Chapter Two
Advanced Technology Training for Aviation Maintenance

2.0 INTRODUCTION

As technology advances, the job of the aircraft maintenance technician (AMT) becomes increasingly difficult. The AMT must deal with new technology (digital components, composite materials, etc.) as well as an aging aircraft fleet. Concurrently, the AMT work force dwindles (Shepherd, et al., 1991). Therefore, maintenance training must respond to these challenges by increasing the effectiveness of the current work force. This chapter outlines how the Office of Aviation Medicine (AAM) uses advanced technology training to address these issues.

2.1 RESEARCH PHASES

The advanced technology training research began in January of 1990. This earlier phase of the work assessed the status of training technology for maintenance technicians. Based upon this assessment, the AAM built a prototype intelligent tutoring system (ITS) for the Environmental Control System (ECS) (Shepherd, et al., 1991). See (Polson and Richardson, 1988) for more information on ITS.

The current phase of the research expands this prototype to be an operational tutoring system for the ECS. In order to provide a measure of the effectiveness of the Tutor, this phase also designs an evaluation of the tutor. Finally, as advanced technology training systems become more commonplace, it is likely that they can be used for AMT certification. Therefore, this phase also reports on the research implications of the mechanic certification rules changes to Federal Aviation Regulation (FAR) Parts 65 and 147.

It is important that the Tutor be an effective training tool. Despite formative evaluation of the Tutor throughout the second phase, a formal evaluation will be conducted during the third phase. This will evaluate the Tutor for user acceptance, training effectiveness, and cost effectiveness. In addition, the third phase of the project will investigate the use of advanced technology training for psychomotor activities.

2.2 ADVANCED TECHNOLOGY TRAINING TUTOR

The Advanced Technology Training research developed an operational tutoring system for the ECS of the Boeing 767-300, as shown in Figure 2.1. This section describes the features of the Tutor, the design of the Tutor, and the lessons learned while developing the operational Tutor.

Figure 2.1 ECS Overview Screen

2.2.1 Description of the ECS Tutor

In the ECS Tutor, the student interacts with panels, controls, test equipment, manuals, and displays. These graphics are meant to simulate the "look and feel" of the real ECS components. A simulation of the ECS responds to the student's actions by updating the appropriate data values on the Engine Indicating Crew Alerting System (EICAS) display and the Overhead Panel, as shown in Figure 2.2 and Figure 2.3, respectively.

