action or which must be considered by the student in going through the procedure. An input results in latches being set to capture the student action and make it available for relay back to the computer for evaluation. The TIE system is fully described in the TCE System Operations Manual.

Student Console--The student console includes an interactive terminal, a random-access slide projector, and a desk and chair.

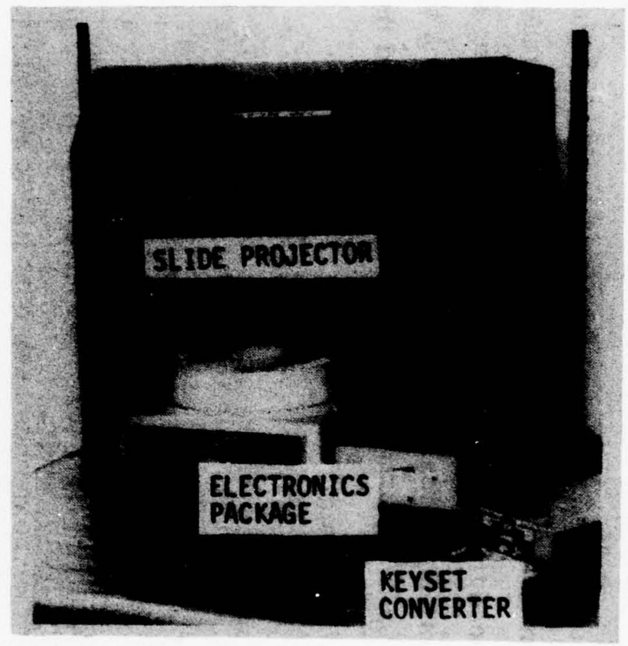
CRT Display/Keyboard--The HP 2640B was chosen for this application as well. However, the keyboard has been modified to restrict the functions available to the student. A complete description of special functions available will be found in Section III.

Random-Access Slide Projector--A commercially available, standard, off-the-shelf MAST Model 137-S Random-Access Slide Projection System was chosen for the 6883 MTS application (Figure 7). The 137-S is under control of the student station controller and consists of four hardware elements:

1. MAST Model 137-RPM Rear Projection Module
2. MAST Model 137-S Unit A (Kodak, Ektagraphic) Slide Projector with 3-inch f/3.5 lens
3. MAST Model 137-S Unit B Electronics Package
4. MAST Model 140-6L1 Keyset Converter



a. Front view



b. Rear view

Figure 7. Slide Projection System

The key features of the MAST system are as follows.

- The rear projection module (Figure 7a) is located at the student console. It is completely self-contained unit which provides an 18-inch wide by 12-inch image display to the trainee. An optics system projects the slide projector image onto the trainee display screen. Optics consist of three front-surface mirrors with silicon-monoxide overcoating, coupled with a non-glare, front-surface Polacoat lenscreen in a light-tight cabinet. Standard 35mm horizontal slides fill the screen with no cutoff using a 3-inch lens.

  The module completely houses both the slide projector and electronic package. (See Figure 7b.)

- The MAST 137-S Slide Projector, via associated logic electronics, retrieves, precisely positions, automatically focuses, and projects any one of eighty-one, 2-inch by 2-inch slides. The average elapsed time between request and projection is less than two seconds. The projector includes a servo-mechanism for transporting slides between the carousel card tray and the projector.

  All control functions, except the "high-low" lamp switch and "tray release" (located on the electronics package), are under computer control. Control functions are projector "on-off", a single slide "forward" and "reverse", and direct access to any one of the 81 slide positions.

This MAST 137-S Slide Projection System satisfies all 6883 MTS requirements. Under program control, the system response time and slide storage capacity permits use as an adjunct performance aid training device.

Simulation Hardware--The 6883 simulation hardware consists of:

- 6883 test station
- Three LRUs
  - Feel and trim assembly
  - Multiplexer converter set
  - Flight control yaw computer
- Four adapters
  - Three station/ LRU interfaces
  - One station self-test
- All cabling and hoses

Test Station--The 6883 test station simulation shown in Figure 8 consists of 28 metal photo panels, three pullout drawers, and an unmodified GFE oscilloscope mounted in four salvage GFE equipment racks. These racks are mounted on fork lift support bases, two racks per base. The level of simulation for each panel varies. Certain panels are complete visual simulation, while others contain many functionally simulated components. Figure 9 provides a panel-by-panel breakdown of the level of simulation fidelity on the test station.

