Chapter Four
Advanced Technology Training for Aviation Maintenance

This chapter reports the status of a project to support the application of advanced technology systems for aircraft maintenance training. The first phase of the research was to assess the current use of such technology in airlines, manufacturers, and approved aviation maintenance technician schools. The findings of the assessment are reported here. The second phase of the research is building a prototype intelligent tutoring system for aircraft maintenance training. The chapter defines intelligent tutoring system technology and presents the specifications for the prototype. This chapter also describes example constraints to the rapid design, development, and implementation of advanced technology for maintenance training.

4.0 INTRODUCTION

The human is an important component in the commercial aviation system that provides safe and affordable public air transportation. Much attention to the "Human Factor" in the aviation industry has focused on the cockpit crew. However, the FAA and the airlines recognize that aircraft maintenance technicians (AMTs) are equal partners with pilots to insure reliable, safe dispatch. The job of the AMT is becoming increasingly difficult, as discussed in Chapter 1. This is a result of the fact that there are increasing maintenance tasks to support continuing airworthiness of the aging aircraft fleet while, at the same time, new technology aircraft are presenting complex digital systems that must be understood and maintained. Sheet metal and mechanical instruments have given way to composite materials and glass cockpits. These new technologies have placed an increased training burden on the mechanic and the airline training organizations.

The FAA Office of Aviation Medicine, as a part of the National Aging Aircraft Research Program and the National Plan for Aviation Human Factors, is studying a number of Human Factors related issues that affect aviation maintenance. As described in Chapter 1, examples of the projects under investigation include the following: a study of job aiding for maintenance tasks (Berninger, 1990); design and development of a handbook of Human Factors principles related to maintenance; a task analysis of aviation inspection practices (Drury, 1989 and 1990); a study of maintenance organizations (Taylor, 1989 and 1990); and the assessment and specification/demonstration of advanced technology for maintenance training. The advanced technology training research, reported here, is exploring alternatives for the effective and efficient delivery of a variety of aircraft maintenance training.

4.1 RESEARCH PHASES

The training technology research is divided into three phases that will be conducted over a three year period. The work began in January of 1990.

In the first six months the status of training technology for maintenance technicians was assessed. This was done with a series of telephone interviews and site visits to manufacturers, airlines, and schools operating under Federal Aviation Regulation Part 147 (FAR 147). Currently the research team is designing and building a prototype intelligent tutoring system (ITS) that can be used as a demonstration of the application of expert system technology to maintenance training. ITSs are described in Section 4.2. The prototype will also be used to help finalize the specifications for a fully operational intelligent tutoring system that will be completed in the second year for a full scale evaluation in year three.

The operational intelligent tutoring system will be built in conjunction with a school and airline that were identified during the first six months of the project. The intelligent tutoring software will be generic in design so that it can be modified for a variety of aircraft maintenance training applications. The product will be a turn-key training system for maintenance. The important by-product will be a field-tested approach to develop, efficiently, subsequent ITSs for aircraft maintenance training.

The third phase will be dedicated to evaluation of the intelligent tutoring system for maintenance training. The system will be integrated into a training program at a school or airline. User acceptance and training effectiveness of the intelligent tutoring system for maintenance training will be evaluated. In addition, there will be an analysis of the cost effectiveness of such training technology. ***Table 4.1*** is a summary of the three phases.

Table 4.1 Phases of Research Plan

Phase 1	1990	Technology Assessment and Prototype
Phase 2	1991	Build Complete Intelligent Tutoring System
Phase 3	1992	Conduct System Evaluation

4.2 DEFINITIONS OF ADVANCED TECHNOLOGY AND ITSs

Over the past decade, instructional technologists have offered numerous technology-based training devices with the promise of "improved efficiency and effectiveness". These training devices are applied to a variety of technical training applications. Examples of such technology include computer-based simulation, interactive videodisc, and other derivatives of computer-based instruction. Compact disc read only memory (CDROM) and Digital Video Interactive (DVI) are two additional technologies that will offer the "multi-media" training systems of the future.

The application of artificial intelligence (AI) to training captivated the instructional technology literature of the eighties (Sleeman and Brown, 1983, Wenger, 1987, Kearsley, 1987). The AI-based training systems are called intelligent tutoring systems (Polson and Richardson, 1988, Psotka, et al, 1988). This section will define the ITS technology as it exists today. The section will show examples of systems that are currently in use and/or development. The examples are those for which the author has responsibility. There are many other excellent ITSs in development today. Intelligent tutoring systems are usually described with some version of the diagram in Figure 4.1 (Johnson et al, 1989; Mitchell and Govindaraj, 1989; Yazdani, 1987).