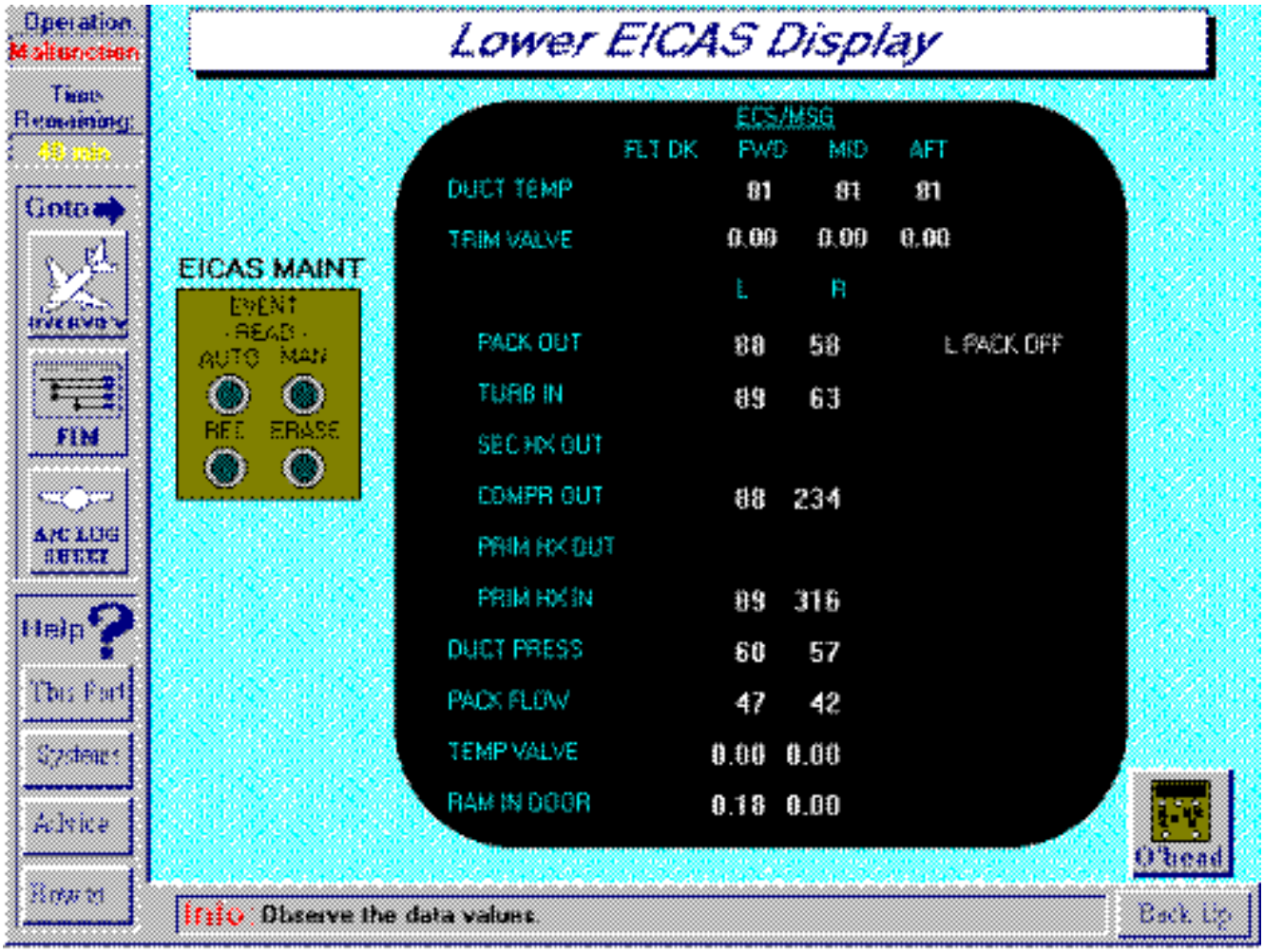

Figure 2.2 EICAS Display

Figure 2.3 Overhead Panel

The system operates in two distinct modes: Normal Operation and Malfunction. During normal operation, the ECS simulation lets the student see the proper operation of the system. During a malfunction, the ECS will exhibit the symptoms associated with the current malfunction. The student controls whether the system operates in normal mode or malfunction mode.

Regardless of the mode, the student's interaction with the system is similar. In both modes, the student has access to all of the tools needed to operate the ECS. The student interacts with control panels, information displays, built-in test equipment, component information, etc. However, malfunction mode is unique in several respects.

As a malfunction begins, the student sees a description of the problem, with the accompanying fault code. After seeing the description, the student may order replacement parts to be delivered to the plane. If the students does not order a part that they need, when they go to replace the part they must wait for the part to arrive. The Tutor simulates this wait by removing 15 minutes from the time that remains.

During a malfunction, the student has access to the Fault Isolation Manual (FIM), shown in Figure 2.4. The FIM is the fault tree that the AMT follows while troubleshooting. It outlines the tests and procedures that should be performed while diagnosing a failure. While troubleshooting from the FIM, the student must perform the tests in the order prescribed by the FIM.

