Phase IV Progress Report

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The research team would like to thank Dr. William Shepherd and Ms. Jean Watson, Office of Aviation Medicine, for their assistance and support during this program.

The authors also wish to thank the many government and industry personnel who continue to cooperate with the research team. As the work continues, the number of contributors (FAA entities, air carriers, and consortiums of industry groups) has grown beyond a reasonable size to individually list all those who have provided guidance and cooperation.

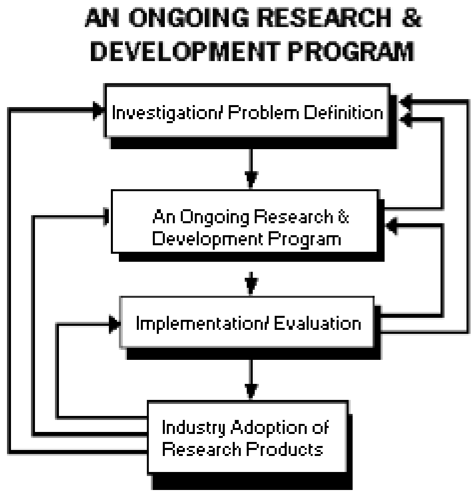
CHAPTER ONE
PHASE IV OVERVIEW

1.0 INTRODUCTION

Since 1989, the Federal Aviation Administration (FAA) Office of Aviation Medicine (AAM) has conducted research related to human factors in aviation maintenance and inspection. The research has been well received by FAA, the scientific community, and the airlines. This research program has sponsored eight workshops on human factors issues in aviation maintenance and inspection. These workshops have been attended by more than 800 participants. The 8th workshop was conducted during this phase of the research program. The theme for this meeting was "Trends and Advances in Aviation Maintenance Operations." The proceedings were distributed in April 1994 and were also included on the second FAA/AAM CD-ROM, produced in May 1994.

Figure 1.1 outlines the research plan for this program. The first phase consisted of extensive investigations of airline maintenance organizations in order to gain a better understanding of the problems/needs of the "real world" of airline maintenance (Shepherd et al., 1991). The second phase developed a number of human performance enhancements based on the findings from Phase I [e.g., the Environmental Control System (ECS) Tutor, NDI Simulation, etc.] (**FAA/AAM** & GSC, 1993a). The third phase continued the investigations and demonstrations of various human performance enhancements. Examples are the FAA/AAM CD-ROM #1, improved workcards for inspection, and the Performance ENhancment System (PENS) for Aviation Safety Inspectors (ASIs). The third phase also began evaluating the effects of the research program outputs (ECS Tutor evaluations) (FAA/AAM & GSC, 1993b; FAA/AAM & GSC, in press). The current phase (Phase IV) also continued with investigations, demonstrations, and evaluations. Phase IV also included fielding of research results. Feedback to all stages of the research program is provided by industry adoption of the research products. All products, procedures, and ideas that have been generated contribute to the continued safety and improvement of operational efficiency through improved human performance.

Figure 1.1 The Research Program



As with the other reports from this research program, this volume begins with a sincere thanks to and acknowledgement of the many government and industry personnel who continue to cooperate with the research team. As the work, continues the number of contributors (FAA entities, air carriers, and consortiums of industry groups) has grown beyond a reasonable size to individually list all those who have provided guidance and cooperation.

The remainder of this chapter describes each chapter in this report.

1.1 PENS FIELD EVALUATION (Chapter Two)

Chapter Two reports on the Performance Enhancement System (PENS) field evaluation plan. PENS **(Figure 1.2)** is a computer-based tool designed to aid ASIs in performing their oversight duties (FAA/AAM & GSC, 1993b). For the evaluation, PENS will be fielded in all nine regions of the FAA, using four different portable computers (three pen-based systems, one trackball system). Approximately 36 ASIs will participate in the evaluation, four at each FSDO. Testing the PENS prototype in the field will identify the tools necessary and viable to ASIs and their supervisors.

Figure 1.2 Performance ENhancement System (PENS)

1.2 DESIGN OF PORTABLE COMPUTER-BASED WORKCARDS FOR AIRCRAFT INSPECTION (Chapter Three)

Chapter Three discusses a computer-based workcard system developed during Phase IV, using a portable computer and hypertext software. This system was based on the improved paper-based workcard developed in Phase III (FAA/AAM & GSC, 1993b). Eight tasks were implemented on the computer-based system (five A-checks and three C-checks). Results from tests performed during Phase IV show that the computer-based system is better than the paper-based system, even though the computer-based system could benefit from improved hardware.

1.3 ERGONOMIC AUDIT FOR VISUAL INSPECTION OF AIRCRAFT (Chapter Four)

In order for airlines to determine which human factors interventions are most urgently needed in their own operations, an ergonomics audit was developed to help evaluate potential human/machine mismatches in any inspection task. Chapter Four discusses this audit which contains a method of choosing tasks to be audited, an audit checklist, and computer program evaluating checklist response against national and international standards to produce an audit report. An evaluation conducted in Phase IV showed that while the audit program is no substitute for a detailed ergonomics analysis, it is a useful tool for identifying error-prone situations. Chapter Four Appendix is an example output from the program.

1.4 INVESTIGATION OF ERGONOMIC FACTORS RELATED

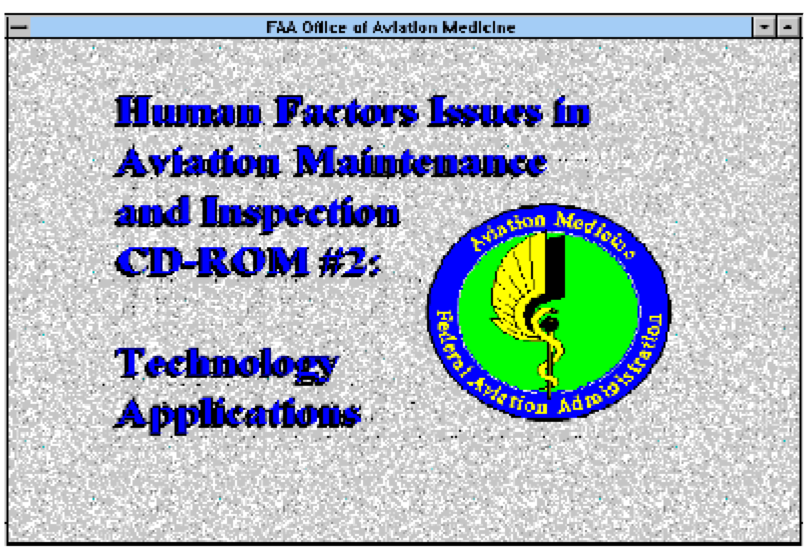
TO POSTURE AND FATIGUE IN THE INSPECTION ENVIRONMENT (Chapter Five)

Chapter Five reports on an investigation of ergonomic factors which may cause increased inspector stress, fatigue and workload, particularly restrictive spaces that cause extreme postures. Phase III developed a methodology for studying the effects of these restrictive spaces on inspector fatigue (FAA/AAM & GSC, 1993b). Phase IV evaluated these effects using a set of four tasks from the C-check of a DC-9. Inspectors were observed and tests were taken to measure fatigue, postural discomfort and workload. The results showed that the same tasks have the greatest impact on the inspector. Based on this evaluation, a posture/fatigue module has been developed and integrated into the ergonomic audit program (Chapter Four). Also several improvements/ interventions were implemented at the partner airline to reduce the effects of restrictive spaces.

1.5 HYPERMEDIA INFORMATION SYSTEM (Chapter Six)

Phase IV continued to expand the Hypermedia Information System (HIS). Research during Phase IV continued to make the tools generic and enhance their functionality. The current HIS contains eight conference proceedings and three phase reports. It also contains one complete training simulation (ECS Tutor) as well as a computer-based workcard system and an ergonomics audit for inspection. The HIS also contains the Performance Enhancement System (PENS). Two new libraries used in conjunction with PENS were added: one contains the Federal Aviation Regulations; the other, the Inspector's Airworthiness Handbook. This edition of the HIS was released on a CD-ROM (**Figure 1.3**) in May 1994.

Figure 1.3. Human Factors Issues in Aviation Maintenance and Inspection, CD-ROM#2



1.6 CORRELATES OF INDIVIDUAL DIFFERENCES IN NONDESTRUC-TIVE INSPECTION PERFORMANCE (Chapter Seven)

A previous report reviewed literature related to differences in inspectors' NDI proficiency (FAA/AAM & GSC, 1993b; FAA/AAM & GSC, in press). Several variables were identified which would appear potentially relevant to NDI inspector selection and/or proficiency:

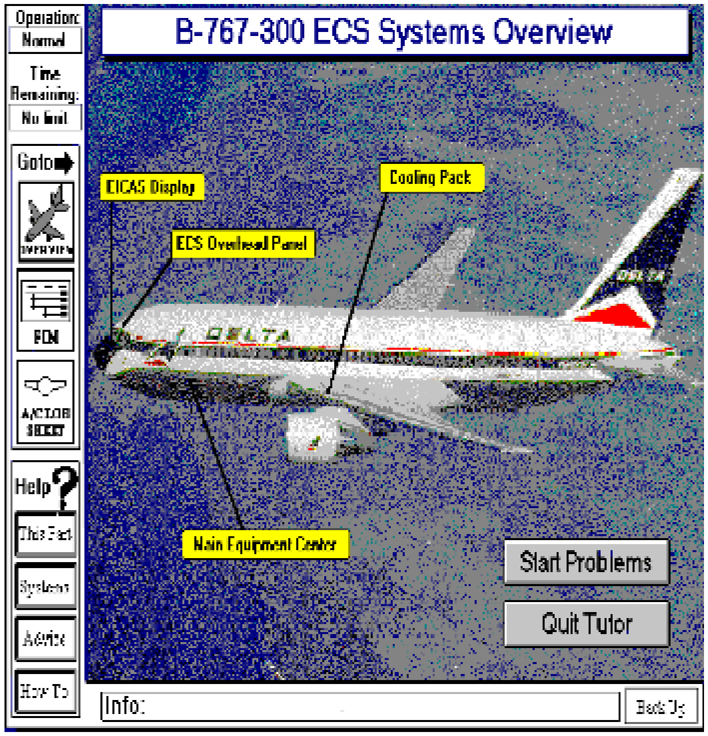
- Boredom Susceptibility
- Concentration/Attentiveness/ Distractibility
- Extroversion/Impulsivity
- Motivation/Perseverance
- Decision Making/Judgement
- Mechanical/Electronics Aptitude
- Need for Autonomy

The goal of Phase IV research was to determine the relationship between selected tests and measures derived from the above category and performance on an NDI task. Research also investigated possible performance changes from sustained performance during a simulated one-day shift and interactive effects between performance changes and the variables identified above. Chapter Seven reports on the findings of this research.

1.7 RESULTS OF THE ENVIRONMENTAL CONTROL SYSTEM TUTOR EXPERIMENT AT CLAYTON STATE COLLEGE (Chapter Eight)

Chapter Eight describes an investigation to determine the effect of an Intelligent Help Agent (IHA) on the effectiveness of computer-based training. The training system used was the Environmental Control System (ECS) Tutor, a simulation-based trainer developed in previous phases of this research **(Figure 1.4).** Subjects used the ECS Tutor either with or without an error-driven IHA. No significant difference in performance was found between the two groups. Other findings are also discussed in the chapter.

Figure 1.4 ECS Tutor



1.8 RELIABILITY IN AIRCRAFT INSPECTION: UK AND USA PERSPECTIVES (Chapter Nine)

The CAA and the FAA co-sponsored an investigation of reliability in aircraft inspection in the United Kingdom (UK) and the United States of America (USA). Aircraft inspection sites in both countries were visited with an analysis made of the overall inspection/maintenance system and of larger floor operations. Similarities were more common than differences due to the technical specification of the tasks, regulatory similarities, and skill and motivation of inspectors. Larger differences in nondestructive testing (NDT) were observed due to a difference in emphasis between the two countries. The USA emphasized rule-based performance; the UK, knowledge-based. Chapter Nine documents the similarities and differences and offers recommendations.

1.9 GUIDELINES FOR DESIGNING AND IMPLEMENTING COMPUTER-BASED TRAINING FOR AVIATION MAINTENANCE (Chapter Ten)

Chapter Ten is a bibliographic overview of selected issues in designing computer-based training (CBT) systems. Issues such as instructional design, information presentation formats, screen design and layout, and hardware are covered. Over 60 references are included.

1.10 FUTURE PLANS

Capitalizing on a research team of scientists and engineers from industry, government and academia, the research program will continue to develop and implement tools and procedures for human performance enhancement. Future phases will increase field studies of research results. The program will also continue to conduct research with partners in both industry and government. All research efforts will continue to emphasize the measurable impact of the research program on increasing maintenance effectiveness and efficiency with resultant cost control.