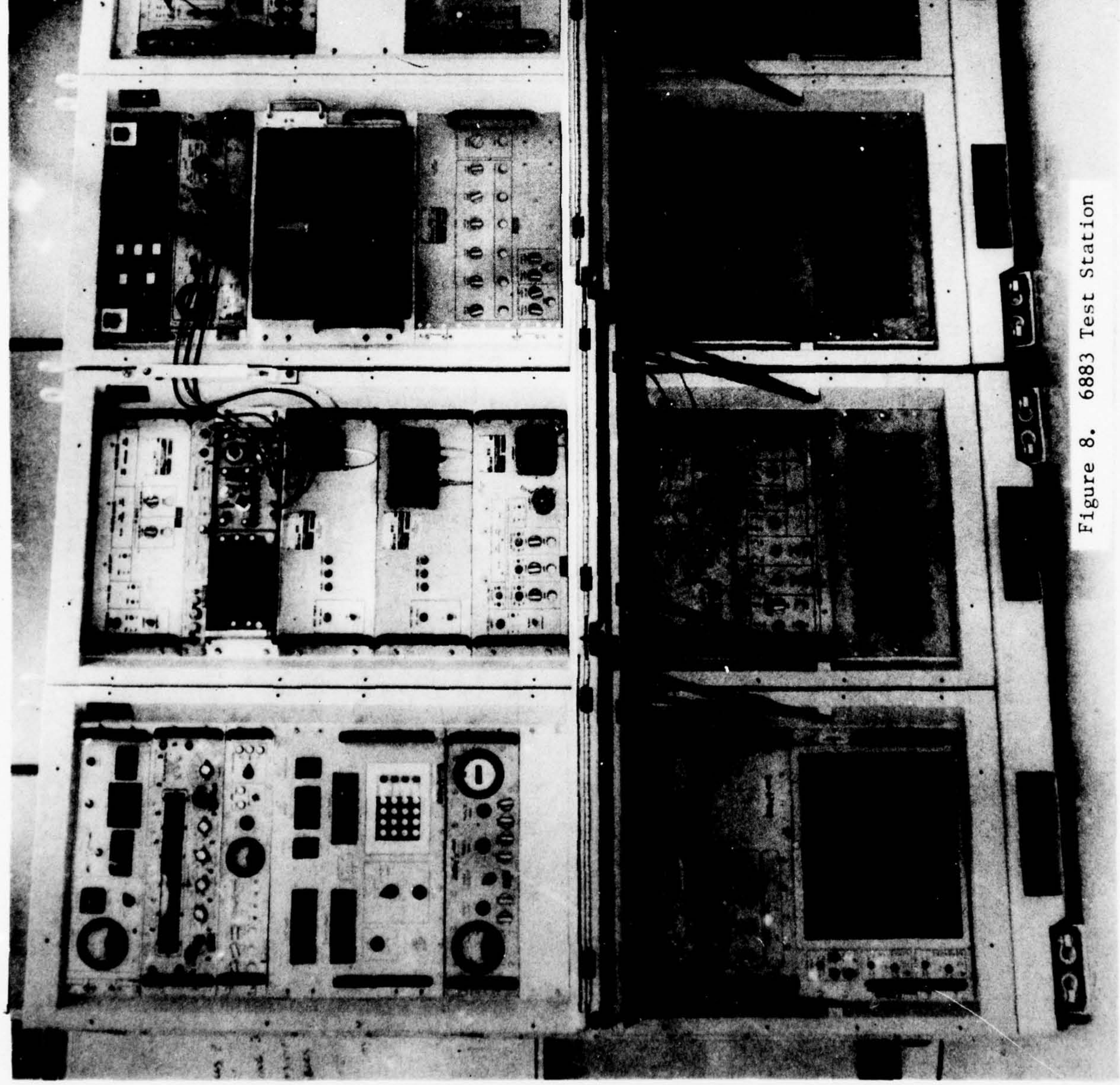


Figure 8. 6883 Test Station

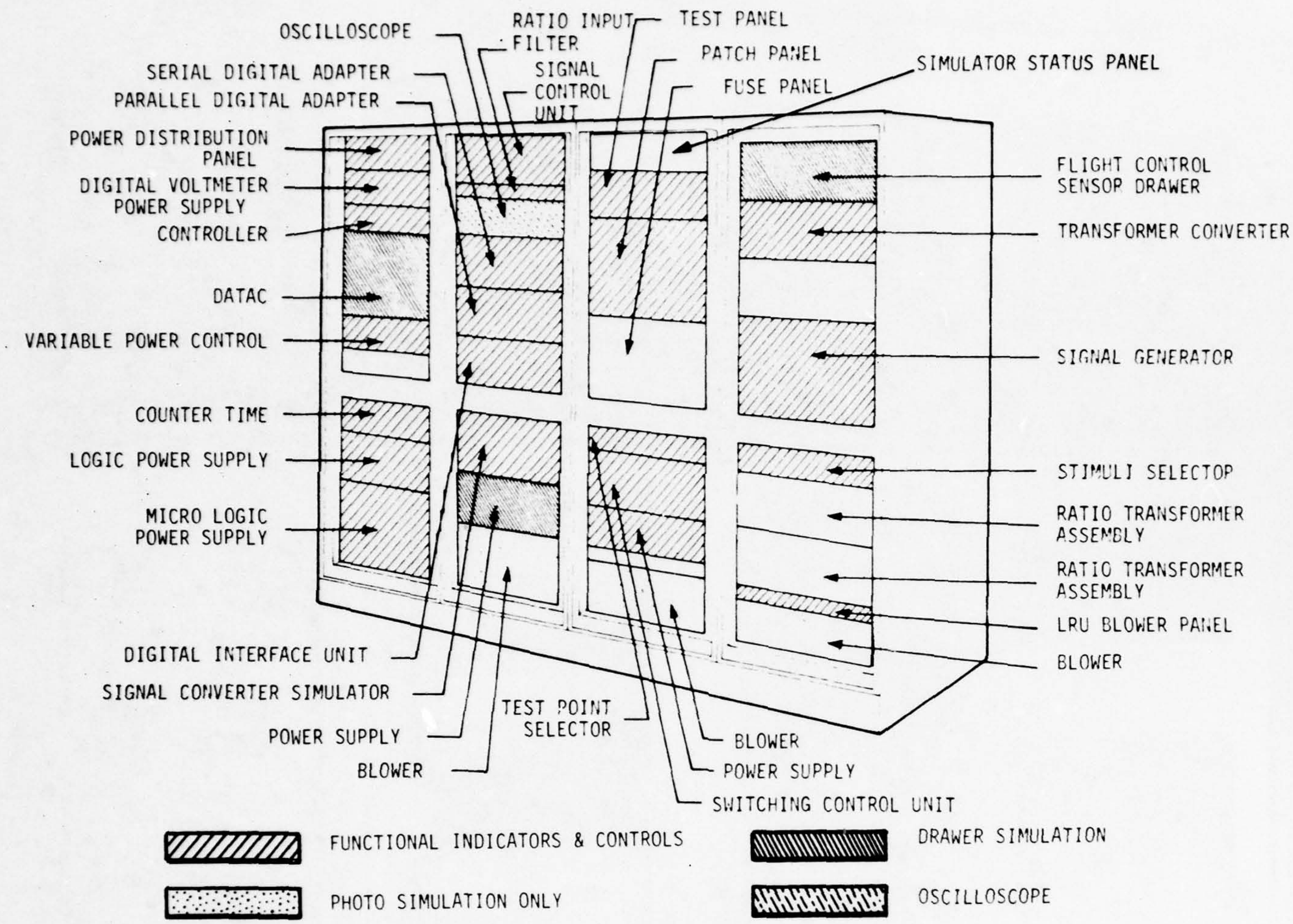


Figure 9. Panel-by-Panel Summary of Simulation Levels Across Test Station

The simulation of the three pullout drawers is described below.

- The DATAC drawer (A1A3) simulation uses a GFE salvage drawer assembly of the approximate size of the operational drawer. A metal photo of the DATAC front panel is attached to the drawer. The drawer extends in the same manner as the operational unit. The upper interior portion of the DATAC drawer contains a simulation of the hinged card frame assembly and register bit display indicators and controls. The card frame assembly contains 56 simulated printed circuit (PC) cards. There are 13 different simulated PC card configurations. Four of the cards are removable and their removal and replacement is sensed by the computer. The other 52 PC cards in the DATAC are removable but not sensed. They are constructed in the same manner as the removable cards except that only those components which are near the exposed edge of the card are represented.

  The hinged card frame assembly containing the PC cards hinges to a locked position. Metal photos are used to simulate visually the internal PC test points on the rear of the upper and lower card frame assemblies. The DATAC simulation also consists of functional simulation; bit display lights; address lights; test sequence lights; subaddress lights; TSW1, TSW2, TSW3, TP1, TP2, TP3; sequence interrupt switch; and manual modify switch.

- The power supply (A2A9) drawer simulation employs a salvage GFE drawer assembly of the approximate size of the operational unit. A metal photo of the front panel is attached to the drawer. The drawer extends in the same manner as the operational unit.

The interior simulation of the drawer consists of metal photos of the power supplies, three functionally simulated circuit breakers, and four salvage GFE relay drivers (modified for use in the simulation). Three voltage adjustments are functionally simulated.

- The flight control sensor (FCS) drawer (A4A1) simulation employs a salvage GFE drawer assembly of the approximate size of the operational unit. The front panel of this drawer is simulated using a metal photo. The drawer extends in the same manner as the operational drawer. The interior simulation contains six printed circuit cards accessible through a hinged cover.

  All six are removable, and removal and replacement are sensed by the computer. These cards are constructed by attaching both real and simulated components to the photoboard laminate. The amplifier gain adjustment potentiometers on cards A4, A6, A7, and A10 are functional and sensed by the computer. The remainder of the interior is visually simulated with metal photos.

LRU Simulations--In general, the exterior of each of the three LRUs is simulated in appearance, using an appropriate GFE-salvaged LRU chassis as the basis for fabrication. These chassis, stripped of operational equipment, and the corresponding covers are painted to match the test station simulator.

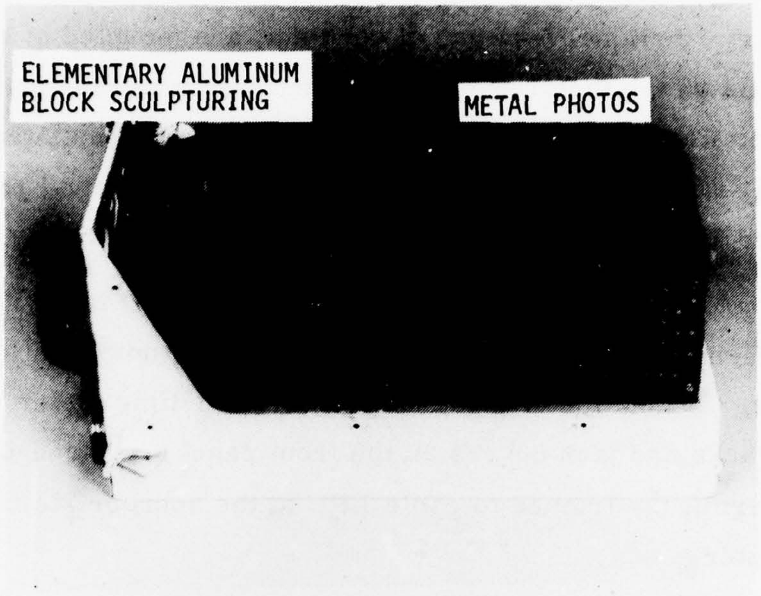
The front panels are represented using metal photos, reflecting identification plates, elapsed time meters, and jack and switch identifiers.

The necessary functional features of each unit are mounted at the appropriate positions on the metal photos; the functional features of specific LRUs are detailed in the following paragraphs. Each simulated LRU is appropriately weighted to resemble the corresponding actual equipment. All simulated LRUs have handles in the appropriate locations.

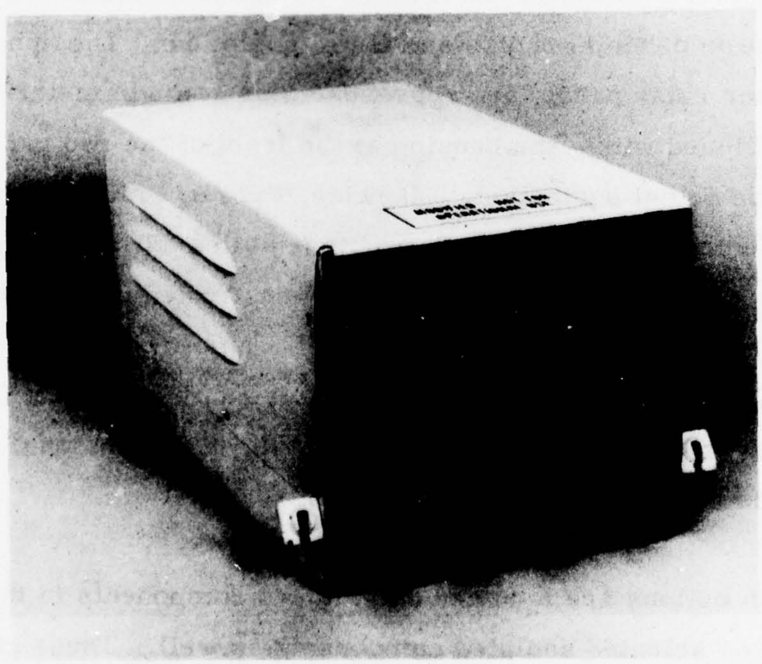
- The front panel of the feel and trim assembly (Figure 10a) is represented by a metal photo, reflecting the unit identification plate, all jack identifiers, and the elapsed-time meter. The six jacks and jack covers on the front panel are three-dimensional to permit the trainee to cable LRU to the appropriate interface adapter.

  The interior of the LRU (Figure 10b) is simulated through a combination of metal photos and metal sculpture. The upper and center relay panels are represented by a single metal photo, positioned within the housing at the level of the two panel boards in the actual equipment. Likewise, the right side of the assembly, including adverse yaw network assemblies TB1, TB2, and TB3, is represented as an appropriately positioned metal photo. Signal converters EM1, EM2, and EM3, amplifiers AQ10, AQ9, AQ4, AQ3, AQ1, AQ2 and the spoiler rectifier assembly are appropriately sized and positioned, three-dimensional sculptures made from aluminum blocks.