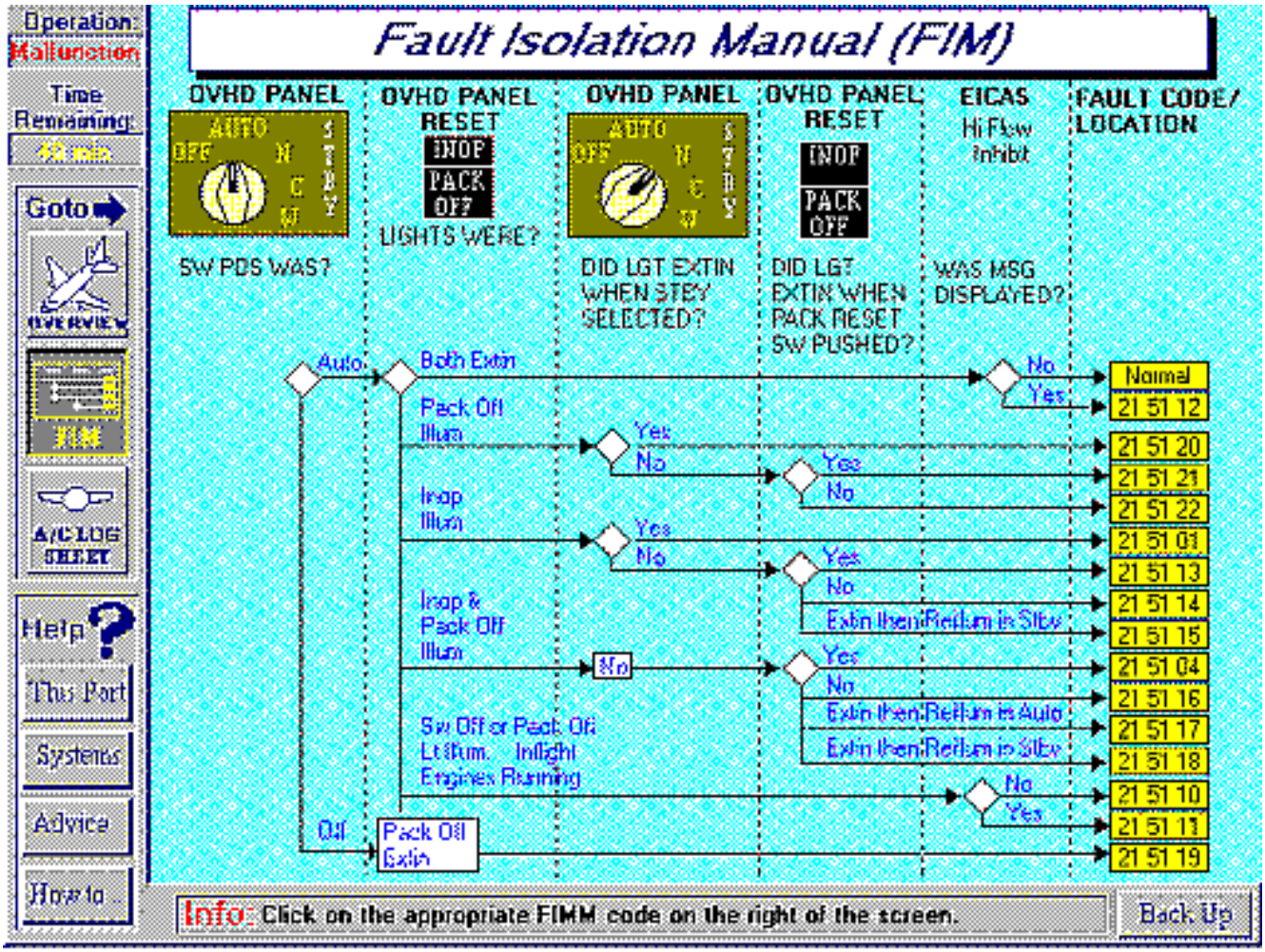

Figure 2.4 Fault Isolation Manual Display

Even though the FIM is the recommended method of troubleshooting, the ECS Tutor supports a more flexible way to troubleshoot. The Tutor provides a schematic of the cooling pack from which the student may troubleshoot. The student selects a component (in any order) from the schematic and then chooses whether to Inspect, Test, or Replace the component.

In both the FIM and the cooling pack schematic, the Tutor records the student's actions. At any time, the student may ask for advice on how to troubleshoot the current malfunction. The tutor compares the student's actions with the actions of an expert. The Tutor suggests the appropriate next step to the student.

When the student replaces a faulty component, the Tutor updates the simulation to reflect proper operation. However, just as on the flight line, the student must verify that the replacement was effective. When the students are confident of success, they can have the Tutor check their solution.

2.2.2 Design of the ECS Tutor

During the design of the ECS Tutor, several separate design issues were addressed. These issues include interface design, instructional design, and simulation design. This section also describes the tools used to implement this design.

2.2.2.1 Interface Design

The design of the ECS Tutor ensures that the majority of relevant troubleshooting information is only one mouse click away from the primary display, shown in Figure 2.5. From this Overview display students may access the displays, controls, and components that they need to troubleshoot a malfunction.