1.11 REFERENCES

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CHAPTER TWO
PENS PROJECT FIELD EVALUATION

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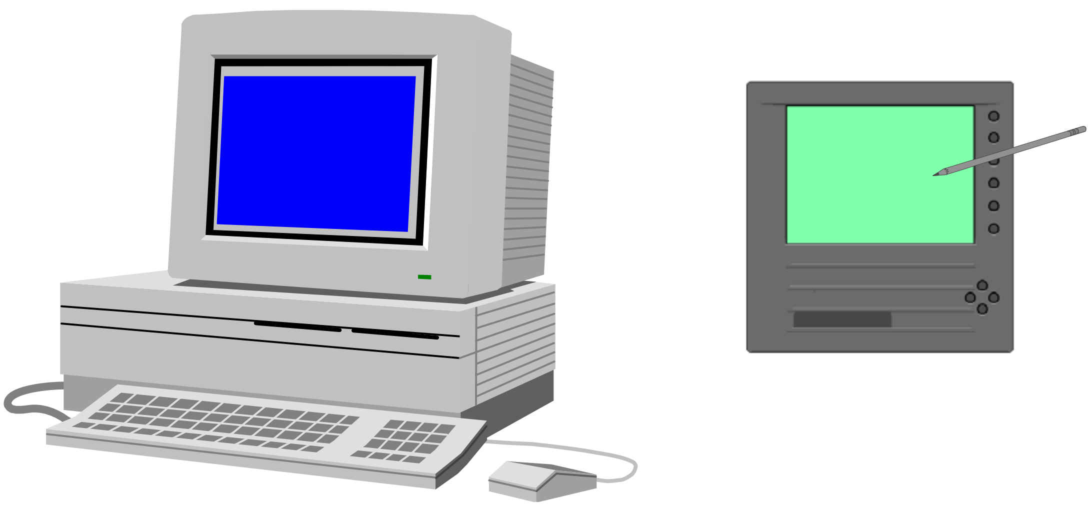
2.1 PENS: A PERFORMANCE ENHANCEMENT SYSTEM

The Performance ENhancement System, PENS, is a tool designed to aid Aviation Safety Inspectors (ASIs) in performing their oversight duties. Aviation Safety Inspectors (ASIs) make up the inspection team for the Flight Standards Service (FSS), which is the regulatory branch of the Federal Aviation Administration (FAA). They perform a variety of tasks, in both commercial and general aviation areas, including: inspecting aircraft and equipment, reviewing manuals and records, certificating pilots, and evaluating training programs.

There are approximately 2,600 ASIs in the nine regions of the FAA. The initial target of PENS is an ASI performing an airworthiness (maintenance) inspection. PENS is an electronic performance support system (Gery, 1991) that combines a "smart" forms application and an on-line documentation system. PENS capitalizes on recent advances in pen computer technology.

Figure 2.1 Comparison of Desktop and Pen Computers



2.2 A BRIEF INTRODUCTION TO PEN COMPUTERS

Pen computers use handwriting recognition software and a pen stylus for input, rather then a keyboard. The operator writes on the screen and the handwriting recognition software translates the written characters to typed characters. The pen stylus also acts as a pointing device, much like a mouse. When combined with a graphical user interface, such as Microsoft Windows for Pen Computing, the pen stylus and handwriting recognition software hold the promise of making computers easier to use than traditional desktop computers. A comparison of typical desktop and pen computers is shown in **Figure 2.1.**

2.3 IMPROVED FORMS

As is typical with regulatory agencies, there are several forms that must be completed while performing an ASI task. Currently, these forms are on paper and require that redundant information be recorded on each form. After completing the forms, the ASI either types the data into a local computer database or he/she submits the forms to a data entry clerk. There are several drawbacks to such an approach. First, redundant recording of data on multiple forms takes time that could be devoted to more productive activities. Second, the two-step process of recording data on paper and then entering the data into a computer is inefficient. Third, one is either paying an inspector to do a task for which he/she is over-qualified, or one is paying for a staff of data entry clerks. Fourth, a data-entry clerk may make transcription errors (due to misreading the inspector's handwriting) or errors due to incomplete knowledge and understanding of the inspector's activities. Such errors mean that the database is an unreliable source of information. Finally, the current process takes considerable time, which means there is a delay in getting safety data into the national database where it can be accessed by other members of the FAA.

Pen computer technology can be easily applied to such tasks to minimize the number of steps required to collect data and assimilate it into the database. Forms will be linked together so that an entry in one form propagates to the other forms, thus eliminating redundant data entries. Furthermore, the data will be collected so that they are ready for direct downloading into the database. This method of collecting data reduces the need for data entry clerks and it reduces data transcription errors. At the end of the work day, the inspector will return to the office, connect the pen computer to the network, and initiate a downloading procedure that will be carried out overnight.

2.4 ON-LINE DOCUMENTATION

The second major contribution of PENS is an on-line documentation system. Whereas ASIs currently must carry two briefcases full of books (including Federal Aviation Regulations (FARs), ASI Handbooks, and other regulatory documents), the necessary data will be stored on the hard disk of the pen computer or on a CD-ROM (compact disc, read-only memory). Not only is the computer media more lightweight and compact, it also facilitates quick retrieval of specific information. For instance, an ASI will be able to search the regulations for the word "corrosion" to answer a question on reporting defects. PENS would then indicate all of the instances of the word corrosion. The ASI could then ask PENS to retrieve the relevant documents and display the pages that discuss the term.

Besides the bulk and inefficiency of the books, inspectors must deal with problems of information currency. One complaint made by inspectors is that they will tell an operator that it is not in compliance with the regulations, only to be shown a more recent edition of those regulations. That is, sometimes the operators get the most recent editions of the regulations before the inspectors do. This problem could be dealt with by distributing updated documents to the pen computers when they are connected to the database computer network. Thus, a new edition of a document could literally be published one day and in the inspector's hands the next.

2.5 ADDITIONAL BENEFITS

A side benefit of using a computer to support inspection activities is that it opens the door to other types of activities and methods for documenting an inspection. For example, an inspector could follow an on-line checklist for an inspection. The checklist would then become the focus of interaction with the computer; by completing the checklist, all of the necessary forms would be automatically completed. We could even develop a scheduling component that would remind the inspector to follow up on an inspection. When documenting an inspection, ASIs currently must record their findings verbally. However, because the bulk of a ramp inspection is conducted by visually inspecting an aircraft, sketching is a more natural method for recording the results of such an inspection. Thus, if an inspector found a leaking seal on the wing of an aircraft, the inspector could annotate a line art drawing of that aircraft on the computer. This graphic could then be stored along with the completed form.

2.6 EVALUATION AND IMPLEMENTATION

There are a number of issues that can affect the success of introducing new technology into the ASI work environment. Many inspectors do not have experience using computers. Of those inspectors, some are willing to try the new tools based on promised increased productivity, while others think that using computers is not part of their job description. Some inspectors are even concerned with how they will be perceived by the operators when they are carrying a pen computer.

We are capitalizing on constraints built into the forms and data to make the system easy to use. For instance, because many fields on the forms require one item out of a finite set of possible entries, one can display that set and select an item from it. This approach has the added benefits of reducing memory demands on the inspectors and of increasing data reliability.

Pen computer configurations and durability must also be considered, as there are significant tradeoffs in these areas. Questions that should be asked include: Is it better to have a lightweight unit without a keyboard, or a slightly heavier unit with a keyboard? Which is more important to inspectors, weight or ruggedness? Is battery life sufficient to even consider using such a device?

Table 2.1 Features of Evaluated Computers

Computer A	Computer B	Computer C	Computer D
486/25 Mhz CPU 200 Mb Hard Drive Built-in Keyboard Pen	486/25 Mhz CPU 80 Mb Hard Drive Separate Keyboard Pen	386/25 Mhz CPU 200 Mb Hard Drive Separate Keyboard Pen	486/25 Mhz CPU 120 Mb Hard Drive Built-in Keyboard Trackball

PENS is undergoing a field evaluation in one Flight Standards District Office (FSDO) in each of the nine FAA Regions in order to answer the above questions and to determine whether pen computers are a viable solution to the FSS information management needs.

2.6.1 Design of the Evaluation

Four models of portable computers, each from a different manufacturer, have been fielded in one office in each of the nine FAA Regions. These computers were selected because each one had a particular differentiating characteristic that may be important to ASIs. For example, three of the computers were pen computers, while the fourth used a trackball. The latter computer was fielded to address the following question: Is a pen computer necessary or will inspectors benefit simply from having a portable computer? This and similar questions have been raised, and rather than dictate an answer and force inspectors to adapt to our decisions, we deemed it more appropriate to provide the inspectors the opportunity to tell us what were their requirements.

The following sections address the details of the evaluation.

2.6.1.1 Evaluated Computers

A total of thirty-six computers (nine units of each of four models) are were fielded. These computers were selected based on their particular combination of features and differentiating characteristics. That is, the computers were selected because they had certain features in common, but they also had a particular feature that made them unique compared to the others. These features are described in **Table 2.1.**

These computers allow us and inspectors to address the following questions:

1. Is a field computer a viable solution?
2. Is a pen computer required, or will any portable computer work?
3. Is a 486 processor required?
4. Is a separate or built-in keyboard preferable (given that it adds weight)?
5. The 80 Mb Hard Drive limits the functionality of the computer, but it also weighs less. Which is preferable: A lightweight machine with limited functionality or a slightly heavier machine with increased functionality?

The following features common to all four computers:

- 8 Mb RAM

- Backlit LCD Monochrome display
- PCMCIA Data Storage Card
- DOS 6.0
- Windows (Windows for Pen Computing or Windows 3.1; functionally equivalent except for handwriting recognition)
- PENS Software

Table 2.2 Evaluation Sites

Region	FSDO	Environment	Installation Dates
Great Lakes	Milwaukee	Cold, snow	November 15-16, 1993
Central	St. Louis	Average	November 18-19, 1993
Southwest	Ft. Worth	Warm, dry	November 21-24, 1993
Western Pacific	Long Beach	Warm, humid	November 29-30, 1993
Northwest Mountain	Seattle	Average, humid	December 2-3, 1993
Alaska	Fairbanks	Extreme cold, dry	December 6-7. 1993
New England	Boston	Cold, snow	December 13-14, 1993
Eastern	Harrisburg	Cold, snow	December 16-18. 1993
Southern	San Juan	Hot, humid, rainy	January 10-11, 1994

The PENS software is common to all four computers and runs nearly identically on each of the three pen computers. (Computer B does not have sufficient hard disk space to contain all of the FARs or the Airworthiness Inspector's Handbook.) It runs essentially the same way on the trackball computer, with the exception that there is no handwriting recognition on that computer.

2.6.1.2 Evaluation Sites

Units were fielded in all nine FAA Regions. This scope gives the project broad exposure to field inspectors and it subjects the hardware to a range of environmental conditions. The nine FSDOs were selected based on the worst-case environmental conditions present in those regions. The FSDOs, environmental conditions, and installation dates are listed in **Table 2.2.**

2.6.1.3 Experimental Design

A team of four inspectors in each FSDO is evaluating these units. These inspectors represent a cross-section of the inspector population in terms of age, sex, work experience, and computer experience. Each inspector is using one of the computers for a week and then switching to a different model. The rotation is counterbalanced to eliminate order effects. This rotation will continue until each inspector has had an opportunity to use each model. At the end of the rotation, each inspector will complete an evaluation form that requests him/her to rate each unit and answer some general questions. **Appendix 2-A** contains a complete set of evaluation forms. The inspectors still have access to the units at this time to refresh their memories of the specifics of each unit. From these data, we will recommend one commercial, off-the-shelf model (or its subsequent version) and a custom design for final implementation. The custom design will be specified because it is unlikely that a commercial, off-the-shelf model will incorporate all of the desired features.

2.6.1.4 Training

The inspectors were trained for two days as a group. The first day of training consisted of DOS and Windows basics, the specifics of Windows for Pen Computing, and training the pen computers to their individual handwriting. The second day of training consisted of using PENS and the On-Line Documentation, the computer rotation procedure, transferring field-collected data to the FSDO database system (the Flight Standards Automation Subsystem, FSAS), and training specific to each of the computers. **Appendix 2-B** contains copies of the training slides. **Appendix 2-C** contains copies of the software user manuals.

2.6.2 Expected Outcomes of the Evaluation

ASI activities are too diverse to expect that a single approach will address all of the difficulties that inspectors encounter in the field. Pen computers will certainly be appropriate for some inspection activities, but it is highly unlikely that they will be appropriate in all situations. For example, cockpit enroute inspections are likely not amenable to a computer tool for two reasons: 1) airlines are becoming increasingly sensitive to devices that emit radio frequency interference (RFI) and the potential for resultant difficulties with avionics; 2) cockpit environments are typically so small that an inspector has room for only a very small notepad, not a computer the size of a clipboard or larger. But one should not condemn the approach just because it does not work in all situations; it just means that PENS tools will have to be modified to meet the requirements of the various environments in which they will be used. For example, we are already investigating voice recognition systems that would permit nearly hands-free operation.

Furthermore, inspectors have already identified specific activities in which PENS would be invaluable even in its present prototype state. For example, inspectors frequently go on week-long trips to remote sites where they will inspect all of the operators in that area. As another example, inspectors also perform in-depth inspections on particular operators. They may spend several days at a single site inspecting all of the maintenance and training procedures, operations materials, and the like to ensure that the operator is complying with the regulations. In both examples, the inspectors need to be able to quickly and accurately collect such field data and they need access to reference materials (FARs, Handbooks, etc.) while they are in the field.

2.7 SUMMARY AND CONCLUSIONS

As discussed above, pen computers use handwriting recognition software and a pen stylus for input, rather then a keyboard. The user writes on the screen and the handwriting recognition software translates the written characters to typed characters. The pen stylus also acts as a pointing device, much like a mouse. The pen stylus and handwriting recognition really make computers viable field devices when they are combined with a graphical user interface, such as Windows for Pen Computing. After extensive in-house evaluations of pen computers, several models were chosen for a field evaluation by Aviation Safety Inspectors. Custom software to support the inspectors was also installed on the computers for evaluation.