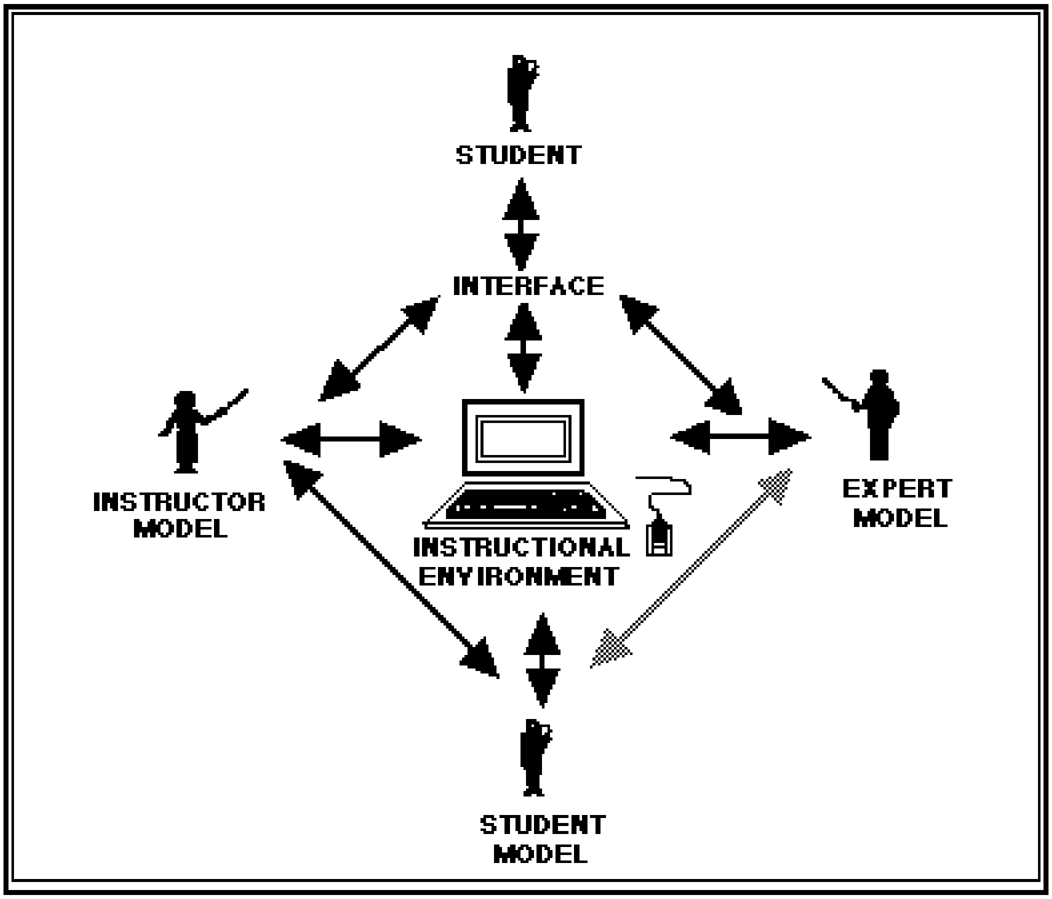

Figure 4.1 Intelligent Tutoring System

At the center of the diagram is the instructional environment. It can include any of the techniques that have been available with conventional computer-based instruction (CBI). This could include the following: simple tutorials, drill and practice, problem solving, simulation, and others. It can be argued that the design of the instructional environment is the most critical element in a training system. However, an ITS is only as strong as its weakest module.

Between the instructional environment and the student is the user interface. The interface permits the student to communicate with the instructional environment. The interface can be as simple as text with a keyboard. However, today's interfaces are more likely to include sophisticated color graphics, animation, audio, and video disc. Example input devices are keyboards, touch screens, mice, trackballs, voice, and other such hardware.

The software that differentiates ITSs from conventional CBI are the models of the expert, student, and instructor. The expert model contains an understanding of the technical domain represented in the instructional environment. There are numerous ways to encode this expert understanding. The most common is with production rules. When the instructional environment is a simulation, a portion of the expert model is often embedded in the simulation. This is true with Microcomputer Intelligence for Technical Training (MITT) (Johnson et al, 1988 & 1989) and with the Intelligent Maintenance Training System (IMTS) (Towne and Munro, 1989).