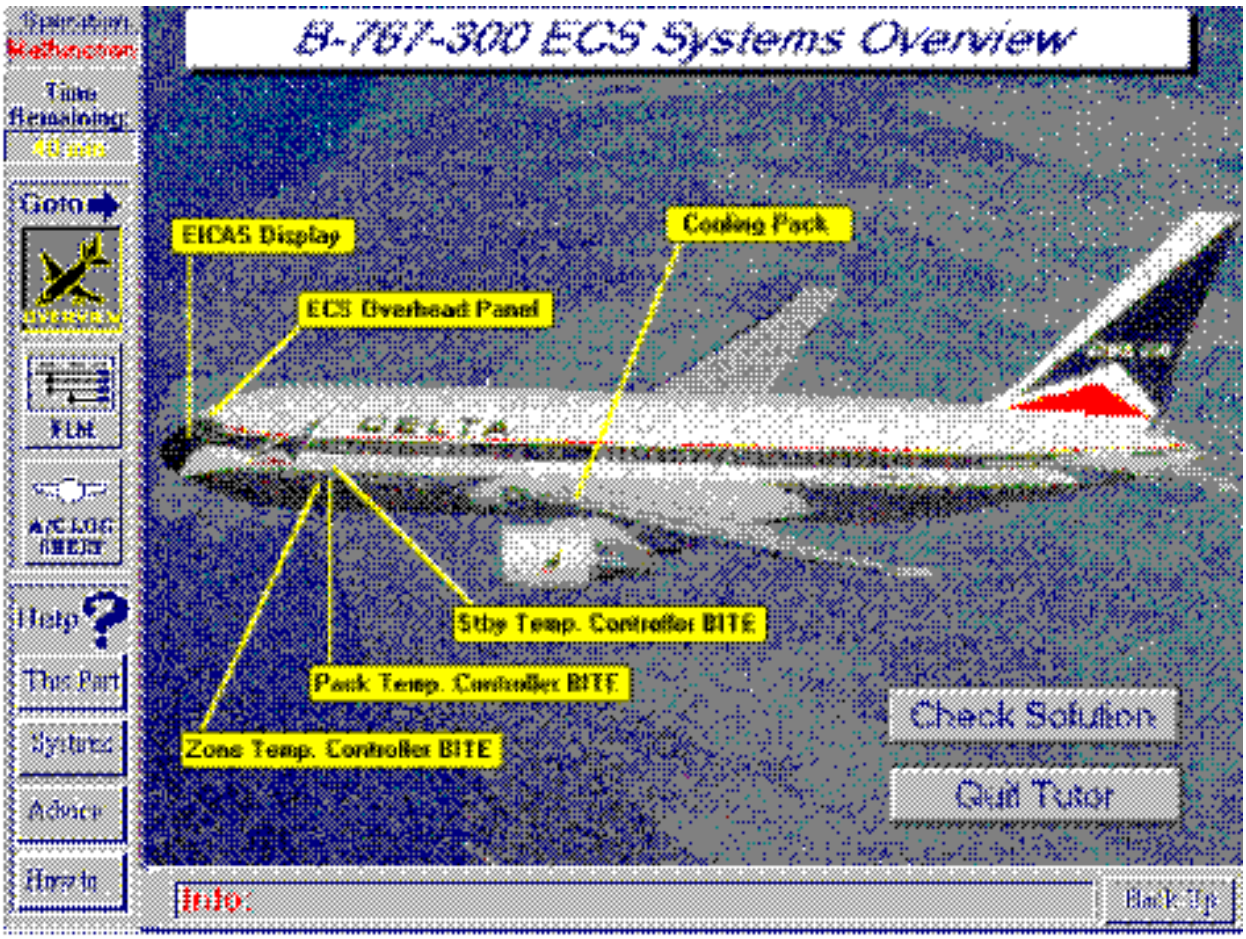

Figure 2.5 ECS Overview Display

Every troubleshooting screen in the Tutor adheres to a standard format, which consists of a grey border on the edge of the screen. The border contains functions that are useful for all troubleshooting screens. The left-hand border consists of three different areas - the Status area, the Navigation (or "Go To") area, and the Help Area. The bottom border contains a Message Area.

The top-most portion of the border is the Status area. This area notifies the student of the current operating mode - "Normal" or "Malfunction". During a Malfunction, this area also indicates the amount of time that remains for troubleshooting. The center portion of the border is the Navigation area. These three buttons allow the student to immediately go to one of three commonly used screens - the Overview Screen, the Fault Isolation Manual, or the Aircraft Log Sheet.