  Push buttons are mounted on selected components in the photos and on selected sculpted components as well. These buttons are used by the trainee to indicate the location of components that



a. Interior



b. Exterior

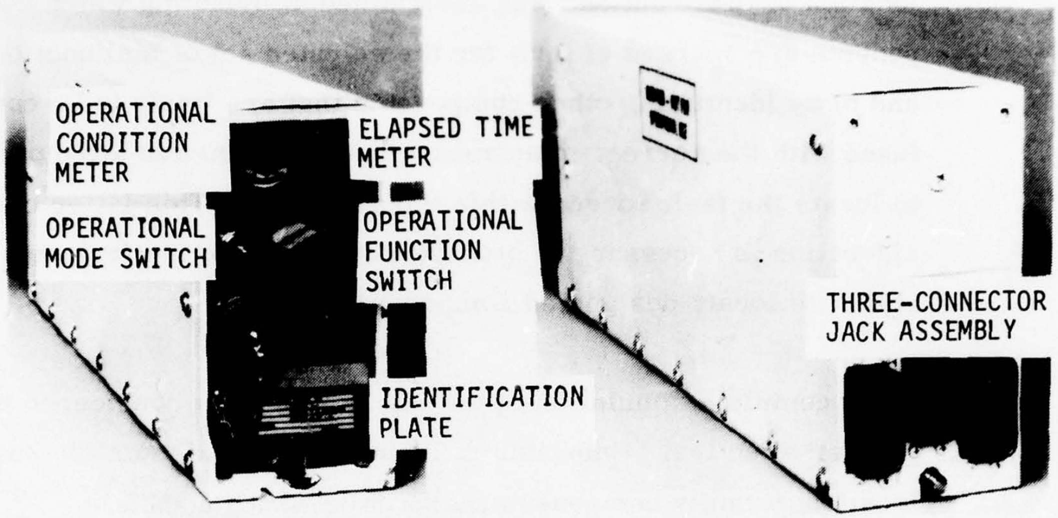
Figure 10. Simulated Feel and Trim Assembly

are identified as fault sources during malfunction lessons. The location of these buttons was determined a) by noting which components are sources of fault for the selected set of malfunctions and b) by identifying other components that are likely to be confused with the correct component when the trainee is attempting to locate the fault source within the assembly. This latter consideration is necessary to provide a valid test of the trainee's ability to locate designated components.

More complete simulation of the interior was not considered to be cost-effective. Emphasis in training is on the isolation and location of faulty components and not on disassembly of the unit.

- The front panel of the flight control yaw computer is represented by a metal photo reflecting the unit identification plate, elapsed-time meter, jack identification, and all switch positions (Figure 11a). The MODE and FUNCTION switches and the CONDITION meter are GFE-salvaged components that are appropriately positioned on the metal photo and are sensed and driven to simulate self-test checks. The single jack on the front panel and the three-connector jack assembly (Figure 11b) on the back panel permit execution of all prescribed cabling procedures.

  The interior of the yaw computer is not simulated. The current operator training course does not require the trainee to perform repairs on the yaw, only to isolate faults to their sources. The removal and replacement of the yaw computer modules is easily learned on the job; therefore, simulation was not merited within the 6883 MTS.

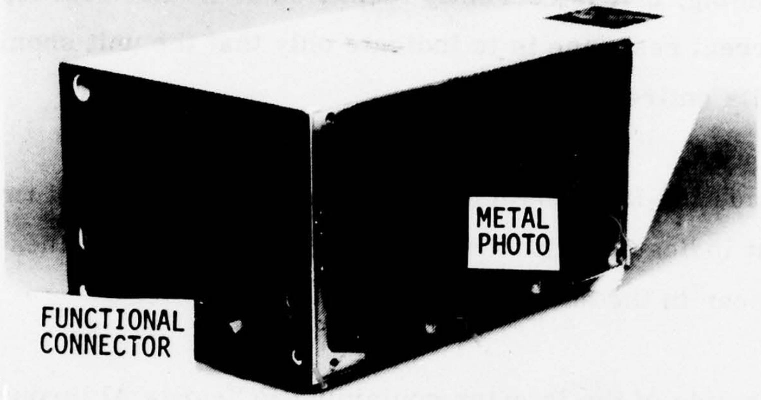


a. Front b. Rear

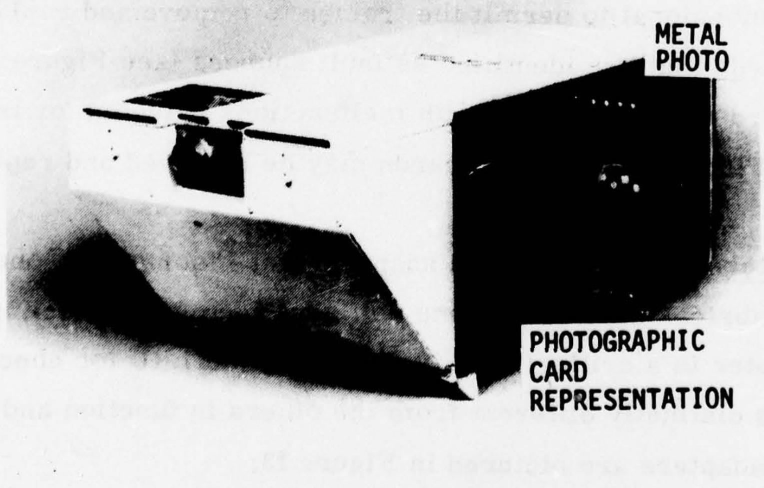
Figure 11. Simulated Flight Control Yaw Computer

- The multiplexer converter (MUX) is simulated separately from the holding fixture. The connector end panel is represented by a metal photo; one functional connector has been added to that metal photo at an appropriate position. The holding fixture has the corresponding simulated functional connector also added to a metal photo of all remaining connectors.

The power supply subassembly (the rear quarter of the MUX; see Figure 12) is a GFE-salvaged unit. It contains two jacks that are necessary for the trainee to execute prescribed cabling procedures in order to connect the MUX unit to the holding fixture.



a. Connector panel view



b. Power supply subassembly view

Figure 12. Simulated Multiplexer Converter Set

The subassembly will not be opened to expose its interior during training; if it is correctly identified as a fault source, the trainee's correct response is to indicate only that the unit should be replaced in its entirety.

Inside the MUX main assembly are metal photos of two diagrams that indicate component locations within the unit; these diagrams appear in the actual MUX unit.

The side of the interior containing PC cards A1 through A26 is represented by a single metal photo (see Figure 12a). On the opposing side of the simulated LRU, the area behind the connector panel and continuing through PC card 35 is represented by a single metal photo. Cards 36 through 51 are represented as three-dimensional to permit the trainee to remove and replace those cards that are identified as fault sources (see Figure 12b). Five cards are associated with malfunctions selected for training, but all 16 of the simulated cards may be removed and replaced.

Adapters--Four simulated adapters were fabricated, one for each of three fabricated LRUs and one self-test adapter. Selecting the appropriate adapter is a critical step in preparing the LRU for checkout; each adapter is distinctly different from the others in function and appearance. The four adapters are pictured in Figure 13.

Figure 13. Interface Adapters

In general, simulated adapter fabrication is based on GFE-salvaged adapters of appropriate size that have been stripped and repainted to match the test station simulator. GFE handles are appropriately positioned on the front side of each adapter, as is a metal photo of the unit identification plate. Simulated adapters resemble the respective actual equipment in both weight and center of gravity.

The pin connectors, at the adapter/test station interface, are replaced by a single metal photo of an actual pin connector panel. A connector not found on the actual equipment has been added to each simulated adapter at the bottom edge of the cited metal photo; a corresponding connector is mounted on the test station simulator's patch panel A3A2A15. This connector provides a means by which the system can sense whether the trainee has mounted the appropriate adapter on the patch panel.

Cables and Hose--All cables needed for proper LRU connection have been simulated. The blower hose required for operation of the multiplexer converter during checkout procedures is provided.

Training System Software--The primary purpose of the software is to close the loop among the student, the technical orders, the simulated equipment, and the lesson material.

The major functions of the software to achieve this purpose include:

- Simulate major observable test station operation
- Simulate LRU operations

- Monitor student actions
- Permit single simulated failure

The software assists the instructor by providing the following functions:

- Record and display of student performance
- Instructor control of simulation
- Self-test of test station simulator

The software is organized in three major levels to provide these functions and to meet the changing requirements of the trainer application. These levels are:

- Operating system software
- Trainer common modules
- 6883-specific modules

Operating System-- The operating system software allows general use of the minicomputer in a variety of ways.

- It provides standard executive functions which ease system use.
- It provides standard subsystems to allow program development and maintenance. Examples include the FORTRAN compiler, the DAP-700 macro assembler, the text editor, and the link editor.
- It provides standard input/output (I/O) components to handle devices such as the disk, CRT/keyboards, cassettes, and printer.

- It provides standard utilities to load programs, copy or list files, delete files, display directories, and set or display system time.

- It provides diagnostics for troubleshooting the CPU, memory, peripherals (including disk, cassette, CRT/keyboards), and interface units.

Trainer Common Modules--The trainer common modules are the building block subprograms that would be common to many types of trainers. They have been designed to be inserted into a variety of trainer applications, both low fidelity and high fidelity as required. These modules include the following:

- The training system controller is an application-level executive which controls the required monitor subprograms.

- The student procedure monitor is the subprogram which tracks student actions and progress against the lesson material.

- The instructor monitor allows the instructor to select faults and initiate lessons, freeze or terminate the simulation and testing; and it delivers various reports to the instructor.

- The student test routines are low-level subprograms which test specific student actions on the trainer (e.g., comparing analog voltages, testing discrete input lines, testing keyboard inputs) or which provide limited capability to modify the simulation, as required, for specific training objectives.

- The trainer self-test is a diagnostic program that exercises the trainer hardware (lamps, meters, switches, etc.) and allows simple troubleshooting of the trainer itself.

- The oscilloscope simulation subprogram in this application drives a real oscilloscope through two commercial signal generators. For trainers with other training requirements, this module would be modified as required.

- The digital voltmeter (DVM) simulation subprogram in this application drives a simulated meter. For trainers with other training requirements, this module would be altered as required.

6883-Specific Modules--The 6883-specific modules are the building block subprograms that apply primarily to the current 6883 trainer and to its unique training requirements. The building block approach has been used here to allow easy modification, resulting from changes in trainer requirements. The approach allows the same outline to be used for lesson material for other types of trainers.

- The instruction/procedure subprograms include the tests that are unique to a 6883-type of trainer, e.g., DATAC keyboard and displays.

- The slide controller module is a general purpose routine, but the data for that subprogram are specific to the 6883 trainer application. These data would be altered for other trainers.

- The text message processor is a general purpose routine, but the text data it uses are tailored to the 6883 application. These data could be modified for other trainers if necessary.