As with the introduction of any new tool into an existing system, the effects are widespread. The potential for enhancing the productivity and job satisfaction of Aviation Safety Inspectors is great. However, with that potential comes the possibility of either having no effect (because of rejection of the tool) or, worse yet, actually decreasing performance. Time and again, experience has shown that buying systems and installing them without consulting the individuals who are supposed to use them does not work. Such an approach results in user and management frustration, as well as a waste of resources. Only by developing prototype systems and testing them in the field will the Flight Standards Service learn what tools are necessary and viable to Aviation Safety Inspectors and their supervisors. The PENS project is taking just such an approach.

2.8 REFERENCES

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Appendix 2-A Evaluation Forms

Personnel Background

Post-Training Comfort Level

Evaluation Form Instructions

Evaluation of Computer A (Computers B and C used the same form)

Evaluation of Computer D

Evaluation of Pen Computer Products

PENS Software Evaluation

Personnel Background

Initials: _______ FSDO: _______

Age: _______ Years as ASI: _______

Type of operator you inspect regularly: 121 125 129 133 135 137

other ________ ________ ________ ________

Type of operator you inspect most frequently: 121 125 129 133 135 137

other ________

Have you ever used a computer before? Yes No How many years? _______

What type of computer have you used? IBM PC Compatible (e.g., AT&T/NCR OATS)

Apple Macintosh

Other: __________________

Do you own a computer? Yes No How many years? _______

What type of computer do you own? IBM PC Compatible (e.g., AT&T/NCR OATS)

Apple Macintosh

Other: __________________

Have you ever used a "Mouse" before? Yes No

Have you ever used a "Trackball" before? Yes No

Have you ever used a "Pen Computer" before? Yes No

Do you currently use the PTRS Transmittal System (Paradox)? Yes No

At this point, how comfortable do you feel using a computer?

1	2	3	4	5
not at all comfortable		somewhat comfortable		quite comfortable

What is your opinion of the following computer manufacturers:

Computer A	Favorable	Unfavorable	No Opinion
Computer B	Favorable	Unfavorable	No Opinion
Computer C	Favorable	Unfavorable	No Opinion
Computer D	Favorable	Unfavorable	No Opinion

Post-Training Comfort Level

Initials: ________ FSDO: ________

Now that you have been trained...

How comfortable do you feel using a computer?

1	2	3	4	5
not at all comfortable		somewhat comfortable		quite comfortable

How comfortable do you feel using a pen computer?

1	2	3	4	5

not at all comfortable somewhat comfortable quite comfortable

How comfortable do you feel with handwriting recognition?

1	2	3	4	5
not at all comfortable		somewhat comfortable		quite comfortable

How comfortable do you feel with the PENS PTRS?

1	2	3	4	5
not at all comfortable		somewhat comfortable		quite comfortable

How comfortable do you feel with the On-Line References (Hypermedia)?

1	2	3	4	5
not at all comfortable		somewhat comfortable		quite comfortable

Do you have any other comments?

If there is anything you feel the least bit uncomfortable about, or if you have any questions, please bring them to our attention now. We are here to address your concerns and ensure that PENS meets your needs. PENS will only be as good as you personally make it. Please take the time to bring your concerns to our attention.

Evaluation Form Instructions

Please use the **Computer A, Computer B, Computer C,** and **Computer D forms** to evaluate the individual computers at the end of each week. *(One form per week.)*

At the end of the evaluation period, use the form labelled **Evaluation of Pen Computer Products** to evaluate all four computers at once. At that time, please use the **PENS Software Evaluation** form to tell us what you think of the project.

Chuck Layton will return between mid-January and early February to debrief you and answer individual questions.

Evaluation of Computer A

(Computers B and C used the same form)

Initials: ________ FSDO: _________

Please rate the computer on the following factors:

Weight	Too Heavy	Adequate	Too Light/Fragile
Size	Too Large	Adequate	Too Small (e.g., screen)
Speed	Too Slow	Adequate	Fast
Display--inside	Too Dark	Adequate	Too Bright
Display--outside	Too Dark	Adequate	Too Bright
Pen Responsiveness	Too Slow	Adequate	Too Fast
Pen Feel	Too Slick	Adequate	Scratchy

Overall Comfort Not Comfortable Adequate Comfortable

What were the environmental conditions in which you used the computer?

snow drizzle rain heat cold frigid

Did you use the computer for five working days? Yes No

If not, why not? Broken On Travel/Vacation/RDO Too difficult to use

Do you prefer to have the pen tethered to the unit? Yes No

Could you comfortably carry this unit throughout a typical day? Yes No

If a neck, shoulder, or waist strap were available, would you use it? Yes No

Which would you prefer? Neck Shoulder Waist

What are the three largest drawbacks to this product?1. ______________________

2. ______________________

3. ______________________

Would you use this computer in the field as part of your job? Yes No

If not, why not?

Evaluation of Computer D

Initials: _______ FSDO: ________

Please rate the computer on the following factors:

Weight	Too Heavy	Adequate	Too Light/Fragile
Size	Too Large	Adequate	Too Small (e.g., screen)
Speed	Too Slow	Adequate	Fast
Display--inside	Too Dark	Adequate	Too Bright
Display--outside	Too Dark	Adequate	Too Bright
Trackball Speed	Too Slow	Adequate	Too Fast
Trackball Ease	Too Cumbersome	Adequate	Easier than a Pen
Overall Comfort	Not Comfortable	Adequate	Comfortable

What were the environmental conditions in which you used the computer?

snow drizzle rain heat cold frigid

Did you use the computer for five working days? Yes No

If not, why not? Broken On Travel/Vacation/RDO Too difficult to use

Could you comfortably carry this unit throughout a typical day? Yes No

If a neck, shoulder, or waist strap were available, would you use it? Yes No

Which would you prefer? Neck Shoulder Waist

What are the three largest drawbacks to this product? 1. ______________________

2. ______________________

3. ______________________

Would you use this computer in the field as part of your job? Yes No

If not, why not?

Evaluation of Pen Computer Products

Initials: _______ FSDO: ________

Please gather together all four of the evaluated computers, then *circle the best computer* and draw an *X through the worst computer* for each of the following characteristics:

Weight	Computer A	Computer B	Computer C	Computer D
Size	Computer A	Computer B	Computer C	Computer D
Speed	Computer A	Computer B	Computer C	Computer D
Display inside	Computer A	Computer B	Computer C	Computer D

Display outside Computer A Computer B Computer C Computer D

Pen Responsiveness Computer A Computer B Computer C Computer D (trackball)

Pen Feel Computer A Computer B Computer C Computer D (trackball)

Handwriting Computer A Computer B Computer C Computer D

Comfort Computer A Computer B Computer C Computer D

Which product do you prefer?

Computer A Computer B Computer C Computer D No preference

Do you think you could carry any of these units for a significant period of time? Yes No

Which one? Computer A Computer B Computer C Computer D

If a neck, shoulder, or waist strap were available, would you use it? Yes No

Which would you prefer? Neck Shoulder Waist

Would you prefer a very rugged unit, even though it weighs nine pounds? Yes No

What are the three largest drawbacks to all of these products? 1. ______________________

2. ______________________

3. ______________________

The following is a description of two products. Which one would you prefer?

Product A. Product B.

Weight: 1-3 lbs.	Weight: 3-5 lbs.
Runs only PTRS form	Runs complete PENS system
Doesn't run Windows	Runs Windows and Windows applications
No keyboard	Built-in or separate keyboard

PENS Software Evaluation

Initials: _______ FSDO: ________

Now that you have used PENS for a signficant period of time, please tell us what you think.

I enjoyed using PENS. True False

I am eager to see PENS evolve to meet my additional needs. True False

I would like all of my forms linked together so that I don't have to fill in the same information on multiple forms. True False

I will continue to use PENS after the evaluation period. True False

I would rather use paper in the field and transcribe the forms at the office. True False

I would rather use the current transmittal system (FSAS) for transcribing forms. True False

I like the On-Line References (Hypermedia), such as FARS and Handbooks. True False

I would like more On-Line References (Hypermedia), such as ADs, ACs, etc. True False

The On-Line References (Hypermedia) are the best part about PENS. True False

I had difficulty transferring my files from the computer to the network. True False

If any of the following need improvement, please comment below:

<u>Section I</u>

PTRS Record ID function

Inspector ID, Inspector Type, Activity Number, and FAR screen

NPG

Status

Callup Date, Start Date, Completion Date

Designator

Airman Certification #

Airman Name/Other

Aircraft Registration #

Make-Model-Series

Loc/Departure Point, Arrival Point

Flight #

Investigation #

Tracking

Miscellaneous

Numeric Misc

Local Use

National Use

Activity Time

Travel Time, Travel Cost

Section II, Personnel

Personnel Name

Position

Base

Remarks

New Entry, Save Entry, Clear Entry

Section III, Equipment

Manufacturer

Model

Serial #

Remarks

New Entry, Save Entry, Clear Entry

Section IV, Comments

Primary

Key Heading

Key Word

Opinion

Clear Comment

Erase Last Ink

Erase All Ink

Undo Last Erase

Transcribe

Transcription Screen

Scratchpad Entries

Transcribed Text

Done For Now, Keep Ink

Done, Erase Ink

<u>Aircraft Graphic</u>

<u>Help</u>

<u>Save</u>

<u>Save Verify</u>

<u>Open</u>

<u>New</u>

<u>Exit</u>

On-Line References (Hypermedia)

Open Book

Topics (Table of Contents)

Viewer

Searching

--This Chapter

--Entire Book

Bookmarks

Copying

Other

Data Transfer

Inspector Name

Transfer List

Record List

Supervisory Review

Previous

Next

Transfer

Print

Delete

Appendix 2-B Training Slides

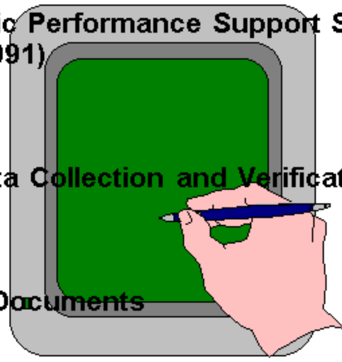
Training Slide 1

Training Slide 2

PENS

The Performance ENhancement System for Aviation Safety

What is PENS?



- Electronic Performance Support System (Gery, 1991)
- Field Data Collection and Verification
- On-line Documents

Training Slide 3

PENS

PENS Timetable

The Performance ENhancement System for Aviation Safety

1993	1994	1995
• Field Evaluation of Airworthiness Prototype	• Complete Airworthiness and Avionics PENS • Prototype Operations PENS • Field Evaluation of Operations Prototype	• Complete Operations PENS • Prototype General Aviation PENS • Field Evaluations of General Aviation Prototype • Complete General Aviation PENS

Training Slide 4

PENS

The Performance ENhancement System for Aviation Safety

Schedule
Day One

- Demo
- Background Information
- Introduction to Computer
- Windows Tutorial
- Windows Practice
- Pen Computer Tutorial

Training Slide 5

PENS

The Performance ENhancement System for Aviation Safety

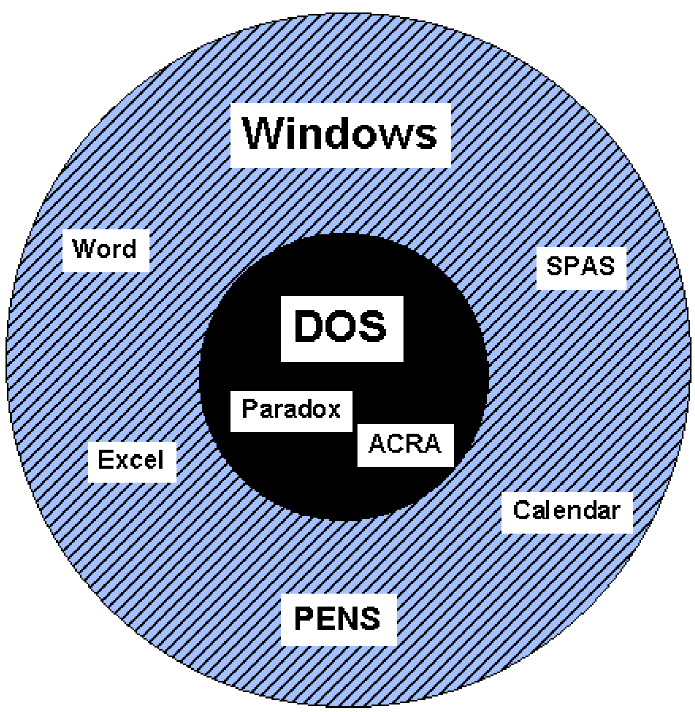
Schedule
Day Two

- PENS Training
- PENS Practice
- Data Transfer Training
- Data Transfer Practice
- Evaluation Forms
- Rotation Schedule
- Specific Computer Training

Training Slide 6

You cannot harm the computer by using it!

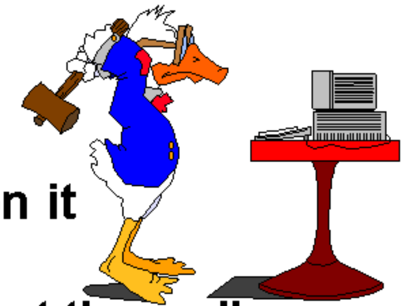
Training Slide 7



Training Slide 8

You can harm the computer by:

dropping it



spilling liquids on it

throwing it against the wall

But if you do, you will make several people very unhappy with you.