The lower portion of the border is the Help area. This area assists the student in four different ways:

- How to use the current screen
- Information about mechanical, electrical, pneumatic concepts
- How to navigate through the system
- What to do next - advice during troubleshooting

Finally, the border that runs along the bottom of the screen is the Message area. As the student moves the cursor across selectable regions, the Message area shows additional information about that selectable region. For example, the Overview display contains a button labeled "Check Solution". When the cursor enters this button, the Message area will read "Info: Click this button when you think you have solved the problem."

2.2.2.2 Instructional Design

The instructional design of the ECS Tutor was improved in two ways. First, a lesson orientation provides more context for each of the malfunctions. Also, the "over-the-shoulder" advice helps students who are not making progress toward a solution. The following sections describe each in more detail.

2.2.2.2.1 Lesson Orientation

The instructional design for the ECS Tutor centers around the idea of a lesson, where a lesson is a logical collection of malfunctions. Since the Fault Isolation Manual (FIM) is driven by symptoms, the ECS Tutor assembles lessons according to the symptoms for each malfunction (e.g., PACK OFF/INOP lights) . As the Tutor presents each lesson, it provides the student with information similar to that shown in Figure 2.6.

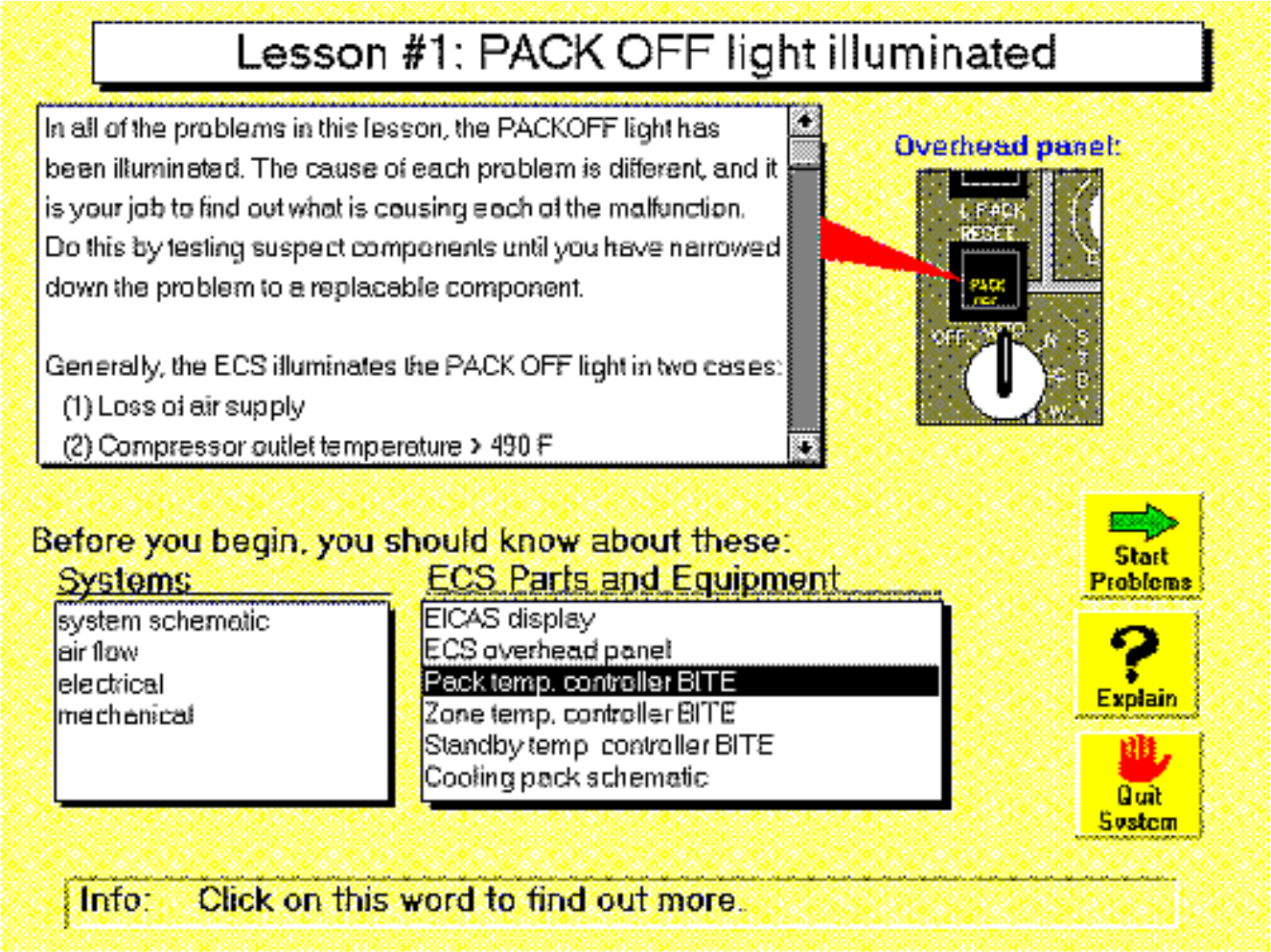

Figure 2.6 Lesson Overview Screen

The Background Information section describes the bases for the indicator lights. This section gives the common causes for the symptom. The Systems section gives a list of systems that relate to the indicator light. The user may choose one of these items to get more detailed information about a specific system. The Objects section provides a list of components that may be useful in solving the current malfunction. The user may choose one of these items to get more information about that component.

After completing a lesson, the Tutor reviews the student's performance from the previous lesson. If the Tutor detects any deficiencies, it will provide material that will help the student overcome the deficiencies.

2.2.2.2.2 Over-the-Shoulder Advice

Another addition to the ECS Tutor makes the advice that the student receives "smarter". In the Prototype, the student received advice only on demand. In the Phase Two Tutor, the system monitors the student's progress toward a solution and offers help to the student if the student does not appear to be making satisfactory progress. The student may choose to see this "over-the-shoulder" advice or ignore it.

2.2.2.3 Simulation Design

The simulation provides realistic responses to a student's actions. For example, the ECS adjusts output temperature of the cooling pack when the student alters the desired zone's temperature. The new data values appear on the Overhead Panel and the EICAS display. The way in which the simulation accomplishes this temperature change should be transparent to the student.