- The test station simulation, for example, a particular display coming on or going off, is specific to the 6883 but the modules are keyed to specific panels and features. These features apply to many types of test stations, enabling simple modifications and reuse. Also, simulation modification data are contained in the lesson material; these data would be modified for other trainers as required.
- The line replaceable unit (LRU) and adapter interface simulation requirements are specific to the 6883. The simulation modification data in the lesson material would be modified as required for other LRUs and/or adapters.

Instructional Features--In this subsection the 6883 system instructional features are described, including courseware function, structure and content, student performance measures, instructor aids, and the simulator status panel.

Courseware Function and Structure--Courseware may be defined as the computer-directed presentation of instructional material via a combination of media. The courseware program controls the interaction between the software and the simulation hardware and between both of these and the trainee. The instructional material includes the text messages presented via the CRT and the graphics presented via slides.

Courseware is essentially a set of computer programs written in a mnemonic language designed for the 6883 application. The text messages called for by the program are written in natural English. Because the 6883 system is a procedures trainer, the courseware completely specifies the sequence of actions expected of the trainee and the information that the trainee receives via the CRT, slide projector, and the test station displays. The courseware provides for prompting and feedback where necessary. For example, because every trainee action is monitored, any incorrect switch or control setting can immediately be called to the trainee's attention.

The structure of the courseware is modular and hierarchical. The highest order unit is a lesson (file), next a chapter (file), and finally the courseware statements as illustrated in Figure 14. Each courseware statement is numbered (Pnnn for paragraph number) and individually addressable. The lesson file contains a sequential list of the chapter files to be used in that lesson. The modularity derives from the fact that each chapter file may be used repeatedly in various lessons. For example, a chapter directing the trainee to set up the test station for turn-on appears in every lesson. The chapter file resides in one place on the disk and is called for execution by the particular lesson file in control of program flow.

Figure 15 depicts a typical lesson file, identified by the L004. An asterisk precedes a statement that is a comment only. After the instructor initiates the lesson program, control is taken by the executive which searches the lesson file for the first chapter file (C999 in the example). Program execution then shifts to the courseware statements in the chapter file. Courseware statements are executed sequentially by paragraph number unless branching is invoked. At the end of the chapter (see Figure 14, P021 NC), the executive searches the lesson file for the next chapter,

```
6883 OPERATOR COURSEWARE LISTING     P/N: NH1049AA01   FILE PAGE:  1   DOC PAGE 782
HONEYWELL INC. 27327                 S/N 1             CRD 02/16/78    REV  NONE

    C999
    P001 BU 999,009
    P009 CL
    P010 EL 1,01
    P011 EL 2,02
    P012 EL 3,02
    P013 EL 4,10
    P014 EL 5,02
    P015 EL 6,02
    P016 EL 7,05
    P017 EL 0,10
    P018 ME
              000000 000000 177777 177777
              177777 177777 000000 077777
              177777 177777 000377 177777
              177777 177777 177741 170076
    P019 MC
              000000 000000 177777 177777
              177777 177777 177777 177777
              000000 177777 177777 100000
              060000 007777 177777 177777
    P020 SM 1
    P021 NC
```

Figure 14. Chapter File

and so on, until the last chapter and an end of lesson (NL) courseware statement.

<u>Courseware Content</u>--There are basically two types of procedures trained by the 6883 system, normal and malfunction. The normal procedures are those associated with correct operation of the test station, cabling of LRUs, LRU testing, etc. The malfunction procedures are those brought into play when a fault in normal testing or procedures is indicated.

```
6883 OPERATOR COURSEWARE LISTING      P/N. NH1049AA01    FILE PAGE:  1    DOC. PAGE: 6
HONEYWELL INC. 27327                  S/N 1              LRD  02/16/78    REV.  NONE

  L004
  *     DESCRIPTION.
  *
  *          THIS IS LESSON 4.  IT COVERS THE 6883 TEST STATION
  *          CONFIDENCE TESTING. '
  *
  *
  *
  *     REVISION HISTORY:
  *
  *          NONE
  *
  *
  *
  *     DOCUMENTATION REFERENCE:
  *
  *              TITLE
  *                                                   DOC. NUMBER
  *          CONVERTER-FLIGHT CONTROLS
  *          SYSTEMS TEST STATION-SERVICE         T.O. 33D7-17-15-2
  *          WITH OPERATION.                           CHANGE 4
  *
  *          TECHNICAL MANUAL-CONFIDENCE         T.O. 33D7-17-15-8-2
  *          TEST INSTRUCTIONS.                         CHANGE 2
  *
  TIME 90
  *
  *     COMPLETION TIME FOR THIS LESSON HAS BEEN SET AT 90 MINUTES
  *
  C999
  C002
  C901
  C003
  C001
  C004
  C903
  END
```

Figure 15. Lesson File

The set of normal procedures to be trained was selected for simulation according to the following criteria:

- Procedures involving trainee action
  - Test station control settings
  - Test station turn-on
  - LRU cabling
- Tape request and shutdown
- Tests involving operator assistance
- Tests involving unusual procedures
- Maximum technical order (TO) use with minimum redundancy

Trainee action is emphasized and redundancy in simulated tests is minimized. This results in a time compression of normal testing procedures. Difficult tests or procedures are augmented by cues and information delivered via the CRT or slide projector.

Malfunction procedures were selected according to the following criteria:

- Representative of real world
- Requirement of varied use of TOs
- Minimization of redundancies between malfunctions
- Appropriate difficulty for 3-level technician
- Requirement of cost-effective simulation only

An intermediate level, F-111 maintenance shop was visited and a survey was taken from existing maintenance records. This survey produced a list of the more frequently occurring test station and LRU malfunctions. This satisfied the first criterion above; subsequently, the list was reduced by applying the remaining criteria. The result was a set of 18 LRU malfunctions and 34 test station malfunctions, each of which was incorporated as a separate lesson in the courseware.

In addition, seven lessons were written that pertain to normal procedures: test station setup and turn-on, confidence test, maintenance test, DATAC manual modify and sequence interrupt, and one basic checkout lesson for each LRU. This represents a total of 58 lessons (one LRU malfunction lesson contains two malfunctions exemplifying a repair-induced fault).

To illustrate the general sequence of a lesson, here is an outline of a typical LRU malfunction:

- Clear error counts and set limits (Student is unaware of this.)
- Introduce lesson
- Preliminary control settings
- Test station turn-on
- Prepare test station for cabling
- Cable LRU
- Initiate checkout
- Automatic checkout
- Fault at predetermined test item

- Troubleshoot, repair, and retest
- Continue checkout

The introduction to the lesson states only that the trainee will check out a faulty LRU. The trainee is given no advance notice of where the fault will occur, although he or she is given the appropriate repair-in-process (RIP) tag information. Following standard procedures for station turn-on and preparation, the LRU is cabled and checkout begun. The fault is thus embedded in the context of a normal, or good, test sequence, exactly as the trainee would encounter it on the real device.

For any particular LRU, therefore, the chapters of a malfunction lesson are exactly the same <u>except</u> for the chapter dealing with the test that fails. This chapter is unique to the malfunction lesson and covers the following:

- Simulate NO GO condition
- Trainee detects fault
- Fault verification
- Corrective action
- Retest
- Simulate GO condition

It is during these malfunction sequences that the courseware is most interactive. The trainee is quizzed on what to do and how to do it. The aim is to teach general troubleshooting skills.

A detailed description of the courseware programming mnemonics and formatting can be found in Volume I of the 6883 System Users Manual. Volumes II and III contain listings of all courseware lesson material.

Student Performance Measures--The 6883 system is designed as a closed-loop device. The actions and responses of trainees are continually monitored. The courseware calls out the expected action or answer at each point necessary and if the correct response fails to occur an error branch is invoked. The system accumulates six error types and two auxiliary measures:

- Critical or safety error
- Fault detect error
- Procedural error
- Keyboard (CRT) error
- Component location error
- Switch/control setting configuration error
- System helps
- Student helps

Critical/safety errors occur in one of two ways: a) the courseware writer specifies that failure to correctly perform a particular action is a critical error, or b) an error limit, for any other error type, is exceeded. In the former case, a courseware statement increments the error counter; in the latter, the application software automatically increments the error counter. In either case the system automatically freezes and locks out the student from further actions. The instructor must intervene to reinitiate the lesson.

Fault detect errors occur when the trainee fails to depress a special function key on the CRT/keyboard indicating a fault condition. When this happens, a courseware statement increments this error type. If the trainee presses the fault detect key when no fault has occurred, the application software automatically increments this error type.

Procedure errors occur when the trainee makes an incorrect switch or control action or takes an action when none is appropriate. In either case the application software automatically increments this error type.

A (CRT) keyboard error occurs when the trainee incorrectly answers a multiple-choice question presented via the CRT. A courseware statement increments this error type.

A component location error occurs when a trainee mislocates an LRU component or removes the wrong card from the test station or an LRU during a malfunction sequence. Because such an occurrence is read by the computer as an incorrect switch-change, this action counts first as a procedure error. A courseware statement is necessary to specifically increment the component location error type.

Switch/control setting configuration errors occur when, upon request of the courseware, application software makes a test and detects a difference between a prespecified pattern of switch and control settings on the test station and the existing pattern. A courseware statement is necessary to initiate this test. It is used at points in the lesson sequence called entry points. These are points in the test procedures where a trainee is routed to reenter the lesson after he or she has made a procedural or other error. The application software automatically increments this error type and the trainee cannot continue with the procedures until the entry point test for switch configuration passes.

The two remaining types of errors are not, properly speaking, mistakes. There is a provision made to record the number of times a trainee requests help. This error type is incremented whenever the trainee presses the HELP button on the simulator status panel (see below) or on the CRT/ keyboard. There is also a provision to record system helps; this is an extra error counter currently not used. This index is incremented by a courseware statement.