The student model is a dynamic accounting of student performance within a given problem. Most student models also contain a historical record of previous student performance. The final model, the instructor, compares the student model to the expert model to assess student performance. The instructor model, sometimes called the pedagogical expert, offers appropriate feedback and/or suggestions for remediation. The instructor model also sequences subsequent instruction based on perceived level of competence of the student. The instructor model is an expert system with production rules about training and feedback. This model does not necessarily know anything about the content matter within the instructional domain.

4.2.1 Example Systems

Research on artificial intelligence in training has been going on for quite some time (Carbonell and Collins, 1973). However, few systems have made a successful transition from the laboratory to real training environments (Polson, 1989, Johnson, 1988b). Johnson has offered a number of the reasons that the transition has been difficult. He also described how to build ITSs for real applications (Johnson, 1988a, 1988b, 1988c).

Flowcharts and diagrams, like the one in Figure 4.1, are helpful to gain a broad understanding of the ITS concept. Examples of operational ITSs are a better way to understand and appreciate their potential for technical training. MITT, MITT Writer (citation), and Advanced Learning for MSE (ALM) (Coonan, et al, 1990) are examples of such systems.

4.2.2 Summary of Examples

MITT, MITT Writer, and ALM are but a few examples of ITSs that have transitioned from the laboratory to the operational training environment. This transition was possible because the systems were designed to meet the hardware, software, and budget constraints associated with real training. These systems operate on hardware that is available, in place, today. If intelligent tutoring systems are to become a part of technical training they must be sensitive to these constraints. Each will be briefly discussed here.

Hardware is the first constraint. Most of the early ITSs were developed on dedicated artificial intelligence workstations. Such hardware is considered to be obsolete and impractical by most developers. However the early ITS development on the Xerox and Symbolics workstations permitted the initial design principles for today's systems.

The hardware problem is history. Today's computers, the IBM-AT, compatibles and the Macintosh, have the capability for ITSs. The faster 80386 and 80486 processors are providing significant capability to deliver intelligent training. Such hardware is becoming increasingly affordable and reasonable for training applications.

Software has also evolved to become more suitable for ITS. The new operating systems, with new hardware, permit parallel processing and direct access to unlimited memory. These two changes, by themselves, will have a major impact on new training software. In addition to these advances are a variety of software tools that facilitate the development of interactive graphics, as an example.

Budget considerations are a third constraint to the development and implementation of ITS in technical training environments. The advent of ITSs on available microcomputers is driving down such costs. The development of authoring systems, like MITT Writer, will also bring down the cost of ITSs.

4.3 ADVANCED TECHNOLOGY FOR AIRCRAFT MAINTENANCE TRAINING

The goal of Phase I was to identify the extent to which advanced technology was being applied to aviation maintenance training. To accomplish this goal, a sample of the population of airlines, schools, and manufacturers was either visited or interviewed by telephone or personal discussion. The organizations that had major input to the survey are shown in Table 4.2.

AIRLINES:	American Airlines Maintenance Academy British Airways Continental Airlines Delta Airlines Northwest Airlines United Airlines ATA Maintenance Training Committee
SCHOOLS:	Clayton State College Embry-Riddle Aeronautical University The University of Illinios
MANUFACTURERS:	West Los Angeles College Boeing Commercial Airplanes Douglas Aircraft Airbus/ Aeroformation ATA Maintenance Training Committee

Table 4.2 Sources of Information for Technology Survey

Each interview began with a discussion of the perceived status quo of maintenance training. Table 4.3 summarizes the preconceptions that served as a basis for initial discussions.

- Maintenance training is traditional.
- Training personnel do not have time to develop advanced technology training systems.
- FAA has not encouraraged the use of advanced technology as a substitute for laboratory practice.
- Advanced technology is an effective maintenance training alternative.
- There are few vendors of advanced technology for maintenance training.
- Most CBI systems require proprietary hardware.
- Training personnal want advanced technology training systems.