Training Slide 9

D O S

- *S*tands for: *D*isk *O*perating *S*ystem
- Basic operating level
- Runs programs and stores data
- Hierarchical organization of data

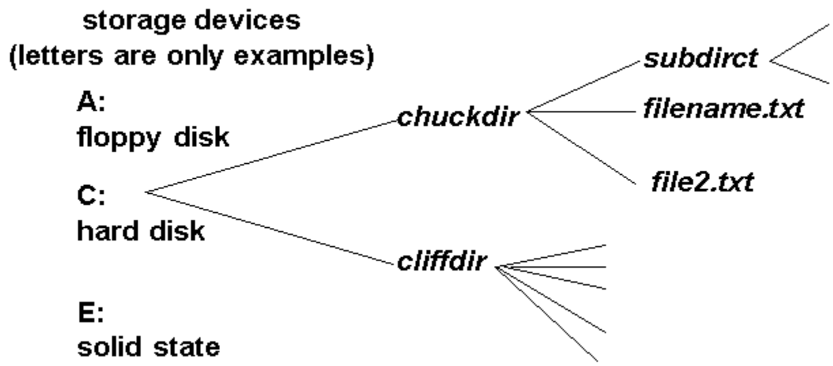
    --files: lowest element

    --subdirectories: hierarchies of files

    --both are limited to eight letter names and three letter extensions: eg. *filename.txt*

Training Slide 10

DOS (cont.)



Training Slide 11

DOS (cont.)

To get out of DOS and back to Windows:

1. Type *exit <Enter>*

2. Type *win <Enter>*

3. Restart the computer

   Hold down *<Ctrl>* *<Alt>* and *<Del>* keys simultaneously

   Turn off the computer and turn it on again

Training Slide 12

Windows

- Graphical User Interface (GUI)
- Shows programs as screen objects
- Take action on screen objects
  - Point
  - Click
  - Double Click
  - Drag

Windows for Pen transcribes printed text to “typed” text

Training Slide 13

Tips

- Turn off the computer before plugging or unplugging any devices:
  - --keyboard
  - --floppy disk drive
  - --network connection
  - --CD-ROM
- Plug the computer into AC power when possible and convenient
- Plug the computer into the cigarette lighter when possible and convenient
- Turn off the computer if it will be idle for a half hour or more

Appendix 2-C Software User Manuals

PENS User Manual

HyperMedia User Manual for FARS and Inspector's Handbook

PENS User Manual

PENS is a suite of tools to assist Aviation Safety Inspectors (ASIs) in their daily activities. It primarily addresses two main aspects of inspector activities: data collection via the PTRS form and accessing regulatory documents. The current PENS softare provides these functions for airworthiness activities, including an enhanced version of the PTRS form. Future development will include the forms, job aids, and reference documents associated with all ASI activities.

1. Data Collection Procedure

Here are the necessary steps to run the PENS software:

1. Start Windows, if you are not already in the Windows envrionment.

2. Start the **PENS** software located in the **PENS** group.

3. Fill out the information on the PENS Login Screen. This information is needed to identify the job aids, forms, letters, and reports that are required for an inspection activity. (See PENS Login Section for detailed information on how to enter this information.)

4. Press the **OK** button. This action brings you to the PTRS screen.

5. The PTRS screen is divided into four sections. Boxes containing the required information for the activity are surrounded with thick black boxes. Fill out these boxes accordingly. (See PTRS Section for detailed information on how to enter this information.)

6. You can also access the FARs and Inspector's Handbook using the PENS Function buttons (the Job Aid and Aircraft functions are not currently functional).

7. Choose either **SAVE** or **SAVE VERIFY** to save your data. **SAVE VERIFY** will review your data for consistency and completeness. **SAVE** will not make such checks, but it will save your data for later verification. PTRS records cannot be transferred to FSAS database if they are not verified.

8. Select **EXIT** when you are finished with the data collection.

2. PENS Login

The following paragraphs illustrate how to fill out information on the Login screen:

1. **Inspector ID:** Enter your three character initials. (Other fields will be blanked until this information is filled in.)

2. **Inspection Type, Section, Heading** and **Subheading** fields will help you select the proper activity number. (These fields replace the small notebooks you currently use.) To supply this information press the down-arrow on the corresponding list box and select one of the options. Once these fields are filled out, the PENS will supply the relevant Activity Number.

3. If you know the Activity Number, you may write or type the number in the **Activity #** field instead of performing step 2. PENS will automatically fill the Inspection Type, Section, Heading and Subheading (if available) information.

4. Once you have entered an activity number, the FAR field will contain a list of relevant FARs for that activity number. Select the appropriate FAR for the activity.

5. Hit one of the following buttons to continue:

CLEAR: Erases all input on the Login screen.

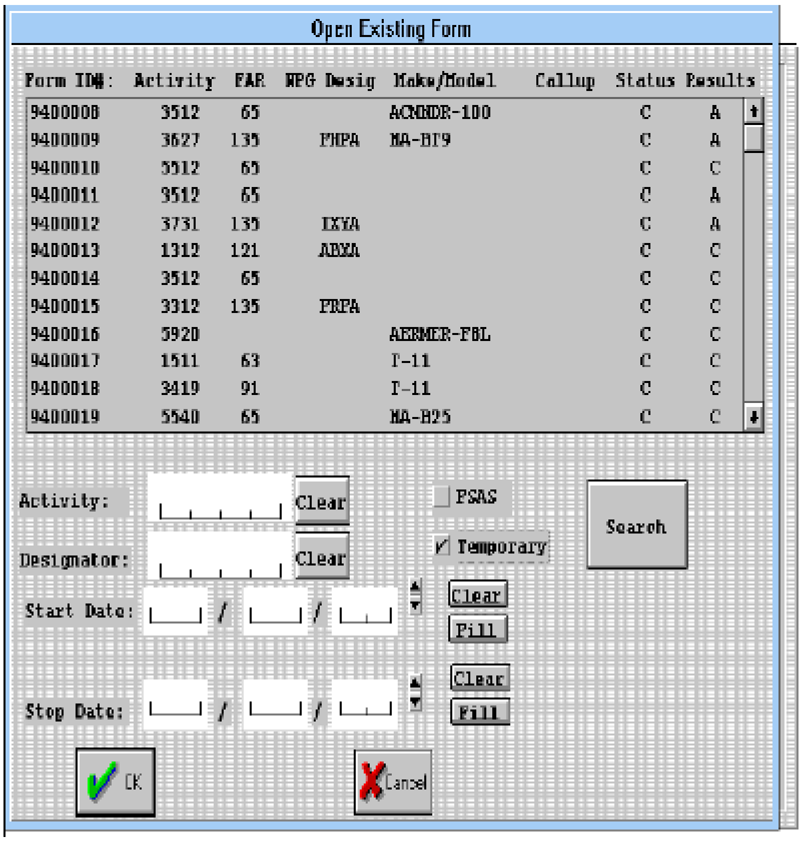
NEW: Creates new PTRS form with the information from the Login screen. If a backup PTRS exists, PENS will give you a choice to restore or delete the backup.

OPEN: Opens a specific PTRS form. (See section 2.1)

CANCEL: Cancels the operation and exits from the PENS software.

2.1 Opening an existing PTRS form

Figure 1. The Open Screen



The OPEN button accesses the Open Screen **(Figure 1).** The screen displays the Record ID Number for all PTRS forms found in the database. When the **FSAS** button is checked, PENS will display only the PTRS forms in the FSAS database. Likewise, PENS will only display PTRS forms in the temporary directory when the **TEMPORARY** button is checked. When a form is selected, PENS also provides the Activity number, Designator, Aircraft, Status, and Verification status to help you identify the desired PTRS form.

You can also search for a specific PTRS form. To do this, follow these steps:

1. Check the **FSAS** or the **TEMPORARY** button to identify the database to search on.
2. Enter a specific activity number in the **Activity:** field.
3. Enter a specific Designator Code in the **DESIGNATOR** field.
4. Hit the **SEARCH** button. All records in the database that match the search information will be displayed in the **FORM ID#** box.

5. Tap the desired form to select it. (Corresponding information about the file will be displayed.)

6. Press **OK**.

3. PTRS

The screen is divided into four sections (see below). Depending on the Activity number, thick black borders will be placed on several fields. This border indicates that the informatin is required for the activity (detailed instructions for completing the form are provided in each section).

Section I: Used for describint the PTRS activity, the overall results, the subject and other basic information

Section II: Used for recording informatin acquired on personnel (other than those recorded in Section I) during the accomplishment of the task. It is also used to record a certificate applicant's information along with the recommending instructor's information for a designated examiner's certification activity.

Section III: Used for identifying a particular item that was inspected by manufacturer, model and serial number (other than that identified in Section I).

Section IV: Used for classifying observations or evaluations into specific areas of interest in a coded format.

3.1 Section I -- General

The following paragraphs illustrate how to fill out Section I of the PTRS Screen:

Inspector Name Code, Inspection Type, Activity Number and **FAR**: These fields are not editable. To modify this information, hit the **SELECT** button next to the **Activity Number** or **FAR** field. This action takes you to the PENS Login Screen where you can change the information.

NPG: Check the box if the activity is an NPG required surveillance.

Status: Select Closed, Open or Planned from the status list.

Callup Date, Start Date and **Completion Date:** Modify these fields using the corresponding arrow buttons. (Some of these dates are automatically filled based on the activity status.)

Results: Select one of the following result codes:

Completed: Indicates that the activity was completed. It is used to close out all work activities except Surveillance.

Assistance: Used to prevent recording more than one unit of work for an activity when inspectors of the same specialty combine their effort to accomplish an activity.

Satisfactory: Used to close out Surveillance activities and indicates the activity was in full compliance. This code should only be used when no comments are made.

Information: Indicates that the result of the inspection was satisfactory in the Flight Standards program area, but there is information in the PTRS Section IV that is pertinent to future surveillance of the activity. Additional information must be provided in Section IV.

Follow up: Used in two ways, either to indicate that a corrective action was taken prior to completing the Surveillance activity, or that a re-inspection was opened for completion in the future to confirm continued compliance. Additional information must be provided in Section IV.

Enforcement: Indicates that a violation was found and an enforcement action opened. Additional information must be provided in Section IV.

X(Canceled): Indicates a Surveillance activity has been canceled. A planned activity should be canceled when the scheduled date exceeds 60 days, if the same activity is scheduled at a later date. Do not use X to cancel an NPG Required Surveillance, except when the DO's division grants a deviation from the required Surveillance in accordance with FAA Order 1800.56.

Terminate: Indicates that a certification activity was aborted or that an NPG required surveillance was terminated because the subject of inspection ceased operation or no longer was active within the region.

Pass or **Fail:** Check either box to indicate the result of certification activity or the conclusion of various evaluation activities.

Designator: Enter the designator code for the subject. If you do not know the code, hit the **SELECT** button to access the Designator Screen.

The Designator screen will help you select the appropriate designator code for an operator. One way to find the code is using the search function: Enter a portion of the operator name or the designator code in the **FIND** field, then press the **SEARCH** button. The first matching data will be highlighted. You may need to press the **SEARCH** button repeatedly until you find the right operator.

An alternative method is to use the INDEX buttons (**A-G** to **0-9**). Push the INDEX button that contains the first letter of the operator name and then scroll until you find the desired operator.

Once the right designator code is selected, press **OK**.

Airman Cert #: Enter the applicable certificate number.

Airman Name/Other: Enter the name of airman, non-certified organization, training course, or topic of a special project as applicable, which is not associated with an Air Operator or an Air Agency.

Aircraft Reg #: Enter the aircraft registration exactly as it appears on the registration.

Make: Enter the manufacturer of the aircraft. If you do not know the manufacturer, press either the **SELECT** button or the **Make/Model/Series** button.

The **SELECT** button will access the Make screen. There are two ways to find the aircraft manufacturer in this screen:

1. Enter the first few letters of the manufacturer name in the field **FIND** and press the **SEARCH** button. The first matching entry containing these letters will be highlighted. Additional manufacturers may be found by subsequent pushing of the **SEARCH** button.
2. Press an INDEX button containing the first letter of the manufacturer and then use the scroll bar to find it. Tap the manufacturer name to select it.

Once the right manufacturer is highlighted, press **OK**. The cursor will change into an hour glass while the software loads the models and series.

The **Make/Model/Series** button accesses the Make/Model/Series screen. This button can be used instead of the above method, provided that you know the aircraft popular name, model, or series. There are several ways of finding the aircraft code in this screen:

1. Enter the first few letters of either the manufacturer, popular name, model, or series in the field **FIND**. Then press either one of these buttons: **SEARCH MAKE** (search the manufacturer), **SEARCH NAME** (search the popular name), **SEARCH MMS** (search the make, model and series), or **SEARCH ALL** (search all information). The first matching entry containing these letters will be highlighted. Additional aircraft may be found by subsequent pushing of the **SEARCH** button.

2. Press an INDEX button containing the first letter of the manufacturer and then use the scroll bar to find the aircraft. Tap the aircraft name to select it.

Once the right aircraft is selected, press **OK**. The cursor will change into an hour glass while the software loads the make, model, and series.

Model and **Series:** Select the appropriate Aircraft Model and Series from the corresponding lists. (These codes will automatically be entered if you used the Make/Model/Series screen to find the aircraft code.)

Depart: Enter the code for the airport most proximate to the location of activities conducted outside of the office (for En Route inspections, enter the code of the departure airport). If you do not know the code, hit the **SELECT** button to access the Airport Screen.

There are three methods to find the airport code in this screen:

1. Enter the first few letters of the city, airport name or airport code in the field **FIND** and press the **SEARCH** button. The first matching entry containing these letters will be highlighted. Additional manufacturers may be found by subsequent pushing of the **SEARCH** button.

2. Enter the state where the airport is located, in the field **STATE:** and press the **SEARCH** button. Use the scroll bar to find the airport. Then tap the airport name to select it.