Simulator Status Panel--The simulator status panel located in Bay 3 of the simulated test station is a trainer-unique panel that provides information about the state of the simulator at any given time. This panel is not found on the actual 6883 test station; it is present for training purposes only. The panel contains a number of push buttons and indicators designed to aid in performing the lessons. Figure 16 shows this special purpose panel.

The simulator status panel contains two push buttons:

- Push to Call Instructor
- Push to Reset Alarm

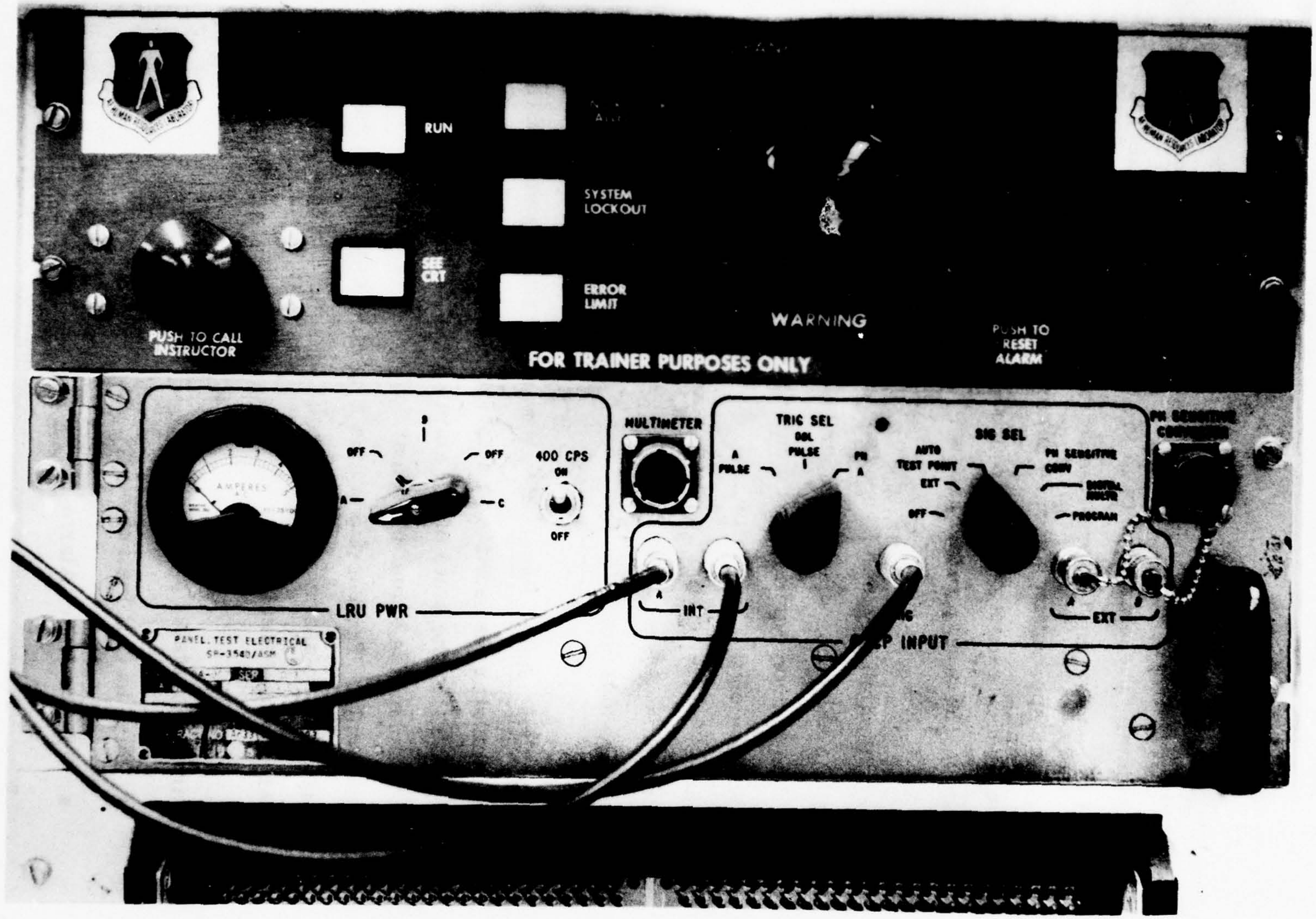


Figure 16. Simulator Status Panel (Detail)

The function and operation of each push button and indicator on the simulator status panel are described below.

- Push To Call Instructor-- This red push button duplicates the function of the special function HELP key on the 2640B display terminal (see Student Interaction, Section III). If the trainee requires instructor assistance, he depresses either this push button or the special function HELP key.

- Push To Reset Alarm--This push button turns off the audio alarm tone when depressed. The trainee depresses this push button when the alarm tone in on continuously, for example when the simulator freezes at an error limit. This action will only shut off the alarm tone. The system will remain stopped until the instructor performs the restart procedures.

- Run--The green Run indicator shows that the lesson is proceeding without problem. The Run indicator should remain on throughout the lesson. Whenever the Run lamp goes out, a red or amber indicator will illuminate, giving some information concerning the problem.

- See CRT--The white See CRT indicator shows that there is text being displayed on the 2640B display terminal. This indicator will be off any time the display terminal is blank.

- Instructor Called--The amber Instructor Called indicator will illuminate whenever the instructor has been alerted, either by the special function HELP key or the Push To Call Instructor push button, by a critical error, or by reaching an error limit. A system lockout will also occur so that the trainee cannot proceed further in the lesson until the instructor restarts the system.

- System Lockout--The amber System Lockout indicator is illuminated whenever the system is stopped. No further inputs are accepted. This is caused by calling the instructor, by exceeding an error limit, or by making a critical error. This condition requires the instructor to restart the system.

- Error Limit--The amber Error Limit indicator illuminates if too many errors have been made. Restarting the system when the Error Limit is illuminated can only be done by the instructor.

- Warning--This large red Warning light will begin flashing whenever either a critical or safety error has been committed, or if too many errors are made. It will continue to flash until the instructor intervenes to restart the system.

- Audio Warning Alarm--This alarm momentarily sounds each time new information is displayed on the 2640B display terminal. In addition, any time a critical or safety error is committed, or too many errors are made, the tone will remain on until it is deactivated by depressing the Push To Reset Alarm push button or by the instructor restarting the system.

<u>Instructor Aids</u>--When any type of error occurs, a status log is automatically displayed at the instructor station CRT. Figure 17 shows the format in which the performance information is presented. The instructor may obtain this display on demand from the system and he or she may request a hard copy of the status log.

```
STATION     STUDENT              CURRENT    PAST     TIME     CUM
               NAME               CH/PAR   CH/PAR    OVER    ERRORS
  6883    TEST 6        END      C025 91   C121 90             02
  STBY
  STBY
  STBY
  STBY
  STBY
----------------------------------------------------------------------

PERFORMANCE AT 6883                        LESSON L009     FAULT 09

TIME LIMIT  60                             ELAPSED TIME  07

                    ERROR SUMMARY

ENTRY POINT        00              FAULT DETECT/ISO             01
PROCEDURE          00              COMPONENT LOCN      00

                    CRITICAL         00
                    STUDENT HELPS    00

                    CAI              01
```

Figure 17. Status Log Display

A hard copy may also be obtained of another log which preserves performance information including where in the lesson an error took place, which wrong answer was given in the case of a CRT/keyboard error, what the switch/control setting configuration was when the error occurred, and the current, cumulative, and limit on number of errors of each type. This log allows tracing all errors that occur. The instructor may use this information to diagnose a trainee's weaknesses.

Manuals--An integral part of the 6883 training system is the manuals describing system operation and maintenance. They are:

- Computer Program Users Manual for 6883 Converter/Flight Control Test Station Maintenance Training System (3 volumes)
  - 6883 System Users Manual (I)
  - 6883 Operator Courseware Listings (II)/Parts 1 and 2
  - 6883 Maintainer Courseware Listings (III)
- Student Manual for 6883 Converter/Flight Control Test Station Maintenance Training System
- Maintenance Manual for 6883 Converter/Flight Control Test Station Maintenance Training System (2 volumes)
  - Installation and Maintenance Procedures (I)
  - Mechanical and Electrical Drawings (II)

Volume I of the Users Manual describes operator procedures for running the 6883 maintenance trainer instructor station and student station computer programs, available options, and built-in hardware diagnostic capabilities of the on-line programs. Volumes II and III contain listings of all courseware programs, documenting 58 lessons for the 6883 system in their entirety. The student manual is written to support trainees on the operation and use of the 6883 MTS. The manual describes all trainee relevant system operating procedures. Correct use of the manual should assure proper equipment function and minimum operating difficulty.

The maintenance manual provides instructions for installing, maintaining, and repairing the 6883 MTS hardware. Volume I describes hardware subassemblies, procedures for unpacking and assembling the trainer for operation, and detailed instructions for performing maintenance and repairs of the designated hardware subassemblies. Volume II contains complete mechanical and electrical drawings for all simulation hardware, simulator interface cards, TIES cards and cable assemblies, as well as the associated parts list.

Scenario--The following scenario provides an overview of how the 6883 MTS is designed to function in the Air Force training environment. Because this is a single example, all types and placement of training features are not included here.

The setting is Room 211A, Building 869 at Lowry Air Force Base. The instructor, MSGT Wilcox in this example, has just entered the room with Airman Jones for a session on the 6883 simulator. Jones had completed the theory portion of the 3ABR32631D-002 course on previous days. Today, Jones will practice the checkout and troubleshooting procedures for the multiplexer converter set.

MSGT Wilcox steps to the instructor station. To initiate the lesson, MSGT Wilcox performs the following actions:

1. Perform the power-on procedures for the computers, the peripherals, and the simulator hardware.
2. Select and mount the disk pack with the required lesson.
3. Load the operating system.
4. Load the student station executive if it is not already loaded.
5. Start the student station computer.
6. Initialize the student station computer.