Table 4.3 The Perceived Situation for Interview Discussions

The interviews confirmed that the initial perceptions were accurate. However, there were noteworthy exceptions. Perhaps the most significant of the incorrect assumptions was the FAA position on advanced technology for maintenance training. The discussions with FAA personnel and training personnel throughout the industry confirm that advanced technology training systems have the potential to substitute for real equipment in certain laboratory tasks. For example, an AMT trainee can learn to start and troubleshoot a turbine engine using a simulation rather than the real engine. Advanced technology cannot substitute for many psychomotor activities but is especially useful where students must practice the integration of knowledge and skill for problem solving, decision making, and other such diagnostic activities. It appears, therefore, that simulators and other advanced technology are becoming an important component of maintenance training curricula. Proposed changes to FAR 147 have suggested that "the curriculum may be presented utilizing currently accepted educational materials and equipment, including, but not limited to: calculators, computers, and audio-visual equipment."

4.3.1 A Discussion of Hardware for Advanced Technology Training

All of the interviews resulted in a discussion about the appropriate hardware systems for advanced technology training. While there is not unanimous agreement, the current favorite is the 80286 or 80386 operating in the DOS environment. VGA seems to be the acceptable video hardware standard. Many airline managers were outspoken about their dissatisfaction with the lack of standards among the various CBI vendors. The Air Transport Association (ATA) Maintenance Training Committee (ATA, 1989) has strongly recommended that all manufacturer-produced courseware be designed for a common non-proprietary system like the IBM-AT and compatible computers. That is not currently the case, although the trends are in that direction. Software developers who meet the ATA standards are more likely to succeed in the new marketplace.

The two largest producers of CBI for aviation maintenance are Aeroformation (for Airbus) and Boeing Commercial Airplane Company. Both systems require some proprietary hardware but are somewhat compatible within the 80286/386 family. Douglas Aircraft is also developing CBI that will be compatible with the ATA standard. Another committee that is promoting standards is the Aviation Industry Computing Committee (AICC). They have published hardware guidelines and a catalog of current and planned CBI developments by its members (AICC, 1990).

Among the major airlines there is some hardware variance. Delta Airlines, one of the few to have a significant CBI development staff, is using a large number of 80386 processors with advanced graphical displays. The Delta systems are also DOS-compatible in order to maximize applications.

The majority of Boeing training software is for the 747-400. The Boeing software was developed under contract to a large CBI company. The Advanced Technology training development group at Boeing are cooperating with United Airlines and Apple Computer Company to explore the concept of "Instructor led CBT." Using MacIntosh computers and a variety of color graphics and hypermedia tools, they have created a variety of dynamic displays to be used for group training. Boeing calls the development "Instructor-led CBT." Eventually this approach should find its way to individualized CBI.

4.4 ADVANCED TECHNOLOGY TRAINING PROTOTYPE

As described in Section 4.1, the first phase of the project would establish the current status of advanced technology for maintenance training, and then would build a prototype ITS. The prototype can be used as a demonstration of the application of expert system technology to maintenance training. The prototype (see Figure 4.2) will be used as a model for the fully operational ITSs to be completed in phase two and evaluated in phase three.

Figure 4.2 Advanced Technology Training Prototype

The prototype was developed with two major areas of concern in mind, the interface and simulation. An intuitive, easy-to-use interface was essential for user acceptance of advanced technology training. A correct and realistic simulation of the instructional domain was also crucial. An iterative design approach involving subject matter experts, technical instructors, educational technologists, and computer scientists was used to ensure that both of these goals were achieved.

4.4.1 The Prototype Specifications

The prototype was developed on hardware that is aligned with the ATA-recommended standards. The specifications are listed in Table 4.4. This hardware insures that the prototype will be of value for demonstration on available computers. It does not require special hardware.

• 80286 or 80386 Processor	• Mouse	• C++ Programming Language
• 1Mb of Memory	• MS-DOS	• MS Windows
• VGA Display	• Off-the-shelf software for graphics and windows	
• Hard Disk Storage		

Table 4.4 Hardware and Software for Prototype

The instructional and pedagogical design is a more important consideration than hardware. While the design is hardware and software dependent, it must be emphasized that robust and expensive hardware does not make up for poor design of the instruction. An incomplete listing of the instructional specifications is shown in *Table 4.5*. These specifications evolved with the software.

Table 4.5 Instructional Specifications for Prototype

- Extensive Freeplay and Interaction
- Problem Solving and Simulation
- Explanation, Advice, and Coaching
- Orientation Towards Maintenance Tasks

- Adaptable to Student Skill Level

4.4.2 The Instructional Domain

The primary criteria for selection of the instructional domain for the prototype was that the finished ITS be of immediate value to airlines and to FAR 147 schools. In order to accomplish this goal, the domain had to be a complex system that is prone to failure. In addition, the system had to have an effect on passenger safety and/or comfort. Candidate systems that were considered included the following: hydraulics, auxiliary power unit (APU), engine information and crew alerting system (EICAS), electric power distribution, fuel distribution, and environmental control system (ECS).