3. Press an INDEX button containing the first letter of the state (**INTL** for international airports) and then use the scroll bar to find it. Tap the airport name to select it.

Once the right airport is selected, press **OK**.

Arrival: Enter the code for the arrival airport. If you do not know the code, hit the **SELECT** button to access the Airport screen. (See the above information for searching the arrival airport code.)

Flight #: Enter the flight number, if available.

Investigation #: Enter the investigation file number assigned to the accident, violation, incident, or complaint associated with the activity.

Tracking: This field is only activated for certain activity numbers.

Miscellaneous: Enter miscellaneous information regarding a work activity. Enter "OBSVD" to document examiner certification activities that are observed by inspector.

Numeric Misc: Enter items for later mathematics manipulation, e.g., the number of records checked during a records system inspection.

Local Use: Used for temporary tracking of selected activities.

Regional Use: Used for temporary tracking of selected activities. This block may be used by the DO on a temporary basis and may be preempted by the region.

National Use: Used for temporary tracking of selected activities. This block may be used by the DO on a temporary basis and may be preempted by the national headquarters.

Activity Time: Enter the time consumed in the performance of an activity (rounded to the nearest hour) when required in Appendices A through F or the PTRS Pocket Guide. Do not use otherwise.

Geographic Activity: Check this box if you are performing the activity outside your geographic area.

Travel Time: Enter the travel time, rounded to the nearest hour. Do not use unless directed by management.

Travel Cost: Enter the travel cost. Do not use unless directed by management.

Triggers (Not Currently Functional): Used to automatically create new records containing some or all information from Section I. It is usually used to trigger an enforcement activity or a follow-up activity. INVS and REXM functions were used to generate letters of investigations and reexaminations, but are no longer available with the PENS software.

Activity #: Enter a new activity number to automatically create another record with this triggered activity number. The new record will have OPEN status and will contain some information from Section I.

R#(repeat): Enter an **R** and the **number** of identical records you want to create (up to 50). The new records will contain all information from Section I.

3.2 Section II -- Personnel

Current Personnel: Lists all personnel involved with the activity. Selecting an entry from the list will display the data on that person and enable you to modify the data. The default list is empty.

To record personnel information into the database, enter the information in the corresponding fields and hit **SAVE ENTRY** or **NEW ENTRY** button.

To erase an entry, select the desired entry from the Current Personnel list and hit **CLEAR ENTRY**.

Personnel Name: For an examiner's certification activity, enter the applicant's or the recommending instructor's name. For other activities, enter the name of any personnel involved with the activity. Enter one person at a time.

Position: For an examiner's certification activity, enter "APPL" (for applicant) or "RI" (for recommending instructor). Otherwise, enter the job title of the personnel.

Base: Enter the airport code for the location where the person is stationed.

Remarks: For an examiner's certification activity, enter the certificate numbers of the applicant or recommending instructors. Otherwise, enter any relevant data about the individual.

3.3 Section III -- Equipment

Current Manufacturer: Lists all manufacturers of the equipment or tools that are the subjects of the inspector's evaluation or inspection. Selecting an entry from the list will display the data on that equipment and enable you to modify the data. The default list is empty.

To record an entry into the database, enter the information to the corresponding fields and hit **SAVE ENTRY** or **NEW ENTRY** button.

To erase an entry, select the desired entry from the Current Manufacturer list and hit **CLEAR ENTRY**.

Manufacturer: Enter the name of the manufacturer of the equipment, component, or tool.

Model: Enter the model of the equipment, component, or tool.

Serial #: Enter the serial number of the equipment, component, or tool.

Remarks: Enter any relevant remarks about the equipment, component, or tool.

3.4 Section IV -- Comment

Section IV gives you the ability to classify observations or evaluations into specific areas of interest. The fields: **Primary, Key Heading,** and **Key Word**, provide the means of this classification. It also contains a special area where you can jot down short notes without the notes being translated to printed characters. When you have the time, you can click the **TRANSCRIBE** button, which will bring up a new screen that shows your notes. You may transcribe those notes, including adding information, until you have completed that comment. When you have completed the comment, press the **DONE, ERASE INK** button or **DONE, KEEP INK** button. You must erase the ink before the PTRS form can be verified.

Primary: Select the general comment classification.

Key Heading: Select one of the headings.

Key Word: Select one of the key words for that heading.

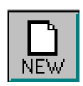
Opinion: Select Unacceptable, Information, Potential or Exceeds from the list.

Comments: Lists all comments you have made under the above classifications

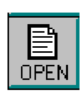
Transcribe: Accesses a screen where you can transcribe the short notes you have entered in the field.

4. PENS Function Buttons

PENS Functions buttons are located on the right side of the screen. The available functions are:

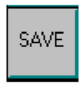


NEW: Creates a new PTRS form, with a new Record ID Number. This Record ID Number is temporary and can be used to help you track your own forms. A permanent Record ID Number will be assigned when you transfer your data to FSAS. Temporary Record ID Numbers can be recognized by the word TEMP in the middle.

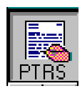


OPEN: Opens a previously saved PTRS form for subsequent editing. This opened form will either use a temporary Record ID Number or a Record ID Number. Along with the Record ID number, PENS provides the Activity number, Designator, Aircraft, Status, Results, and Verification status to help you identify the desired file. You can also specify an activity code and a designator, PENS will list only these Record IDs. (See **Section 2.1** for more detailed information.)

SAVE VERIFY: Checks the PTRS data to ensure that ll required fields have been completed and that there are no conflicts between data. You will be notified of either case. When a form does not pass the verification, you will be returned to the PTRS form. Thick black borders will be placed around fields that need correction. Modify the form and re-verify the data. Only verified forms can be transmitted to FSAS.



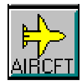
SAVE: Saves the current file without any verification.



PTRS: Accesses the PTRS screen.

Job Aid (Not currently functional): Accesses the Job Aid screen for your PTRS activity if there is one available. Any data you record on the job aid will be automatically shared with the PTRS form and vice versa.

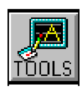
REFS: Accesses the on-line versions of the Federal Aviation Regulations and the Inspector's Handbooks. Which handbook is selected depends upon the inspection type. (Currently, only the Airworthiness Handbook is available.) These on-line documents allow you to quickly find specific information without having to thumb through the bulky paper books. Specific help for these on-line references is available when you are using them.



AIRCFT (Not currently functional): Illustrates an improved capability to document visual inspection. PENS provides line drawings for some Boeing and Airbus aircrafts. You can then mark the area of defects and add your comment to the drawings. If the FSAS database were modified properly, these drawings could then be saved with the PTRS data.

TOOLS: Accesses the standard windows for PEN computing tools:

Gives you information on editing gestures



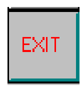
Is not currently useful for PENS software

Is the standard on-screen keyboard

Starts the handwriting recognition trainer

Provides help for Windows for PEN Computing

HELP: Accesses PENS On-line Help File



EXIT: Exits the PENS software. If the changes in your PTRS form have not been saved, PENS gives the following options before it exits:

Verify and Save: Saves and verifies your file.

Save without Verifying: Saves your file.

Don't Save Changes: Exits PENS without saving the changes you made.

Return to Form: Cancels the exit command and returns to the PTRS form.

5. Data Transfer Utility

The Data Transfer Utility allows you to transfer your PTRS records either directly to the FSAS database or to a temporary data storage. The purpose of the temporary data storage is to hold your data until your supervisor verifies the data. When your facilities do not require this supervisor's approval, you can directly transfer the data to the FSAS database. **Figure 2** shows the Data Transfer Utility Screen.

5.1 Data Transfer Procedure

To transfer the data follow these steps:

1. Connect the Xircom Adapter to your computer. (Follow the steps for **Connecting the Xircom Pocket Ethernet Adapter** in your computer user manual.)

2. Follow the prescribed network login procedure.

3. Start the **Data Transfer Utility**.

4. Select your name from the **Select Inspector Name** box.

5. Select the type of data transfer from the **Transfer...** box. Files available from the selected data transfer type will be shown in the **Select Forms** box. (See Type of Data Transfer section for more detailed information.)

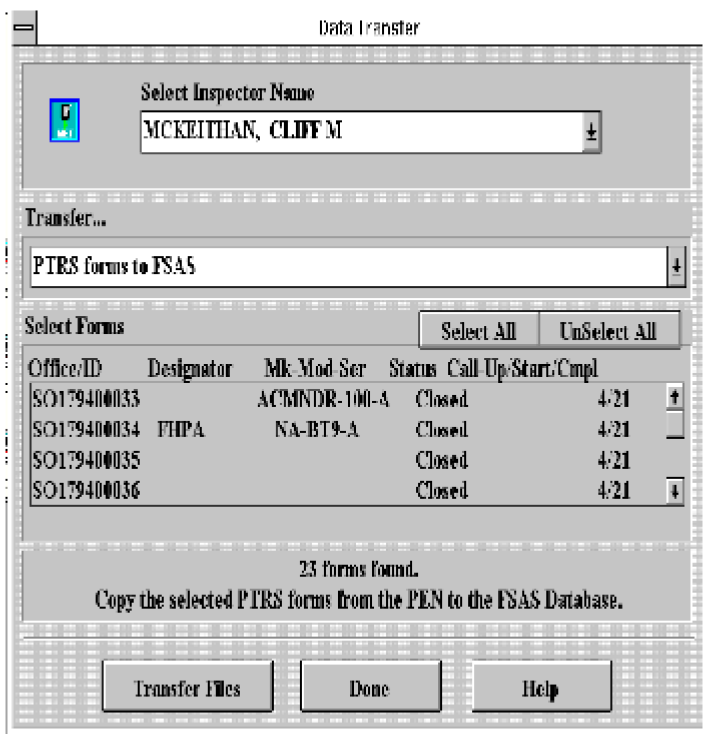
6. Tap the file(s) you wish to tranfer with your pen. (Press the **SELECT ALL** button to select all files; Press the **UNSELECT ALL** button to deselect all files.)

7. Press the **Transfer Files** button. (Messages about the transfer status will appear on the screen.)

8. Repeat steps 5 to 7, if you would like to transfer other files.

9. Choose **DONE** to exit from the Data Transfer Utility.

Figure 2. Data Transfer Utility Screen



5.2 Types of Data Transfer

Data Transfer Utility provides the following types of data transfer:

PTRS forms to Supervisory Review: This function transfers your PTRS data to a temporary storage location where your supervisor can review it before it is entered into FSAS.

PTRS forms from Supervisory Review to PEN: This function transfers PTRS data from the temporary storage to your computer.

PTRS forms from Archive: This function transfers PTRS data from the archive to your computer.

PTRS forms from FSAS to PEN: This function transfers PTRS data from FSAS to your computer.

PTRS forms to FSAS: This function transfers your PTRS data directly to FSAS.

Delete PTRS forms from PEN: This function erases PTRS data from your computer.

Delete PTRS forms from Archive: This function erases PTRS data from the archive.

Handwriting files from PEN to TEMP: This function transfers handwriting recognition files from your computer to a temporary network directory.

Handwriting files from TEMP to PEN: This function transfers handwriting recognition files from the temporary network directory to your computer.

Note: Depending on your site's policy, the options: **PTRS forms to Supervisory Review, PTRS forms from Supervisory Review**, or **PTRS forms to FSAS** may not be available to you.

5.3 Data Transfer Help

The Help function provides an on-line version of this manual.

6. *Supervisory Review Utility*

The Supervisory Review Utility allows you to review your inspectors' PTRS data before it is added to the FSAS database.

6.1 Supervisory Review Procedure

You have indicated that you wish to review your inspectors' PTRS data before it is added to the FSAS database. Here are the necessary steps to run the utility:

1. Start Windows.
2. Start the **Supervisor** utility located in the **PENS** group. (When you start this program, it loads the most recent record transferred by the Data Transfer Utility.)
3. Examine the PTRS record. (Use the scroll bar to move the record up and down.)
4. If you find errors or inconsistency in the record, write down the Record ID, the Inspector name, and Activity Number. Notify the inspector about the errors or inconsistencies and ask him to resubmit the revised record.
5. Select **Next** or **Prev** to examine other PTRS records.
6. Choose **Transfer** from the **Form** menu. (A transfer dialog box appears with a list of PTRS records in the directory.) You can also select **Print** to print the current record.
7. Tap the record IDs to select the records you want to transfer to FSAS. You can select more than one record. The selected records will be highlighted. You can also use the **Select All** button to select all records.
8. To deselect a record tap the highlighted file with your pen (or mouse). Use the **Unselect All** button to deselect all records.
9. Press **OK** to transfer the selected records to FSAS and press **Cancel** to cancel the transfer process.
10. Choose **Exit!** when you are finished.

6.2 Supervisory Review Help

The Help function provides an on-line version of this manual.

Hypermedia User Manual for FARS and Inspector's Handbook

1. On-line Documentation

The PENS **REFS** button accesses the on-line versions of the Federal Aviation Regulations and the Inspector's Handbook. (Currently, only the Airworthiness Handbook is available.) These on-line documents allow you to quickly find specific information without having to thumb through the bulky paper books. It also eliminates the necessity to carry the FARs and the Handbooks to the field. Specific help for these on-line reference systems can be found when you are using it.