At this point, the entire simulator has been powered up and is ready to receive further instruction from MSGT Wilcox.

The next step is for MSGT Wilcox to call up the multiplexer converter set lesson to be performed by Airman Jones. This process involves:

1. Referencing the Users Manual and selecting the lesson number and fault number desired.
2. Keying in the lesson number and fault number via the instructor CRT/keyboard.

(Note: Had a system fault occurred during any of the preceding or subsequent steps, MSGT Wilcox's response would have been to use the CRT/keyboard to load the diagnostic self-test.)

With the instructional program loaded, Airman Jones now begins his training sequence using the simulated 6883 and multiplexer converter set hardware, the CRT/keyboard, and the appropriate TOs. First he enters his name and ID number via the student station keyboard. This entry identifies him to the system for recordkeeping and performance measurement purposes.

The initial display asks Jones to indicate which of the following actions he would take first in checking out the multiplexer converter set:

A. CONNECT THE LRU TO THE TEST STATION

B. PERFORM THE TEST STATION PRELIMINARY CONTROL SETTINGS

C. ENTER TEST REQUEST NUMBER 730303

D. CHECK ON CENPAC AVAILABILITY

Jones keys in answer "B".
The display changes and responds with a tone and the following message:

RIGHT. THE TEST STATION MUST BE PROPERLY SET UP SO THAT CORRECT TESTING OF THE LRU CAN BE ACCOMPLISHED.

Jones is then told to perform the test station preliminary control settings procedure in accordance with the proper TO and to indicate completion via a specific keyboard entry.

Jones performs the procedures, but in the process, he skips the step requiring him to turn on the DATAC PWR CONT circuit breaker on the micrologic power supply. Jones indicates that he has completed the procedures. The display changes, a tone sounds, and the following message appears:

> YOUR TEST STATION IS NOT PROPERLY SET UP FOR LRU TESTING. SET THE PROPER CONTROLS TO THEIR REQUIRED SETTINGS AND INDICATE WHEN YOU HAVE FINISHED.

(Note: At the same time a new status display appears at the instructor CRT.)

Jones returns to the test station, finds the error, corrects it, and indicates via the keyboard that he is ready to continue. The display changes, a tone sounds, and the following message appears:

> VERY GOOD. NOW THAT THE CONTROLS HAVE BEEN SET PROPERLY, WHAT IS THE NEXT THING YOU SHOULD DO?
>
> A. PERFORM THE TEST STATION TURN-ON PROCEDURE
>
> B. CONNECT THE MULTIPLEXER CONVERTER SET TO THE TEST STATION
>
> C. PERFORM MANUAL-PROGRAMMED TESTING
>
> D. BEGIN LRU TESTING

Jones responds, keying in "A", which is correct.

This sequence illustrates the interactive features of the computer-assisted instruction (CAI) system. A key element is the immediate, specific feedback to the student concerning all of his actions and answers. Throughout this sequence the instructor has been monitoring Jones' performance, both visually and via the instructor station CRT. The computer system has been keeping track of Jones' performance on the various test questions and will produce a hard copy at the instructor's printer if so desired at the end of the session. So far the instructor has been operating "hands-off," i.e., with the system in an "automatic" mode.

Now assume that Jones has just indicated that he connected the multiplexer converter set to the test station. The display changes, a tone sounds, and this message appears:

> THE MULTIPLEXER CONVERTER SET IS NOT PROPERLY
> CONNECTED TO THE TEST STATION. REATTACH PROPERLY.

Jones inspects the connections and finds the adapter cable assembly P2 not properly attached to J2 on the parallel digital adapter. He reconnects and indicates he has completed the procedure. The display changes, a tone sounds, and this message appears:

GOOD. NOW BEGIN TESTING AS INDICATED IN FIGURE 2-3 OF YOUR TO.

Jones references his TO Figure 2-3 and initiates LRU testing procedures by the following steps:

1. Places "MODE" switch at "NORMAL"
2. Enters test request number
3. Depresses "Test Request" push button
4. Observes test number on DATAC "Test Number" display
5. Depresses "Start"
6. Verifies correct date code appears in "Measurement" display
7. Depresses "Start"

The computer system has been continually monitoring Jones' actions and displaying the correct information. Once automatic testing begins, the 6883 training system simulates the performance of the selected tests. All indications found on an operational 6883 test station are reproduced as the automatic test sequence proceeds.

At test number 275447, the "Test Number" display freezes (indicating a failure) and a NO GO message appears in the results window. The student station display tone sounds and the following message is displayed:

WHAT IS THE MEANING OF THE INDICATION IN THE TEST NUMBER DISPLAY?

A) ALL TESTS ARE COMPLETE

B) TEST 275447 IS RUNNING

C) THE NEXT TEST WILL BE 275447

D) A FAILURE IS INDICATED

Jones keys in "D". The display changes, a tone sounds:

RIGHT. WHEN A TEST NUMBER HANGS IT NORMALLY INDICATES A FAILED TEST. PRESS THE RETURN KEY TO CONTINUE.

Jones depresses the RETURN key on his keyboard and the following message is displayed:

WHAT IS THE NEXT THING TO DO?

A) DEPRESS START

B) KEY IN 131027 and 315100

C) CONSULT THE TO.

D) REPEAT THE FAILED TEST

Jones selects "B". The display changes:

WRONG, THE NEXT STEP WOULD BE TO VERIFY THE MALFUNCTION INDICATION BY REPEATING THE TEST THAT FAILED, WHICH WAS ANSWER D.

PRESS RETURN TO CONTINUE.

Jones presses RETURN, the display changes, a tone sounds, and this message appears:

ASSUMING THAT YOU REPEATED THE TEST AND IT STILL INDICATED A NO GO CONDITION, WHERE MIGHT YOU SUSPECT THE PROBLEM TO BE LOCATED:

A) IN THE TEST STATION ITSELF

B) CARD A51, A50, OR A46 IS DEFECTIVE

C) CARD A45 IS DEFECTIVE

Jones answers "B".

Through additional CAI, presentations of visuals via the slide projection system, and by use of the proper manuals, Jones determines that A51 is the defective card. He is directed to remove and replace card A51 following the proper repair procedures. He removes the power from the simulated LRU, removes the simulated covers, and mistakenly removes card A50 instead of A51.

The tone sounds and the following message appears:

HOLD IT, YOU REMOVED THE WRONG CARD. RE-PLACE THE ONE YOU REMOVED AND THEN PRESS RETURN.

Jones replaces card A50 and depresses RETURN.

The following is displayed:

OK, NOW REFERENCE THE MULTIPLEXER CONVERTER SET ILLUSTRATED PARTS BREAKDOWN MANUAL, THEN REMOVE AND REPLACE CARD A51.

Jones looks at the manual, but removes the wrong card again, and the following things happen:

1. Both audio and visual alarms activate.
2. The student station's status display indicates the error.
3. The instructor is notified of the student error.
4. The simulation system automatically locks the student out.

At this point the instructor goes "hands-on." He will want to communicate directly with Jones concerning his failure to locate card A51.

After MSGT Wilcox provides the appropriate feedback to Jones, he decides to insert a similar malfunction into the multiplexer converter set checkout. To do this, the MSGT returns to his console, consults his table of available malfunctions, and selects a similar fault.

Within the limits of the time available, training continues until Jones successfully completes the chosen lesson. The simulator is then secured for the day or the next student signs on.

SYSTEM PRODUCTION/DESIGN IMPLEMENTATION

This subsection deals with technical problems that arose during the production phase of the 6883 training system program; several technical issues are discussed for hardware and software production. This discussion is intended to provide some insight into the technical problems that had to be resolved in going from a design to a product.

Hardware

The visual simulation required for panels and the three-dimensional simulation needed for printed circuit cards led to application of two technologies that saved considerable time and money in production.

Metal Photos--A metal photo is a high-resolution photograph embedded in the surface of a metal plate. Photographs are taken of the actual equipment as the first step in the development of metal photos. Next, photographic half-tone negatives are produced and a photo-sensitive aluminum plate is then exposed to the negative in the same manner as in producing a standard black-and-white photographic print. The resultant high-resolution image (1000 lines/mm) is sealed under an anodized, clear, sapphire-hard surface that protects the image from scratching, fading, peeling, and chipping. Normal metal working processes such as bending, cutting, or installing components may be used on these panels. The metal photo panels thus provide the durability of an aluminum panel with the low cost of a photograph. The use of this technology avoids the cost of the artwork and engraving associated with actual panel production.

Circuit Cards--The simulated circuit cards were produced by laminating color photographs onto a rigid substrate, an aluminum alloy sheet for all cards except those in the FCS drawer. For the FCS cards a glass/epoxy substrate was used to electrically insulate their edge connectors. The color photographs are embedded in plastic which both attaches them to the substrate and provides a durable surface. The cards for the DATAC drawer have simulated transistor cans bonded to their surface. The color photographs of the actual circuit cards provide a high degree of fidelity with low cost. Since actual circuit cards are quite expensive, this technique resulted in cost savings of 75 to 80 percent.

Software

The top-down, modular approach to software design proved to be the best method for achieving reliable and manageable programs for the training requirement. A top-down, modular approach using hierarchy plus input-processing-output reports allowed a more efficient use of programmer talent, provided visible levels of responsibility, yielded a definite software architecture easily checked for consistency (due to well-defined software interfaces), and aided the system integration and verification activities.

The top-down modular approach assured compliance with training requirements by a check-off method. That is, each computer program component was divided into functional portions and each module's output, function, and input requirements were defined and validated. This close relationship between functional requirements and software module allowed rapid cross-checking by nonprogramming personnel. The use of an informal, structured program design language assisted the Air Force technical personnel in understanding how functionality was accomplished. Due to the modular software design, the system production proceeded with a minimum of problems. Some of the technical issues that were resolved are discussed below.