ECS was chosen for the prototype system. This system is ideal for many reasons. On the ECS, diagnostic information and maintenance checks occur throughout the aircraft. The system is integrated with the APU and the main engines. The ECS is critical to passenger safety and comfort. Further, the ECS principles can be generalized to many aircraft. Therefore, currently, the ECS is the prototype domain.

4.4.3 Prototype Development Partners

At the outset of this research, the intent was to elicit participation from at least one FAR 147 school and at least one major air carrier. A large number of schools and airlines offered to participate. That is encouraging to the research team and to the FAA sponsor.

The development partners are Clayton State College and Delta Airlines, both in Atlanta, Georgia. The combination of a major airline and an approved FAR 147 school will insure that the ITSs will meet the instructional needs across a wide spectrum of AMT personnel. The combination will insure that the training system is technically correct and instructionally sound. Further the airline/school combination will be ideal to conduct evaluations of training effectiveness and cost efficiency during phase three.

4.4.4 Prototype Development Environment

The development environment for the prototype was chosen in accordance with the prototype specifications outlined in Section 4.4.1. The prototype was developed with Asymetrix Toolbook under Microsoft Windows 3.0. Both of these products allowed access to extra memory, when available.

Toolbook is a software construction set with a graphical user interface and object-oriented programming features (Toolbook is not a programming language). These features allowed for the rapid development of an interface prototype and accompanying simulation.

The Toolbook development environment was excellent for development of an interface prototype. However, as the system grew, Toolbook ran into memory limitations. Also, because Toolbook was not a programming language, there were inherent limitations on flexibility. This inflexibility was highlighted during the development of the simulation.

While adequate for the prototype, Toolbook will not be acceptable for the ITS that will be developed in the second phase. Therefore, different options are being explored for the next phase. A combination of a programming language and an interface development package (still under Windows 3.0) will be used for the next phase. This will allow for a more flexible and more powerful development environment.

4.4.5 Iterative Design Approach

After discussions with subject matter experts, an initial interface prototype was developed. This interface prototype was presented to the development partners for evaluation and critique. Changes were made to the prototype based on these comments. The modified system was again presented to the development partners. This iterative process continued throughout development of the prototype.

As the user interface evolved, work also began on the simulation that works behind the interface. Once again, the simulation development was an iterative process. The subject matter experts ensured both correctness and completeness of the simulation.

4.4.6 Prototype Description

The prototype addressed the following three major areas: Equipment Information, Normal Operation, and Troubleshooting (see Figure 4.3). Help is also available to the student at any time. Each of the major areas is described below.

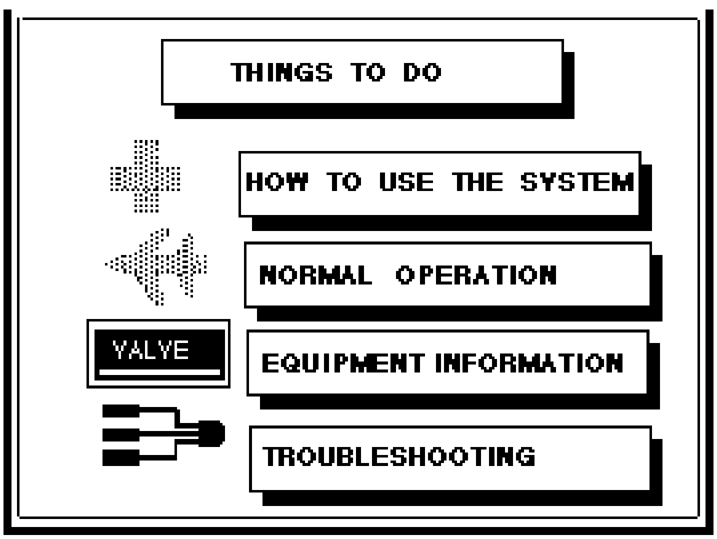

Figure 4.3 Menu Options

4.4.6.1 Equipment Information

The "Equipment Information" mode allows the user to get information about the different components of the ECS. This information describes various switchlights, knobs, buttons, video displays, and warning lights for the equipment used to troubleshoot the ECS.