Here are the necessary steps to access these documents:

1. Press the PENS **REFS** button. A separate Galaxy Hypermedia window appears on your screen.
2. Press the **Bookshelf** button. Three book icons: **FARs, Handbook** and **ADs**, appear on the screen. (See Figure 1.) The **ADs book icon** is disabled because the ADs documents have not been incorporated into this version.
3. Press the desired book icon to open the corresponding book. The topic outline of the book will appear on the screen. (Figure 2 shows an example of the topic outline.)
4. When the Outline is first displayed, all topics are shown in a collapsed state with subtopics not shown. The three-dots following a **file icon** indicates the topic contains hidden subtopics. To display hidden subtopics either press the **file icon** twice, or select the topic and then choose the **Expand** menu item from the **Outline Menu**.
5. All hidden subtopics can be displayed by choosing the **Expand All** menu item from the **Outline Menu**.
6. To hide subtopics for a selected topic, either press the selected topic **file icon** twice, or choose the **Collapse** menu item from the **Outline Menu**.

7. Subtopics for all topics can be hidden in one step by selecting the **Collapse All** menu item from the **Outline Menu**.
8. To view a selected topic (or subtopic) either press the selected topic twice, or choose **View Topic** from the **Outline Menu.** A Viewer window will appear, displaying the selected document. (See Figure 3.)
9. You can also use the search function to quickly locate specific information. See the Search section for more detailed information.

Searching for a specific information.

To search fro a specific information, first you will have to choose the location of the search from the **Search Menu**:

> **This Chapter** searches for the information in a chapter or a portin of the chapter.
>
> **Entire Book** searches for the information in the whole book.

When you are searching for the information in a chapter, a Find dialog box will appear. (See Figure 4.) Here are the steps to search for a specific phrase or term in a chapter.

1. Enter the terms or phrase to search in the **Find** box, choose the search direction, and then press OK. Boolean conditions can be assigned to the search string. For example, the search string "(cats and dogs) or "wild horses"" will execute a search for the documents that contain the terms "cats" and "dogs" or the phrase "wild horses".
2. The Hypermedia Viewer will display and highlight the first occurance of the search term.
3. Use either the **Find Next icon** or the **Find Next** menu item to find the next instances.
4. Use either the **Find Previous icon** or the **Find Prev** menu item to find the previous instances.

When you are searching for the information in the entire book, a Search dialog box will appear. (See Figure 5.) Here are the steps to search for a specific phrase or term in a book.

1. Enter the terms or phrase to search in the **Enter Search:** box. Boolean conditions can be assigned to the search string. For example, the search string "(cats and dogs) or "wild

horses"" will execute a search for documents that contain the terms "cats" and "dogs" or the phrase "wild horses".

2. Check the **Same Paragraph** button when you want to locate the paragraphs that contains all the search terms or phrases.
3. Press the **Enter** key or the **Do Search** button.
4. The **Topic Found** box will display all topics where search conditions were satisfied.
5. Press the topic twice to view the document.

Copying information to the PTRS form.

You can copy any information from the Viewer into the comment box in Section IV of the PTRS form. Here are the steps to copy the information:

1. Open the desired document.
2. Select the portion you wish to copy by dragging your pen (or mouse) across the document.
3. Select **Copy** from the **Edit** menu.
4. Switch to the PENS PTRS form.
5. Press the **TRANSCRIBE** button.
6. Press **Shift-Insert** keys simultaneously.

Exiting the On-line Documentation.

Choose **Exit** from the **File** menu.

CHAPTER THREE
DESIGN OF PORTABLE COMPUTER-BASED WORKCARDS FOR AIRCRAFT INSPECTION

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3.0 Abstract

From the analysis of workcards performed in Phase II, an improved paper-based workcard was developed in Phase III. Issues raised and designs developed all directly apply to workcards on a portable computer. Such a computer-based workcard system was designed, using an IBM ThinkPad and hypertext software. It was implemented for eight tasks: five A-check tasks on a B-737-200 and three C-check tasks on a DC-9-30. We undertook a direct test of the computer system against both the original and improved paper-based systems, using eight inspectors performing an A-check task of the landing gear of a B-737-200. Results show that the superiority of the computer-based system enabled rapid learning by the inspector. Significant savings can accrue from the use of such an integrated, portable system.

3.1 INTRODUCTION

The workcard, as the primary document controlling an inspection task, has a great influence on inspection performance. During Phase I, many human-system mismatches were identified which could contribute to errors. The costs of undetectable faults or faulty detection when weighed against those of providing quality documentation make a strong case for developing optimum documentation and for developing a methodology coupled with a set of guidelines for designing such documentation. This study develops such a methodology based on applying human factors knowledge to the analysis of aircraft inspection tasks. In Phase II, a paper workcard was designed as a replacement for the current workcard. From this design, we developed a set of guidelines to improve workcard design. This generic methodology can be extended to the design of portable computer-based workcards.

Portable computer-based workcards can overcome some limitations of paper-based workcards. Feedforward and feedback information can be presented, in addition to traditional directive information. Access to detailed information in attachments and maintenance manuals is easier. The display can act as an external working memory keeping all relevant information in front of the user at all times. Computer-based information also provides additional flexibility for organizing information about the tasks. Multi-layered information usage can cater to the needs of both experts and novices. As an example of these benefits, Glushko (1989) described the advantages of using an "intelligent electronic manual" in organizing the information contained in maintenance manuals. According to Higgins (1989), there can be as many as 70 manuals for one plane.

Advances in portable computing systems make it more feasible to realize these benefits. The combination of inspectors' increasing information needs and technological advances ensures that portable computer-based workcards will replace traditional hardcopy workcards. Specialized computer hardware and software systems have been designed to automate complex diagnostic tasks (maintenance) such as the Air Force's Integrated Maintenance Information System (IMIS) (Johnson, 1989). There remains a need for a simpler, less-expensive system using off-the-shelf components. Such computer-based systems have been aimed at diagnostic tasks, but here they are applied to more information-intensive procedural tasks that form a major portion of aircraft inspection activity. The objective of this study is to develop and test a prototype of a simple, inexpensive inspection workcard implementation on a lap-top computer. Specifically, the design had to be effective for both A-checks and C-checks.

3.2 METHODS

The computer-based workcard's design used and extended guidelines developed for the paper-based workcard. Computerization of information solves some problems and opens a new set that this project had to identify and resolve. The computer-based workcard's design was compared against the paper-based workcard's to determine if these issues were properly identified and resolved.

3.2.1 Hardware

The choice of hardware for the computer-based workcard was a critical issue. The original paper-based system studied lacked a convenient hand-held integrated workcard holder, although one was designed for the improved paper-based system. Current lap-top systems are inexpensive and are getting smaller while adding new sets of features and sacrificing little in computing power. Key breakthroughs in technology are feeding this process: storage devices are getting smaller; IC designs supporting fewer chips are lowering power requirements (Linderholm, O., Apiki, S., and Nadeau, M., 1992). Also, designs are getting more rugged, inspiring confidence when a computer is intended for field usage. Using these systems is still inconvenient, due to keyboard and pointer interfaces. Systems operated by keyboards and mice partially defeat goals of accessibility and connectivity (Meyrowitz, 1991). Pen-based computing allows links between information to be created by a mere pointing gesture. Thus, the first step in implementing computer-based workcards is to define the hardware requirements as part of the overall design requirements.

3.2.2 Defining Design Requirements

During Phases I, II, and III of this project, we conducted field visits at various A-check and C-check inspection sites. An A-check is a more frequent, less-detailed inspection. A C-check is a less-frequent, more detailed inspection scheduled according to zones. Field visits included direct observations, observational interviews, and personal interviews of inspectors (inexperienced as well as experienced), technicians, and supervisors. Inspector's perceptions of workcard usability were obtained from various inspection sites within the airline.

3.2.2.1 Inspector Feedback

During Phase II, mechanics' responses about using the A-check workcard usage indicated a moderate level of satisfaction with the current workcard, as well as a number of users needing different information. There was substantial agreement that the current order of information was incorrect and that the sign-off procedure was not performed after every step. An analysis of the task sequence preferences obtained from inspector's responses gave an optimal task sequence (Galaxy Scientific Corporation, 1993).

Information readability and organization issues are similar for the C-check and the A-check. The information content issue, however, is different so far as requirements for graphic information are concerned. Most C-check inspectors seem to be troubled about information content, pointing at a scarcity of information and their need for more and better quality graphic information. As far as information organization was concerned, most users felt that there was no clear differentiation between general and specific information.

3.2.2.2 Issues Identified within the Taxonomy

In the Phase III report, issues highlighted by the inspector responses and generic knowledge of the tasks were compared against a taxonomy of guidelines for designing of paper-based documentation to identify paper-based workcard design requirements. **Table 3.1** presents design issues for an A-check workcard; **Table 3.2** does the same for a C-check workcard. Computer-based workcards give flexibility beyond anything possible with paper-based systems; thus, they are uniquely able to meet some of the requirements in **Tables 3.1** and **3.2.**

Table 3.1 A-Check Workcard: Issues identified within the Taxonomy

1. INFORMATION READABILITY	
A. Typographic Layout	•no consistent typographic layout •layout discontinuous, breaks within pages •no usage of secondary typographic cueing, e.g., boldface, etc. •no use of full justification of typographic material
B. Sentence, Word, and Letter	•non-conformability with printing conventions •use of all capitals format, resulting in a low reading speed

•use of a 5x7 dot matrix typeface, hence no choice of any standa

2. INFORMATION CONTENT

A. Appropriate Content

•some inaccuracy in the information
•incomplete information for certain tasks
•language difficult to use and comprehend
•syntax not standardized
•directive information ambiguous
•generalization across aircraft types causes confusion
•not flexible for use by both novice and expert inspectors
•use of difficult acronyms
•logical errors and contradictory statements
•redundancy and repetition
•not consistent with user training
•does not foster generalizations across tasks, as every task is de

B. Graphic Information

•system unsupportive of graphics
•spatial information conveyed through text, resulting in the use
comprehend

3. INFORMATION ORGANIZATION

A. Information Classification

•no categorization or classification of tasks
•notes, cautions, methods, directions, etc., not prioritized
•no demarcation among directive information, references, notes
•directive information is not broken up into command verb, obj
•directive information includes more than two or three related a
•general and specific information chunked together
•external and internal tasks not properly demarcated, mixed

B. Information Layering

•no layering of information
•not conducive to expert as well as novice usage
•difficulty in writing such unstructured information

C. Other Organizational Issues

•no use of naturally occurring page modules for fitting in inform
•improper task sequencing

4. PHYSICAL HANDLING & ENVIRONMENT

•physical handling difficult due to unwieldy size
•excessively heavy, cannot be held continuously
•usage in extreme environments difficult
•not compatible with the other tools used during the task
•inadequate lighting conditions
•no holder or place for holding the workcard while using it
•all these factors force inspectors to carry out the external inspe
memory.

Table 3.2 C-Check Workcard: Issues identified within the Taxonomy

1. INFORMATION READABILITY	
A. Typographic Layout	•no consistent typographic layout •layout discontinuous, breaks within pages •no usage of secondary typographic cueing, e.g., boldface, etc., •no use of full justification of typographic material
B. Sentence, Word, and Letter	•non-conformability with some of the printing conventions •use of all capitals format, resulting in a low reading speed •no room for selecting an appropriate typeface •use of a 5x7 dot matrix typeface
2. INFORMATION CONTENT	
A. Appropriate Content	•some level of inaccuracy in the information •incomplete information for certain tasks and lack of informatio •language difficult to use and comprehend •syntax not standardized •directive information ambiguous •generalization across aircraft types causes confusion •use of difficult acronyms •logical errors and contradictory statements •redundancy and repetition •does not foster generalizations across tasks, as every task is de
B. Graphic Information interpretation	•no figure numbering, even though the workcard refers to speci •no consistent layout of figures, use of mixed layout with no de •no consistency in view directional information, e.g., use of bot •non-contextual figure views, or views as the inspector sees it, j •no information to aid in spatial location of parts •no back references to the workcard page/task which refers to th •improper usage of technical drawing terms, e.g., "section• and •no typographic differentiation between: figure titles, part name •no use of standard drawing conventions, e.g., location of sectio •same graphics for both left and right wing tasks, mentally inve •some figures use high fidelity graphics, causing confusion and •no consistency of scaling graphics, close-up views not differen
3. INFORMATION ORGANIZATION	
A. Information Classification	•no categorization or classification of tasks •notes, cautions, methods, directions, etc., not prioritized •no demarcation among directive information, references, notes •directive information is not broken up into command verb, obj •directive information includes more than two or three related a •general and specific information chunked together

	•general and specific tasks not properly demarcated
B. Information Layering	•no layering of information •not conducive to expert as well as novice usage •difficulty in writing such unstructured information
C. Other Organizational Issues	•no use of naturally occurring page modules for fitting in inforn •improper task sequencing •no consistency in the number of signoffs across the task
4. PHYSICAL HANDLING & ENVIRONMENT	
	•size of attachments different from the workcard, causing incon •inadequate lighting conditions in certain work areas •no holder or place for holding the workcard while using it

3.2.2.3 Hypertext

Many advantages computer-based information have over paper are due to hypertext. Hypertext is a technology of nonsequential writing and reading: it is also a technique, a data-structure, and a user interface (Berk and Devlin, 1991). Hypertext systems split documents into components or *nodes* connected by machine-supported links or relationships. Conklin (1987) summarized the operational advantages of hypertext as follows:

1. Information structuring: Both hierarchical and non-hierarchical organization can be imposed on unstructured information.
2. Global and local views: Browsers provide table of contents-style views, supporting easier restructuring of large or complex documents; both global and local views can be mixed effectively.
3. Modularity of information: Since the same text segment can be referenced from several places, ideas can be expressed with less overlap and duplication.
4. Task stacking: The user can have several paths of inquiry active and displayed on the screen simultaneously; any path can be unwound to the original task.