In Phase One, the prototype "simulation" consisted of a table of data values for certain predefined conditions. The data shown to the student was updated according to this table. This approach was adequate for the prototype because of the limited scope of the prototype. However, due to the expanded number of potential malfunctions, the Phase Two operational tutor needed a more robust simulation of the ECS environment.

Phase Two's simulation contains a model of individual components. The simulation acts upon each component's inputs to produce that component's outputs. This approach allows a malfunction to propagate through the system. For example, if a valve fails, it will affect its outputs (such as air flow). The component that is downstream from the valve will receive unsatisfactory air flow and produce an erroneous output. The next component will receive this as its input, and the fault will continue to propagate.

The simulation will act upon inputs to produce outputs, whether those inputs are good or bad. This design allows for the same simulation to be used in both normal operation as well as during malfunctions.

2.2.2.4 Development Tools

The ECS Tutor uses a variety of software tools. The Tutor uses different tools to create the interface, the simulation, and the graphics, as described below.

The interface was developed using Asymetrix *Toolbook*. *Toolbook* supports quick and easy interface development in the Microsoft Windows environment.

The Prototype simulation also used *Toolbook*. However, as the simulation matured, it migrated from *Toolbook* to the "C" programming language. "C" provided greater speed and more flexibility than *Toolbook*.

The graphics used in the operational tutor combine many different graphics creation techniques. Some graphics were custom-designed using graphics packages, while others were scanned from existing training documentation. The Tutor also used photographs taken with a digital camera and stored as graphics files. As the training display hardware advances, digital photographs will become crisper and more realistic.

2.2.3 Lessons Learned from the Development of the Tutor

As the Tutor progressed from the Prototype to the complete, operational system, formative evaluations highlighted several different areas that needed to be addressed: advice, instructional motivation, and student confidence with the interface. A description of each area follows.

2.2.3.1 Advice

When the Prototype gave advice to the student, the advice told the student what procedure to perform next. It followed the FIM exactly. However, it did not provide enough motivation as to why to perform a certain procedure. The current tutor enhances the advice to help answer the question "Why perform this procedure instead of a different procedure ?" With this extra information, the student learns the logic behind the FIM, instead of blindly following procedures.