The equipment that is available to the student includes the following: ECS Overhead Panel, Bleed Air Supply Panel (See Figure 4.4), BITE Boxes, EICAS display, and Cooling Pack Schematic. The approach used to implement Equipment Information is very modular to support the addition of any new equipment in the future.

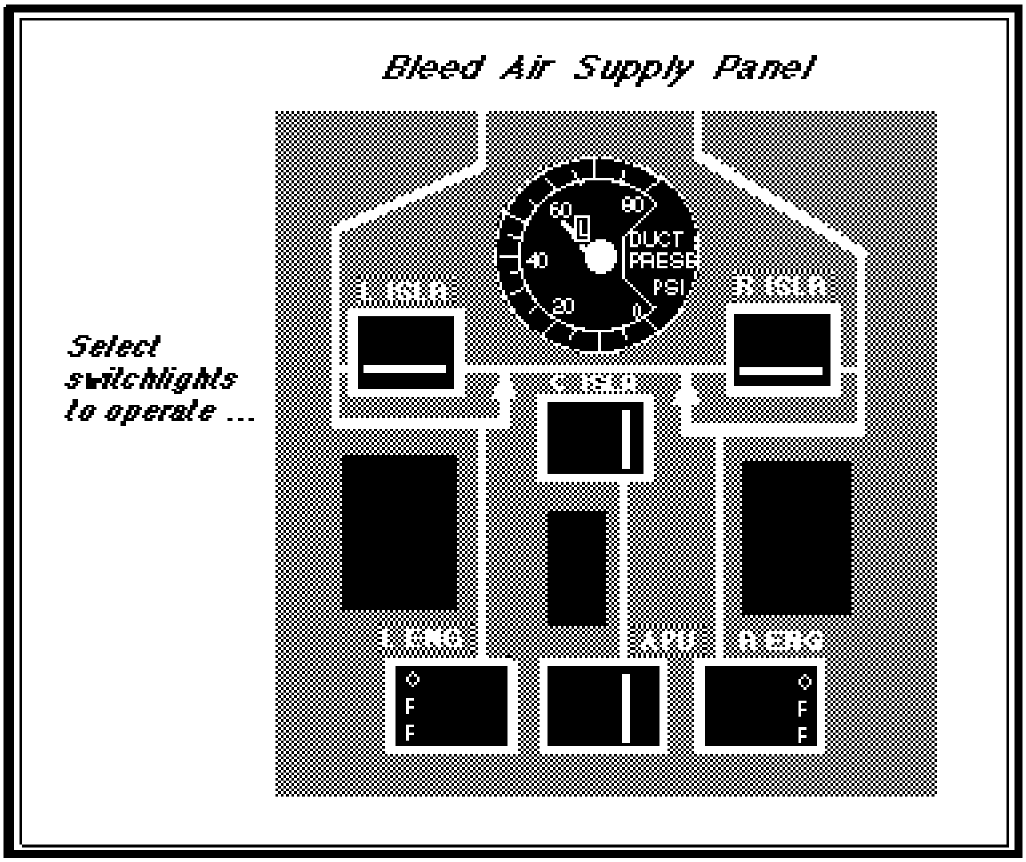

Figure 4.4 Bleed Air Supply Panel

4.4.6.2 Normal Operation

The "Normal Operation" mode simulates how the ECS responds under normal operating conditions. This mode will provide the students with a baseline against which they can compare a malfunction. The student has access to all of the equipment described in Equipment Information. The student can change knob and switch positions just as in the "real" world. In this mode it would not make sense for the student to replace components because every component is good. Part replacement is reserved for Troubleshooting.

4.4.6.3 Troubleshooting

The "Troubleshooting" mode simulates how the ECS operates when a component has failed. As in "Normal Operation", the student can change switch positions. Changes in switch positions will affect the operation of the Cooling Pack as in the "real" world. Also, the student has access to a variety of diagnostic tests (Built-in Test Equipment) and tools to aid in troubleshooting.

The prototype also supports the manufacturer's Fault Isolation Maintenance Manual (FIMM). The FIMM, as shown in Figure 4.5, represents the decision tree that the student may follow to troubleshoot the aircraft. The student chooses the Fault Code to indicate the suspected malfunction. The simulation knows about the current malfunction and notifies the student of any logical errors in the selection. If the correct fault code is selected, then the student sees the specific troubleshooting instructions for that fault code.