These hypertext features solve many design issues identified in the taxonomy given in **Tables 3.1** and **3.2**. For example, computer-based information provides a consistent typographic layout and a continuous layout with no page breaks. It also reduces redundancy and repetition, fostering generalizations across tasks. Computer-based systems are more supportive of graphics than paper-based systems. Hypertext easily allows for categorization and classification of tasks and information so that general information can be separated from specific information. Layering of information is conducive to expert and to novice usage. Hypertext should make accessing and referring to information such as attachments and manuals considerably easier. In addition, the inspector can sign off tasks after completing them, write notes For non-routine maintenance in the computer-based system, and then easily return to the correct place in the task list to continue inspection.

Thus, we hypothesize that hypertext can solve many design issues associated with paper-based workcards. The next step is to design specific examples of computer-based workcards, using the lessons learned from designing paper-based workcards, knowledge of hypertext, and information on inspection tasks.

3.2.3 Development of the System

A prototype computer-based workcard system was developed on an IBM Think Pad 700 PS/2 using Spinnaker PLUS. This hypertext program is an object-oriented programming language that simplifies creation of detailed information management applications by using links between stacks of information. Eight different inspection tasks were implemented into the system. A-check inspection tasks for a B727-200 included log books, nose landing gear, main landing gear, aircraft wings, aircraft empennage, and aircraft fuselage inspection. Left wing and right wing inspection for a DC-9-30 C-check were also implemented.

System design adhered to the lessons learned from developing of the paper-based workcard identified in **Tables 3.1** and **3.2**. The design also followed design guidelines specific for computer interfaces (Brown, 1988; Smith and Mosier, 1986). The specific guidelines which were used to develop the computer-based systems are identified in **Table 3.3.**

Table 3.3 Design guidelines for the computer-based workcard system

1. INFORMATION READABILITY	
1. Layout	•Use a fixed set of proportions/grids •Use spatial layout as a primary cue for object grouping •Use a consistent layout across fields •Use fixed size/location for "functional category fields• •Left justify the most important information •Use blank lines in place of graphic lines to reduce clutter
2. Typography	•Use upper case only for short captions, labels, and headings •Use conventional punctuation and formalisms
3. Metaphors	•Be very explicit in the use of metaphors •Use explicit screen transitions, e.g., iris open vs. scroll •Use paper form metaphor for data input •Use soft button metaphor for all external links
4. Contrast	•Use contrast sparingly and as a last option •Use contrast to attract attention to select portions of text •Use a maximum of three levels of contrast coding
2. INFORMATION CONTENT	
1. Input information	•Use familiar mnemonics for input •Use congruent command pairs, e.g., R/Wrong, not R/Close •Use "radio buttons• for all multiple choice information
2. System output information	•Use the display as an external working memory of the user

•Provide screen identity information
•Display only necessary information
•Condense all unnecessary information into icons
•Avoid a display density higher than 15%
•Use the inheritance metaphor to identify position in hyperspace
•Use affirmative dialogue statements
•Provide input acknowledgments and progress indicators
•Use auditory feedback conservatively
•System messages should be polite and instructive
•Do not provide a system-initiated help feature

3. Graphic information
•Use graphics to reduce display density
•Show all spatial, numeric, temporal information graphically

4. Iconic information
•Use icons for all direct manipulation
•Use icons to save display space and reduce clutter
•Use icons for all external links
•Use icons to permit cross-cultural usage

3. INFORMATION ORGANIZATION, MANIPULATION, AND ACCESS

1. Linking
•Provide contextual internal links
•Use internal links for all reference information
•Use external links sparingly and only for non-contextual informat
•Provide a link backtrack option
•Provide an UNDO option for navigation
•Make linking explicit; do not leave anything to exploration or bro
•Use linking sparingly to avoid user confusion and disorientation
•Label links where possible

2. General organizational philosophy
•Organize for progressive disclosure and graceful evolution
•Keep layered information optional
•Do not use scrolling fields
•Organize tasks in a fixed linear as well as optional nested structures

4. OTHER PRAGMATIC ISSUES

1. Physical handling and infield
•Develop and implement standards for reverse video, contrast for v
•Follow a pencentric display design philosophy
•Design for a single-handed operation
•Minimize the use of key entries, use direct manipulation

2. Hardcopy
•Provide feasible options for obtaining hardcopies in a fixed forma

3. System response time
•Keep the system response times for all actions within standards

4. User acceptability
•Honor user preferences
•Provide only those functions that a user will use

3.2.3.1 Features of the System

The computer-based workcard meets these design guidelines with the following features. The first workcard screen is the input manager the inspector/mechanic uses to enter data normally found at the top of every page; the inspector/mechanic, the supervisor, and aircraft's identification number. This information is then reproduced on all other documentation such as the Accountability List and the Non-Routine Repair forms, relieving the inspector of repetitive form filling. The global view displays all inspection tasks and highlights completed tasks, serving as an external display to augment working memory. While performing the tasks, the inspector/mechanic has direct access to both input and output information such as the general maintenance manual, the airplane's manufacturer maintenance manual, engineering change repair authorization(s), airworthiness directives, and attachments. This eliminates the need for the inspector/mechanic to carry bulky attachments or to leave the inspection site to refer to a manual. For each task, the inspector/mechanic has options of signing off, reporting a non-routine repair, making a note on the writeup note feature, going to the home screen to show the signoffs remaining for the task, going to the global screen, viewing an overview feature displaying the number of completed signoffs, or using a help feature. All these features reduce memory and information processing requirements on the inspector/mechanic. A continuously updated Accountability List may also be viewed any time. This feature records the inspector/mechanic's activity using the workcard such as signoffs done, notes made, and tasks previewed.

The system's outputs are the Accountability List and the Non-Routine repairs the inspector/mechanic wrote up. An inspector/mechanic accesses these features by selecting icons or radio buttons with pictures or labels designed for rapid learning. Links between these features are explicit and always have a backtrack option. Information for performing the tasks was categorized and layered to assist both experienced and inexperienced inspectors. General information was separated from specific task-directive information. All spatial information was conveyed through graphics. Thus, these features meet design requirements and address the issues for developing workcards for aircraft inspection and the guidelines for human-computer interfaces.

3.2.4 Usability Evaluation of the Computer-Based Workcard

3.2.4.1 Methodology

The computer-based workcard was compared against the current paper-based workcard and against the proposed paper-based workcard designed in Phase III of this project. The comparison was made using questions derived from the issues identified by the taxonomies in **Tables 3.1** and **3.2**. The evaluation and the specific questions were designed to be similar to the evaluation of the C-check workcard performed in Phase III. Eight mechanics used all three designs of the A-check workcards to perform a nose landing gear inspection with fifteen signoffs. They were given an overall briefing as to the purpose of the study and general instructions, and they answered a questionnaire on personal data. Before using the computer-based workcard, mechanics were given a training session. A quiz on using the computer-based workcard ensured that they understood how to use the workcard. After mechanics completed the inspection using each form of the workcard, they were asked to complete a questionnaire evaluating that workcard. The subjects rated their evaluation of the issues addressed by each question on a 9-point rating scale.

3.2.4.2 Results

Demographic data on the eight mechanics participating in the experiment are shown in **Table 3.4.** All values were reasonable for the mechanic population, including a large variability in number of A-checks they perform each month.

Table 3.4 Personal data on mechanics used to evaluate workcards

Subject Characteristic	Mean	Standard Deviation
Age (years)	38.4	13.6
Years in civil aviation	9.9	8.8
Level of experience on A-checks (years)	4.6	1.7
Average number of A-checks performed every month	3.8	4.1
Years of computer experience	3.5	1.9

Two analyses of the evaluation response data are of interest:

1. Whether the features of the computer-based workcard were judged better or worse than a neutral rating.
2. How the computer-based workcard was evaluated in comparison with the existing paper-based workcard and the redesigned paper-based workcard.

Results of the first analysis are presented in **Table 3.5.** The three parts of this table identify issues that were rated significantly better than neutral (A), not significantly different from neutral (B), and significantly worse than neutral (C). Of the 39 issues, 25 are in (A); 13, in (B); and 1, in (C), showing that mechanics were highly enthusiastic about most aspects of the system. Many items judged better than neutral were overall evaluations such as the degree to which workcards like those should be used, but some were for very specific features such as readability of buttons and icons, both the overall concept and detailed design. Most of the neutral responses (B) were for completeness and organization, or for features such as automatic generation of Accountability list and Non-Routine Repair forms. The only feature mechanics significantly disliked was one which showed what percentage of the standard time had been spent. As has been found consistently in earlier phases of this project, mechanics strenuously resist implications of time pressure in their jobs. The time feature has now been removed.

The computer-based workcard compared favorably against both the current and proposed paper-based workcards. **Tables 3.6A** and **3.6B** show the mean ratings and standard deviations for the three workcards on each issue the computer- and the paper-based systems.

As in Table 3.5, results have been divided into those where there was a significant difference among the three systems (**Table 3.6A**) and those where there was no difference (**Table 3.6B**). The mechanics did not rate the computer-based system worse than the paper-based system on any issue. Fourteen of the nineteen issues were judged significantly in favor of the computer-based system, including all issues asking for an overall evaluation of the system, overall ease of usability of workcard. The amount of information provided was judged almost the same in all three systems. This result was expected since no information was added to or subtracted from the original workcard to develop the two new systems.

Although the main comparison was between the original paper-based workcard and the computer-based system, the inclusion of an improved paper-based workcard was instructive. In addition to the omnibus test of difference among the three mean ratings used in **Table 3.6**, it is possible to perform three pairwise tests of the three workcards:

- Original paper-based versus computer-based
- Original paper-based versus improved paper-based
- Improved paper-based versus computer-based.

Table 3.5 Classification of evaluation factors as Better Than, Not Different From, and Worse Than Neutral Rating

A. Significantly Better Than Neutral Rating

$p<0.01$	$p<0.05$
•Readability of text	•Task of reading
•Readability of buttons and icons	•Information covered everythin
•Readability of graphics	•Separating information by freq
•Ease of understanding information	•Flexibility of use
•Ease of understanding symbols/icons	•Ease of referring to attachment
•Chance of missing information	•Often confused about location
•Degree of interest	•Often confused about how to re
location	
•Degree to which rater would like to use workcard again	•Degree of fatigue after using th
•Degree to which workcards like these should be used	
•Would rather rely on substituting computer for paper-based workcard	
•Overall ease of usability	
•Degree of simplicity	
•Degree of tension while using system	
•Usefulness of Global View feature	
•Usefulness of Home View feature	
•Usefulness of Automatic Non-Routine Writeup feature	
•usefulness of direct access to all references	

B. Not Significantly Better Than Neutral Rating

•Tasks were well organized
•Effort required in locating information
•Consistency of organization
•Ease of physical use
•Ease of writing up an Accountability List
•Ease of writing up a Non-Routine
•Ease of learning to use the computer-based workcard
•Need to refer to "Global View•
•Performance rating using the computer-base workcard
•Usefulness of Automatic Accountability List Generation feature
•Usefulness of Writeup Note feature

C. Significantly Worse Than Neutral Rating

•Usefulness of Time Overview feature

Table 3.6A Issues on which systems were significantly different; data is mean (SD)

Issue Addressed	9 Point Rating Scale End Points		Workcard System			Significance
	0	8	Current	Improved	Computer	
Ease of understanding	Very difficult	Very easy	4.4 (1.1)	6.25(1.7)	7.1(1.0)	0.02
Information covered everything for task	Disagree fully	Agree fully	1.5(1.4)	4.4(2.4)	6.6(2.1)	0.01
Tasks were well organized	Disagree fully	Agree fully	1.9(1.6)	5.5(2.1)	6.1(2.4)	0.02
Effort required in locating information	Very difficult	Very easy	1.8(1.4)	5.5(2.0)	5.8(2.0)	0.01
Consistency of organization	Terrible	Excellent	3.4(0.9)	5.3(1.0)	5.4(1.8)	0.05
Separating information by frequency of use	Terrible	Excellent	3.3(1.6)	5.9(1.4)	6.1(1.6)	0.05
Chance of missing information	Always	Never	4.4(0.7)	6.5(1.7)	6.5(0.9)	0.01
Ease of physical use	Very difficult	Very easy	3.0(0.9)	5.5(2.1)	6.4(2.5)	0.05
Ease of referring to attachments or manual	Very difficult	Very easy	1.8(1.7)	4.5(2.3)	7.0(1.9)	0.01
Ease of writing up an Accountability List	Very difficult	Very easy	2.4(1.3)	4.8(2.3)	5.1(2.0)	0.05
Degree of interest	Very boring	Very interesting	2.3(1.7)	4.8(1.0)	6.9(1.2)	0.01
Degree to which rater would like to use W/C again	Definitely not	Definitely yes	3.0(1.1)	5.8(1.3)	7.1(0.9)	0.01
Degree to which W/C like these should be used	Definitely not	Definitely yes	3.1(1.0)	5.9(1.4)	6.3(1.2)	0.01

Overall ease of usability of W/C	Terrible	Excellent	2.5(0.9)	5.9(1.4)	6.5(1.4)	0.01

Table 3.6B Issues on which systems were non-significantly different; data is mean (SD)

Issues Addressed	**9 Point Rating Scale End Points**		**Workcard System**		
	0	8	Current	Improved	Computer
Readability of text	Terrible	Excellent	4.0(2.1)	6.6(1.4)	6.5(0.76)
Task of reading	Very difficult	Very easy	3.9(2.0)	6.5(2.3)	6.6(1.8)
Amount of information	Too little	Too much	4.8(1.8)	4.0(1.1)	3.5(1.8)
Flexibility of use	Terrible	Excellent	3.5(1.4)	5.5(0.9)	5.6(1.8)
Ease of writing up a Non-Routine	Very difficult	Very easy	2.9(2.4)	4.9(2.1)	5.4(2.2)

Table 3.7 shows comparisons for each of the 19 common questions made using the Wilcoxon test. Note that 16 comparisons showed that the computer-based workcard better than the original paper-based system, reflecting the results given in **Table 3.6**. The improved paper-based system was better than the original paper-based system in 17 comparisons, and the computer-based system was only rated higher than the improved paper-based system on 2 comparisons. It is interesting that the two comparisons where the computer-based workcard was rated higher than the improved paper-based workcard measured the inspector's degree of interest in the system and in using the system again.