2.2.3.2 Instructional Motivation

The Prototype emphasized troubleshooting, but lacked instructional focus. During this phase, the Tutor adds more emphasis to instructional issues. As described above in **Section 2.2.2.2**, each lesson contains background information, system information, component information. Much of this information was available for the Prototype, but the student had to search for it. The Tutor now presents the information to the student in a more directed manner. This method reinforces to the student which pieces of information are important under different circumstances.

2.2.3.3 Student Confidence with the Interface

As students used the system, especially for the first time, they were hesitant to click on buttons with the mouse because they weren't sure what would happen. To allay some their indecision, the Tutor now contains the Message area. Anytime the cursor enters a selectable region, a short descriptive message appears in the Message area that describes the function of the selectable region. As training developers, we must be mindful to provide as much reassurance to the student as possible.

2.3 EVALUATION PLAN

If Advanced Technology Training is to become commonplace, it must be accepted by the user population. Also, if it is acceptable to the AMT it must also prove to be an effective training tool. This section outlines a plan to evaluate the ECS Tutor for user acceptance, cost effectiveness, training effectiveness.

2.3.1 User Acceptance Testing

User acceptance testing will be conducted in the following different user populations:

- Delta Air Lines instructors
- Delta Air Lines students
- Clayton State College Airframe & Powerplant (A&P) students

This testing will use questionnaires and interviews to gather data. The ECS Tutor will be modified as necessary to accommodate problems areas that the test identifies.

2.3.2 Training Effectiveness Study

The training effectiveness study will test the following hypothesis:

> A combination of conventional, classroom teaching and the ECS tutor is more effective than conventional, classroom teaching.

This experiment uses both a control group and an experimental group (from the Delta Air Lines student population). Both groups will receive the normal 4 to 5 hour ECS classroom training segment. The control group will receive an additional classroom session on ECS troubleshooting. The experimental group will receive the lesson on ECS troubleshooting via the ECS Tutor. After the troubleshooting session, each group will take an exit exam which will measure their ECS proficiency. The scores on the exit exam will be used as the basis of comparison. Figure 2.7 summarizes the experiment.