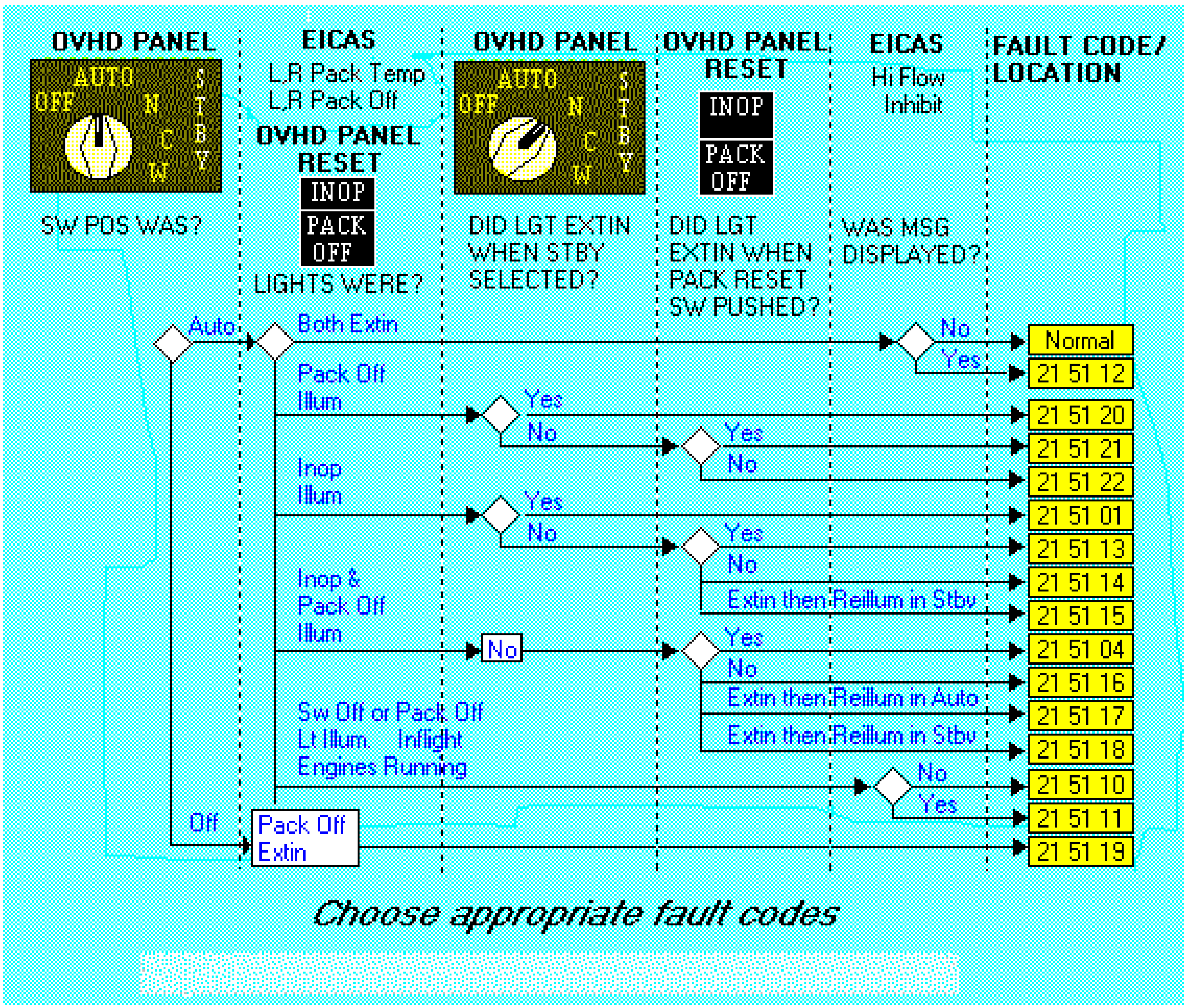

Figure 4.5 Fault Isolation Maintenance Manual

Even though the system supports use of the FIMM, it is not required. The students may troubleshoot in any order that they choose. The student may also swap circuit cards, use a voltmeter to check continuity and voltages (see Figure 4.6), and replace components. Eventually, the student will be able to replace a component and then verify that the replacement corrected the malfunction.