The following technical issues were encountered:

- Parallel development of 6883 station hardware and software
- Additional main memory required to support requested increases in functional capabilities
- Development of a courseware programming language
- Reconfiguration of the operating system activity areas to support requested functional enhancements
- Dynamic waveform generation techniques
- A/D hardware

The above technical issues were resolved in various ways, but the general theme of their resolution was the modular structure of both the application and operating software.

Specifically, the issue of parallel development of station hardware and software was resolved by the self-test application program, which allowed rapid isolation of faults to hardware component or software module. The modular structure eased the addition of new modules in expanded main memory to support requested functional enhancements. The courseware programming language is a special purpose language with clear functional mnemonics that allowed easy development and maintenance of lesson material. The A/D chip first used did not perform to manufacturer's specifications. This necessitated a switch to a different vendor and a single software interface module revision to support the new manufacturer's control sequence and signals.

SECTION III

SYSTEM OPERATION

This section provides a description of the 6883 Maintenance Training System (MTS) operating procedures, including instructor functions and student interaction.

INSTRUCTOR FUNCTIONS AND PROCEDURES

The 6883 MTS was designed to simplify instructor interaction with the computer system so that the instructor could operate more efficiently to assist the student. A description of instructor procedures follows.

The primary steps necessary to initiate an instructional lesson are the following:

- Power up all system hardware components
- Select/verify equipment settings
- Load and initialize system
- Select and mount the removable courseware disk pack containing the desired lesson
- Initialize the training session using the INIT activity
- Select the specific lesson and malfunction required using the TEACH activity

- Select the level of detail of the student error response log via the CREATE activity.

The above sequence of steps will initiate the instructional session. While the instructional software is executing, the instructor may want to see how the student is progressing. This is accomplished by scheduling the ST6883 activity to obtain the student performance status log on the instructor CRT. The status log format and a discussion of the error types can be found in Section II, Instructional Features. The same report is made available at the student station by entering the instructor mode and depressing the PERF DSPLY key.

At lesson termination, the instructor must determine if the latest performance display log is to be saved. This is handled by the TERMIN activity.

The special functions available at the student station are shown in Table 1.

The instructor has the capability to halt the training session and, via the activity ECHO, to single-step the courseware, to branch to a desired lesson step, or to run the courseware in reverse.

In addition, the instructor has the 6883 station status panel, which provides visual and audio status of the student's progress. See the preceding section for a discussion of the status panel indicators.

TABLE 1. SPECIAL FUNCTION KEYS AT STUDENT STATION

Key	Current Mode	Use
S	Student	Ignored.
S	Command	Switch to student training mode. RUN lamp ON.
I	Command	Ignored.
I	Student	Switch to command mode. SYSTEM LOCKOUT lamp ON.
FAULT DETECT	Student	Signals courseware (via a KB test) that a fault is detected/ isolated.
FAULT DETECT	Command	Ignored.
HELP	Student	Signals training program that student wants to call the instructor; same as PUSH TO CALL INSTRUCTOR button on the simulator status panel. INSTRUCTOR CALLED and SYSTEM LOCKOUT lamps are ON.
HELP	Command	Clears the INSTRUCTOR CALLED lamp and the "help" condition.
PERF DSPLY	Student	Ignored.
PERF DSPLY	Command	Request status/performance display (similar to ST6883 activity) at student station.
SLIDE	Student	Ignored.
SLIDE	Command	Display a slide. Can be used in coaching the student, but contents of the slide tray must be known.

STUDENT INTERACTION

Lessons

The 6883 MTS includes a set of 58 preprogrammed lessons: 7 normal operating procedures lessons, 34 test station malfunction lessons, and 17 LRU malfunction lessons. These lessons were designed to provide the student with hands-on experience in performing the procedural maintenance tasks; to increase the instructional effectiveness of training by incorporating feedback, guidance, and branching techniques; and to give the student experience in detection and repair of commonly occurring malfunctions.

Each lesson will average between 45 and 60 minutes to complete. During the lesson, the student will be taken through all steps in the repair process. These steps include: test station turn-on, perform checkout procedures, fault detection, fault isolation, repair, and retesting. The actual technical manuals are used in the lessons, thereby giving the student exposure to and experience in using these manuals.

Student Keyboard

The student keyboard (see Figure 18) is used by the student to make necessary inputs during the lesson. The student keyboard is identical to the instructor's keyboard except it has been simplified for student use. The left section, which resembles a normal typewriter keyboard in both appearance and operation, was not modified. The student will use this section

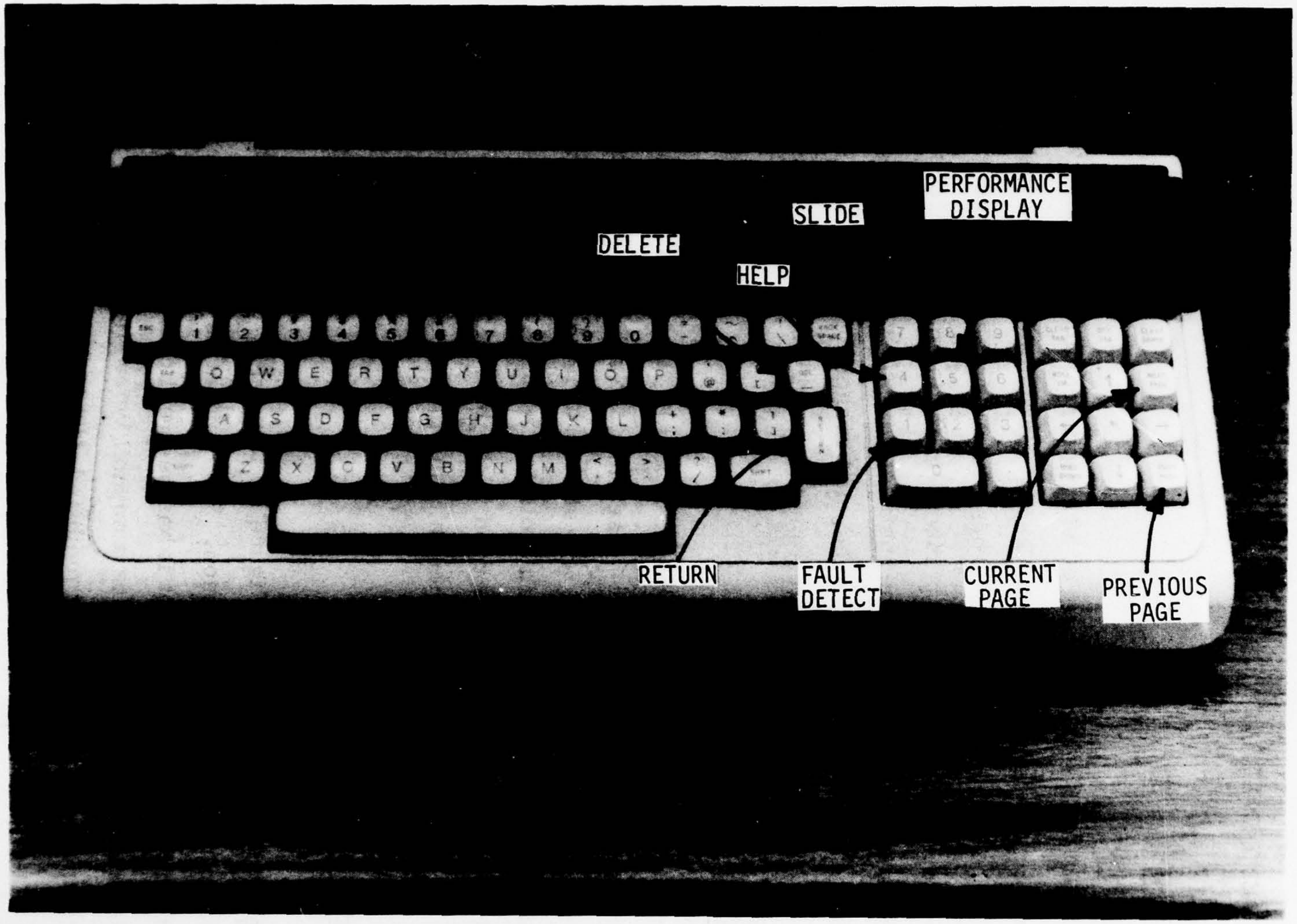


Figure 18. Keyboard at Student CRT

for most of his or her responses (e.g., entering student name and answering multiple choice questions).

The right section of the keyboard was simplified. All keys whose functions were not required had the key caps replaced with blanks, then were locked in place to prevent accidental actuation. The keys to be used as special function keys had new key caps engraved. The keyboard contains six special function keys, two for the instructor's use and four for the student's use.

The instructor's special function keys are the SLIDE key and the PERF DSPLY (performance display) key. The training system must be in the instructor mode for these two keys to operate. The SLIDE key is used by the instructor to display any of the slides in the random access slide projection system. The PERF DSPLY key is used to write out the summary performance display on the student's CRT.

The four special function keys for the student are: PREV PAGE (previous page), CURR PAGE (current page), FAULT DETECT, and HELP. These keys operate when the training system is running in the student mode. The function of each key is described below.

- The PREV PAGE (previous page) key allows the student to look back at the last message displayed on the CRT. This can be done any time simply by depressing this key, and what was previously displayed on the CRT will appear again. This key is to be used with the CURR PAGE key.
- After the PREV PAGE key has been depressed, the CURR PAGE (current page) key must be pressed in order to return to the

appropriate point in the lesson procedure. By depressing the CURR PAGE key, the student is returned to the present message. The key is only used after the PREV PAGE key has been depressed.

- The FAULT DETECT key is used when the student has identified a malfunction indication in the checkout procedures. If this key is depressed at the wrong time, the student will receive a message indicating that the key should not have been pressed and to continue with the lesson. The fault detect error type will also be automatically incremented.

- The HELP key is used to signal the instructor that the student requires some type of assistance. When this key is depressed, the training system will halt and not proceed until the instructor restarts the system at the student station.