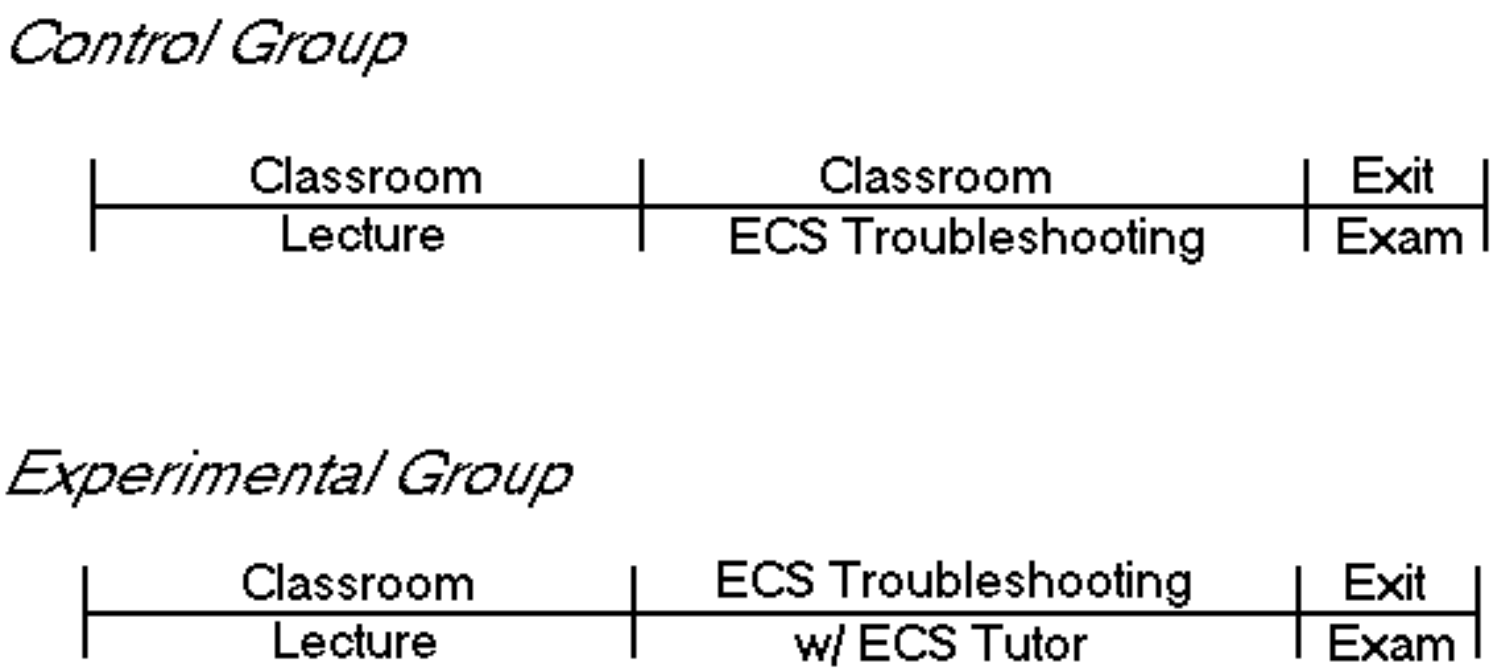

Figure 2.7 Evaluation Plan

2.3.3 Cost Effectiveness Study

A cost effectiveness study will measure the effectiveness of the ECS Tutor along several dimensions. Among these are both development costs and delivery costs.

2.4 PART 147 & PART 65 RULE CHANGES AND HUMAN FACTORS IMPLICATIONS

2.4.1 Part 147 - Aviation Maintenance Schools

From 1989 through 1991 there has been a rule change in the making for FAR Part 147 - Aviation Maintenance Technician Schools. After extensive public hearings, the rule changes are completed and will be published in 1992. The changes in the approved curricula were designed to be more responsive to the needs of today's aviation industry. For example, skill and knowledge requirements for gas turbine engines have been increased while requirements related to fabric covered aircraft have been lessened.

A second significant change in FAA philosophy regards educational media. The new rule permits the substitution of advanced technology training systems (like computer-based training, CBT) for classroom and laboratory instruction. This change in the rule is likely to foster an explosion of CBT for aviation maintenance training. The FAA should monitor the quality of such CBT to ensure that content and the delivery methods are appropriately applied.

The changes to Part 147 are not significant in number. However, the recognition of the potential for computer-based training is a very positive step in helping the schools to train for modern aircraft systems.

2.4.2 Part 65 Certification: Airmen Other than Flight Crewmembers

The public hearings and Aviation Rulemaking Advisory Committees are currently working with the FAA to consider changes to Part 65. The changes that are being considered address such issues as experience requirements, training and proficiency requirements, and issues related to issuances of certification of personnel for repair facilities outside of the United States.

2.4.3 Job/Task Analysis

All who have been involved in Part 147 and Part 65 agree that there is a dire need for a new Job/Task Analysis (JTA) for the Aviation Maintenance Occupation. Such a JTA has not been done since 1969. The activity related to this rule change is prompting the appropriate funding for the AMT JTA.

2.5 SUMMARY

This research shows that Advanced Technology Training can be applied to the Aviation Maintenance community. This particular system concentrated on the ECS because of the generic nature of the ECS system (i.e., ECS principles are similar from aircraft to aircraft). However, this same approach is applicable in all other aviation maintenance areas. Up to this point, the Advanced Technology Training has concentrated on the mental aspects of training (logical troubleshooting). As this work continues, the research will attempt to combine the logical troubleshooting techniques with the psychomotor skills required to maintain the aircraft.

2.6 ACKNOWLEDGEMENTS

This research would not be possible without the cooperation of the aviation industry. Delta Air Lines and Clayton State College have enthusiastically offered their time and ideas to make the final product a success. The authors thank Rick Spavelko, Gary Drake, and Bruce Gindlesperger of Delta Air Lines and Jack Moore of Clayton State College for their cooperation and support.

2.7 REFERENCES

Code of Federal Regulations 65, 147

Polson, M.C., and Richardson, J.J. (Eds.) (1988). *Foundations of intelligent tutoring systems.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Shepherd, W.T., Johnson, W.B., Drury, C.G., Taylor, J.C., Berninger, D. (1991) *Human factors in aviation maintenance phase 1: progress report*(DOT/FAA/AM-91/16) Washington, D.C.: Office of Aviation Medicine.