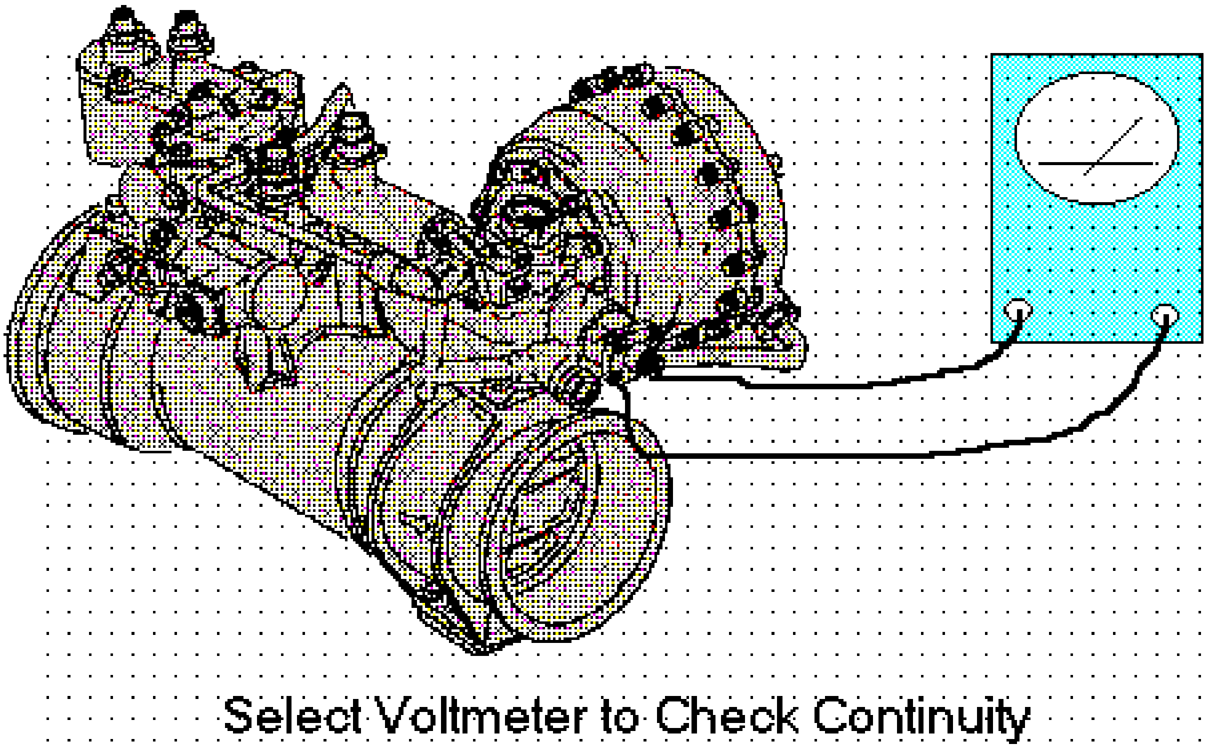

Figure 4.6 Example of ECS Trainer Tools

4.5 PLANS FOR PHASE II

During Phase I the prototype was completed and reviewed by the cooperating airline and Part 147 school. The overall design and technical accuracy of the environmental control system simulation was acceptable. During Phase II the prototype will be converted to a turn-key intelligent simulation.

The Phase I prototype was developed with software tools designed for rapid prototyping. While the tools were easy to use they lacked the robust capability that can be derived from a programming language. During Phase II the simulation will be written in a programming language (C++). The graphics will be developed in a manner that will provide higher resolution and more color with less memory requirements than the prototype.

During Phase II a robust evaluation plan will be designed. The evaluation is likely to involve a design with experimental treatment and control groups. The plan will include methods to assess training effectiveness and cost effectiveness. The experiment will be conducted with the cooperating airline and Part 147 school during Phase III.

4.6 SUMMARY

This chapter has described the ongoing research and development related to the application of advanced technology to aircraft maintenance training. The research has characterized current use of advanced technology for maintenance personnel. Subsequent phases of the research will design, develop, and evaluate an intelligent tutoring system for aircraft maintenance training.

Training humans to learn new skills and to maintain current skills and knowledge is critical to the safe operation and maintenance of manufacturing, power production, and transportation systems. As the U. S. labor force changes, the criticality of such training becomes even more eminent. Intelligent tutoring systems, combined with human technical instructors, offer a cost-effective, reasonable alternative that can impact training immediately and into the future.

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