Student Procedures

There are five trainer-peculiar procedures that the student will most likely encounter during performance of a lesson. They are:

- Student sign-on
- Lesson reentry
- Fault detection
- Fault correction
- Lesson termination

For the lesson to continue, each must be performed correctly. The procedures are discussed below.

Student Sign-on--This is the first step in the lesson. The student is required to enter his or her name and student number into the training system so that the performance records are assigned correctly.

Lesson Reentry--If the student makes a procedural error during the lesson such as making an incorrect switch setting, an improper adjustment, changing a control when not directed to, or incorrectly cabling an LRU, the student will receive feedback concerning the error and directing him or her to correct it. When the error is properly corrected, he will receive instructions on reentering the lesson. The general reentry during the automatic testing involves correcting the error, manually entering a specified test number on the DATAC keyboard and then pressing the DATAC start switch to resume normal testing. If the student follows instructions, he should have no trouble reentering the lessons.

Fault Detection--This procedure simply involves the student depressing the FAULT DETECT special function key when a malfunction is identified in checkout. If the student fails to depress the key at the appropriate time, he will be given appropriate feedback so that testing may resume.

Fault Correction--The procedure to correct the fault will depend on which lesson the instructor has selected. In some lessons the fault correction procedure may be as simple as finding the correct part number of the failed component; in other lessons the student may actually be required to remove and replace the failed component.

Other fault correction procedures include:

- Performing component adjustments
- Identifying the failed components illustrated parts breakdown index number
- Identifying failed component repair code
- Locating failed component by depressing associated push button

Lesson Termination Procedure--The test station shutdown procedure is usually the last action that will be taken in the lesson. The student normally will receive a text message on the CRT after the shutdown procedure has been performed, indicating that the lesson has ended. No further actions are required of the student for lesson termination.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

In this section several issues are discussed relating to the research issues addressable with the 6883 MTS, to the potential training and cost-effectiveness of simulation as exemplified by the 6883 MTS, and to the program achievements and potential benefits for the Air Force.

RESEARCH ISSUES

There are at least three general areas of technical training research that can be addressed using the 6883 MTS: a) transfer of training, b) advanced training techniques, and c) automated performance/proficiency measurement.

Transfer of Training

This issue concerns the utility of simulation in maintenance training. The major question is whether a simulator-trained technician will be able to perform maintenance tasks on the actual equipment as well as an equipment-trained technician. Many studies indicate positive transfer from simulators to actual equipment (Miller, 1974). However, in many instances, the performance/proficiency data measuring transfer are suspect for some reason; for example, because of their lack of objectivity, reliability, or validity.

The 6883 system provides a tool for collecting appropriate data on this question. As discussed below, performance measures obtained on the system could help achieve an acceptable level of objectivity, reliability, and validity in proficiency measurement. This, in turn, will suggest ways to obtain measures of proficiency on the actual equipment. Another possibility is that the 6883 system itself could serve as the criterion device for measuring training transfer. This would be particularly useful when evaluating the transfer of training of a simulator with less fidelity than the three-dimensional 6883 system.

Training Techniques

Computer-based training systems offer unique training capabilities, for example, freeze capability, performance playback, etc. However, little is known about the training-effectivness of some of these options. The 6883 MTS provides a test bed for evaluating the training utility of freeze, playback, and other techniques. The 6883 MTS provides the instructor with the capability to stop an instructional sequence at any point in a lesson to provide assistance and either back up or move forward within that particular sequence. What is the frequency with which such capabilities are used in training? And is it effective compared with the same sequence when no instructor intervention occurs? If the answer to the latter question indicated no detectable difference, future simulation-based training systems could be procured without such features or with a reduced set of features, thus reducing acquisition costs.

The 6883 MTS has an unlimited courseware expansion capability as a result of the disk storage medium. It will therefore be possible to write courseware to teach certain procedures that use different instructional strategies, different media, or different levels of feedback. For example, there are three distinct instructional media with which the 6883 MTS can support hands-on training: a) handbook, b) slides, and c) computer-assisted instruction (CAI). The relative effectiveness of each of these media could be determined for learning different procedures and for acquiring troubleshooting skills. Furthermore, within each medium it is possible to vary the specificity and immediacy of feedback provided on student actions. For example, it is possible to provide feedback on completion of an action or an entire procedure. Thus, the effect of delayed feedback on procedures training can be tested.

At the most general level, the 6883 MTS can be used to evaluate the promise of simulation via proceduralized courseware (instructional programming that specifies each event and expected action), as opposed to simulation via system modeling. This latter capability is quite expensive and the training-effectiveness versus cost issue needs further research.

<u>Automated Performance/Proficiency Measurement</u>

The 6883 MTS records many different types of student errors. The selection of these error types was based on logical analysis and empirical data in the general training literature. Are these error categories sufficient for 6883 training? Are there too few or too many? What is the validity of the measures? No performance norms exist for such measures and, therefore, the task of relating performance to proficiency or skill level remains to be done. The 6883 MTS provides a research tool for accomplishing this task.

POTENTIAL TRAINING EFFECTIVENESS

The answer to the training-effectiveness question of the 6883 MTS rests with future empirical research. However, it must be pointed out that the system is designed to maximize learning at several levels of detail as well as to provide a test bed for simulation research.

First, the information presented in the courseware meets the training objectives established at the outset of the study. The courseware structure and content are based on a thorough analysis of the operator and maintainer tasks trained on the actual test station. The lesson material is not of uniform difficulty; the lessons deal with malfunctions varying from straightforward, automatic troubleshooting to those demanding application of logical analysis to determine the source of a fault. The difficulty of each operator lesson is noted in the 6883 MTS Users Manual.

Second, the information is presented in accordance with well-established principles of learning. The system combines CAI, pictorial cueing, and simulation of hands-on procedures, thus producing a powerful instructional combination. The system automatically detects errors and provides immediate feedback. Procedures training, particularly for 3-level technicians, should be enhanced as a result of this feature. The CAI messages and questions are written at a level appropriate to the reading skills of the trainee population. One feature of the positive feedback is that it duplicates the reasoning which should have led to the correct answer; thus even in the event of guessing learning can occur. Finally, the time compression programmed into the courseware, achieved by eliminating certain automatically performed tests, will allow more practice of operator-assist tasks.

Third, the 6883 instructor has at his or her command abundant information on trainee performance. This should make it possible to diagnose trainee weaknesses and pinpoint the needs for remedial training. With the wealth of lesson material provided, remedial training should be readily accomplished.

POTENTIAL COST EFFECTIVENESS

The general issue of simulation cost-effectiveness has not been fully resolved. It is clear that low fidelity simulators are less expensive than actual equipment, but as fidelity increases, so does cost. Increasing fidelity improves transfer of training but only to a point of diminishing returns, i.e. a point where additional significant increases in fidelity (and cost) result in inconsequential increases in transfer of training (Miller, 1954). The research topics outlined above can provide data pertinent to determining the relations between transfer, fidelity, and cost.

The need for user acceptance also impacts the cost of simulation. Increased engineering fidelity may occasionally be necessary or desirable in order to ensure that instructors and students accept the training device as a valid instructional tool.

A number of trade-offs were made in the design of the 6883 MTS. The primary driving factor was the training requirements. To ensure cost-effectiveness, a philosophy of training by representative example was adopted. Frequently it was found that cost reductions could be achieved by using the same functionally simulated hardware to train a variety of different procedures. Concentration of simulated hardware in a single location reduced mechanical assembly costs. For example, each bay of the actual test station has an over temperature indicator that is tested during turn-on procedures. Because this test procedure is the same for all four indicators, only one of the four indicators is functionally simulated though all four indicators are represented visually.

Acquisition cost of a training system is only one aspect of cost assessment. Of more interest is the issue of life-cycle costing (LCC) which requires that both the acquisition and support costs of training equipment be addressed. Most studies of LCC indicate savings of between 50 and 70 percent for simulation-based training systems as compared to operational equipment. There are several difficulties inherent in comparative LCC, not the least of which is obtaining accurate cost data for operational equipment used for training. Furthermore, cost estimates for extensive use and support of simulators in maintenance training at this time are based only on projections. These projections may prove in need of revision. For example, simulator maintenance may require the future institution of new Air Force job categories, the impact of which is currently difficult to include in an LCC analysis.

It would be misleading to use cost data from the development of the 6883 MTS in LCC. The 6883 MTS is a prototype system designed as a training and research device. The system, therefore, includes features which may not be necessary for production models of similar devices. There are also many one-time costs associated with the development of simulation techniques and the production of training system software. If the acquisition cost of the 6883 MTS is used as data for LCC, then it should be recognized that the result will be confounded by the above facts.

PROGRAM ACHIEVEMENTS

The technology achievements represented by the 6883 program are applicable to the procurement of future simulation-based training systems. For example, the techniques described for achieving high fidelity simulation of printed circuit cards and for producing metal photos can be readily generalized to other applications, as can be the trainer common software modules. Also, the front-end analysis techniques discussed in the introduction are appropriate to developing engineering designs for any training device.

The future of simulation technology lies in extended applications. It will be in the procurement of such systems that potential cost savings over operational equipment are fully realized. This is true of any mass-produced item: large-scale production techniques. For example, the production of courseware could be greatly simplified by development of a generalized programming language suited to the peculiarities of combining CAI with simulated equipment functions.

In sum, the training effectiveness of the 6883 MTS, as compared to actual equipment used for training, is predicted to be quite high. The relatively high fidelity of the device should yield high positive transfer. The flexibility of the device provides means for answering many questions that will impinge upon the design and cost of future maintenance training simulators.

RECOMMENDATIONS

The following recommendations regarding the 6883 MTS are made:

- The 6883 MTS should be used to provide much needed data on simulator training effectiveness.
- The 6883 MTS should be used for, and evaluated in the context of, regular classroom instruction whenever possible.
- The 6883 MTS should be used according to the procedures and recommendations outlined in this report and the associated manuals.
- The Air Force should continue to vigorously pursue the development and application of simulation technology to technical training.

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