Improvement appears to better layout, organization, and presentation of information, whether on hard-copy or on computer. The computer features add some benefit, but not much, to the improved paper-based workcard. Indeed, of the total degree of improvement from the original paper-based workcard to the computer-based workcard, an average of 81.6% across all rating scales was due to the improved paper-based workcard. This re-emphasizes the benefits of implementing good human factors principles in workcard design, whether or not the system is computerized.

Our conclusion is that many improvement can be made without resorting to computer-based systems. The text and graphics in our computer-based hypertext system were the same ones used in the improved paper-based system. Thus, any company would be well-advised to modify its paper-based system, as this completes most of the work needed to implement any future computer-based system.

All mechanics quickly became familiar with the computer-based system; no mechanics took more than one hour to learn the system well enough to go through the steps of single A-check task. More time would obviously be required for mechanics to become fully adept at navigating the system and using all of its features, but the time and cost overhead associated with introducing this system is very low. This vindicates the design philosophy utilizes detailed task analysis and human factors interpretation of the mechanics' jobs, and including feedback from the mechanics themselves, to produce the final design.

Despite the good rating of ease of physical use (**Tables 3.5** and **3.6**), the computer-based system will clearly benefit from improved hardware. Weighing 6 pounds and requiring both a keyboard and a pointing device, the current system cannot be used as easily as, for example, a future pen-based system. All features of the current hypercard system can be used directly on a pen-based system, with the added advantage of bit-mapped storage of signatures. All that is required is better screens for pen-based systems, and improved handwriting recognition for filling out Non-Routine Repair forms rapidly. According to computer industry sources (see Byte, October 1993) such systems should be fielded within a year.

Table 3.7 Pairwise comparisons among original paper-based, improved paper-based, and computer Wilcoxon Test

Issue Addressed	**9 point Rating Scale End Points**		**Significance of Current Paper-based Workcard Versus**	**Significance vs. Compute**
	0	8	New Paper Workcard	Computer Workcard
Readability of text	Terrible	Excellent	0.031	0.025
Task of reading	Very difficult	Very easy	n.s.	0.025
Ease of understanding	Very difficult	Very easy	0.025	0.01
Amount of information	Too little	Too much	n.s.	n.s.
Information covered everything for task	Disagree fully	Agree fully	0.025	0.005
Tasks were well organized	Disagree fully	Agree fully	0.031	0.005
Effort required in locating information	Very difficult	Very easy	0.005	0.005
Consistency of organization	Terrible	Excellent	0.025	0.025
Separating information by frequency of use	Terrible	Excellent	0.025	0.025
Chance of missing information	Always	Never	0.025	0.005
Flexibility of use	Terrible	Excellent	0.031	n.s.
Ease of physical use	Very difficult	Very easy	0.025	0.01
Ease of referring to attachments or manual	Very difficult	Very easy	0.005	0.005
Ease of writing up an Accountability List	Very difficult	Very easy	0.01	0.025
Ease of writing up a Non-Routine	Very difficult	Very easy	0.025	n.s.
Degree of interest	Very boring	Very interesting	0.01	0.005
Degree to which rater would like to use W/C again	Definitely not	Definitely yes	0.01	0.01
Degree to which W/C like these should be used	Definitely not	Definitely yes	0.01	0.025
Overall ease of usability of W/C	Terrible	Excellent	0.025	0.005

3.3 CONCLUSIONS

A similar set of design guidelines to those used to improve paper-based workcards was developed and used to design a portable computer-based workcard system for A-checks and C-checks. An evaluation of this system against both the original and improved paper-based workcards for one task of an A-check showed that the computer-based system is better than either paper-based system.

Direct access to documentation reduced reliance on memory and waiting time to retrieve information. Compared to the original paper-based workcard, the computer-based system was easier to understand, reduced the effort to locate information, increased organization and consistency of information, and increased overall workcard usability. Most of the improvements from the computer-based system were also found for the improved paper-based system. It is important to make human factors improvements to existing workcard systems even before they are computerized. The mechanics found the computer-based workcards interesting and would like to see them implemented at the workplace. The time necessary to become familiar with the system was brief.

The next step in implementing the computer-based workcards is to update the system with future hardware. Pen-based systems would assist in meeting the goals of hypertext better than lap-top portable computers. The advantages of the computer-based workcards over their paper counterparts make the implementation of the system into the workplace on future hardware well worth the effort, but the usefulness of the improved paper-based system suggests that this aspect should be implemented as a step towards a computer-based workcard.

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CHAPTER FOUR
ERGONOMIC AUDIT FOR VISUAL INSPECTION OF AIRCRAFT

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4.0 Abstract

As more demonstrations of applying human factors interventions in aircraft inspection have been completed, the need has arisen to give airlines a tool to determine which interventions are most urgent in their own operations. An ergonomics audit was developed to provide a rapid evaluation of potential human/machine mismatches in any inspection task. The audit consists of a method of choosing tasks to be audited, an audit checklist, and a computer program evaluating checklist responses against national and international standards to produce an audit report. An evaluation of all three parts of the system showed that inspectors made consistent judgements for choice of tasks, that the audit checklist gave consistent reliability among auditors, and that the computer program produced valuable results for the airline partners cost-effectively.

4.1 INTRODUCTION

An aircraft's structure is designed to be used indefinitely, provided that any defects arising over time are identified and repaired correctly. Most structural components do not have a design life but rely on periodic inspection and repair for their integrity. The primary defects are cracks and corrosion, resulting from the intermittent flexing of structures when in the air, from pressure loads, and as a result of weathering or chemicals.

Inspection, like maintenance, is scheduled regularly for each aircraft. Each schedule is translated into a set of workcards. Equipment impeding access to the inspected area is removed. The aircraft is then cleaned, and the access hatches are opened. This is followed by the inspection process. Inspection can be described as a complex socio-technical system exerting both mental and physical stress on the inspectors and on other organizational players (Drury, 1985). At a more detailed level, the inspection task can be broken into a set of subtasks which follow a logical order **(Table 4.1).**

With these seven task steps, the complex problem of error control, design of equipment used, and environmental issues become more manageable as specific human factors knowledge is brought to bear on each issue in turn. Arising from human factors analyses of inspection tasks, a number of studies have been completed under the auspices of the Federal Aviation Administration, Office of Aviation Medicine (FAA/AAM). Projects with the airline industry have considered improved lighting (Reynolds, Gramopadhye, and Drury, 1992), better documentation design (Patel, Prabhu, and Drury 1992), revised training for visual inspection (Gramopadhye, Drury, and Sharit, 1993) and the impact of posture and restricted space (Eberhardt, Reynolds, and Drury, 1993). The aim of these studies has been to allow airlines to benefit from ergonomics without their necessarily having trained ergonomists. There is now a need to provide integrative tools enabling a maintenance organization to develop an overall strategy for applying human factors principles systematically. The audit program developed in this report is an essential step towards such integration.

Table 4.1 Generic task description of inspection with examples from visual and **NDT** inspection (Dr

TASK DESCRIPTION	VISUAL EXAMPLE	NDT EXAMPLE
1. Initiate	Get workcard. Read and understand area to be covered.	Get workcard and eddy curre Calibrate.
2. Access	Locate area on aircraft. Get into correct position.	Locate area on aircraft. Posit equipment.
3. Search	Move eyes across area systematically.	Move probe over each rivet h any indication.
4. Decision-Making	Examine indication against remembered standards.	Reprobe while closely watch current trace.
5. Respond	Mark defect. Write up repair sheet or if no defect, return to search.	Mark defect. Write up repair no defect, return to search.
6. Repair	Drill out and replace rivet.	Drill out rivet. **NDT** on rivet out for oversize rivet.
7. Buy-Back Inspect	Visually inspect marked area.	Visually inspect marked area.

In order to know where to apply human factors, for example using the FAA/AAM-developed *Human Factors Handbook* (Parker, 1992), it is first necessary to identify the mismatches between the human (inspector) and the system (equipment, tools, environment). The audit program provides a convenient, quantitative way to identify these mismatches. It starts from the common ergonomics basis of inspection as a task/operator/machine/ environment system. The audit's output can be used to focus design/redesign efforts where they will have the greatest impact on reducing human/system mismatches which cause inspection and maintenance errors.

There have been previous ergonomics audit programs for manufacturing (Mir, 1982; Drury, 1988; Kittusway, Okogbaa, and Babu, 1992), but the problems of the aircraft hangar are different from those of the factory floor. In inspection and maintenance, the workplace is rarely static; task, equipment, and environment can change considerably throughout the course of a single inspection task.

The original two-phase audit program (Mir, 1982) used outcome measures in Phase I to provide an overall context of the plant, followed by a workplace survey (Phase II) of the departments selected in Phase I. Information from first aid reports, medical records, OSHA reports of accidents and injuries, workers' compensation payments, turnover rate, absenteeism frequency, lateness reports, and productivity for the various departments were used to identify the most representative departments for conducting the workplace survey.

Ergonomic Audit

The ergonomic audit developed here provides an overview of the inspection system's ergonomics (human factors). It will not point out specific human errors that might result during the task; rather, it indicates the **important** human factors issues that need to be addressed to improve the performance of the operator doing the task. It compares the current conditions with the standards prescribed by current human factors good practice, incorporating national and international standards where appropriate. The report the computer program generates gives guidelines to prioritize and systematize the application of human factors techniques, to improve and to achieve the standards.

As with the previous audit programs for manufacturing (Mir, 1982), continuing observations of the task specify a series of measurements that need to be made. Some are made with the help of instruments such as light-meters or tape measures; others are answers to checklist questions. The audit program is modular so that the auditor can apply the particular measurements needed for each task.

4.2 REQUIREMENTS FOR AN AUDIT SYSTEM

4.2.1 Deciding Which Tasks to Audit

Every auditor has to use a sampling process. Any sampling strategy has to address the following issues:

- how to sample
- how much to sample
- how to appraise sample results (Hill, Roth, and Arkin, 1962).

For the ergonomics audit, how to sample is more important than how much to sample. The mechanics of sampling may well decide the success or the failure of the test in providing the auditor with valid, reliable information. First, the auditor needs to identify the basic unit to be audited. In a manufacturing environment, the natural unit is the **workplace**. In inspection (or maintenance) however, the task represented by the workcard is more appropriate since all job and quality control procedures are already based on the task.

There are two possible sampling techniques: judgment sampling and statistical sampling (Willingham and Carmichael, 1979). Judgment sampling selects items subjectively, without statistical considerations for sample size, method of selection, or evaluation. Since selection criteria are based on the auditor's subjective judgment, one obviously cannot project the sample results to the entire population. Statistical sampling, in contrast, provides objective criteria for sample selection and is more appropriate for quantitative ergonomics audit. Of the various statistical sampling techniques available, only two can be effectively used to decide which task to audit: random sampling and stratified random sampling (systematic sampling).

In random sampling, all tasks (workcards) have given an equal chance of being selected. While ensuring that the sample selection is unbiased, random sampling may require larger sample sizes to provide appropriate coverage.

However, an important additional consideration is the fact that all inspection tasks may not be considered equally important. It may be more appropriate to concentrate on sampling those tasks considered most critical. Stratification can be used to segregate items to be examined by sampling within pre-determined groups, or strata, of tasks. Some care must be exercised while establishing the strata. They should be determined so as to form a group having similar characteristics. The methods discussed below provide one stratification strategy, although other strategies can be adopted for screening tasks.

Parallel to the development of audit systems, there have been job analysis systems aimed at evaluating the ergonomics and the technical design of working systems (Landau and Rohmert, 1989). The documentation and diagnosis of working system involves describing and quantifying the system's elements and their characteristics, e.g., stresses they exert, deduction of design needs, formation and verification of design properties, prevention of possible impairments by detecting unsupportable stresses, and purposeful reduction of stresses. Thus, job analysis and ergonomic auditing share many commonalities and have the same need to identify critical tasks.

The technique for selecting tasks (work-cards) in the ergonomics audit program used a points system (Lanham, 1955) similar to those used in job evaluation systems. Any sampling system must be:

- able to provide a thorough study of *all jobs to be evaluated*
- one which the *supervisor and the employees can understand* and are willing to accept
- *easy to execute*
- able to produce a *high degree of accuracy* (Lanham, 1955).

A points system fulfills these requirements. The system uses judgements of inspectors and/or management to determine which factors are important to error reduction.

The point system provides the rater with a scale or a "yardstick" to use in measuring the differences among jobs. In designing a point scale, the following steps must be completed:

- Select and define factors common to all the jobs to be evaluated
- Allocate the number of degrees to each factor (length of the rating scale)
- Weigh the factors, depending upon their relative importance

- Assign point values to each degree of each factor.

The task to be rated is measured, factor by factor, against the scale. The degree on the scale most nearly describing that factor's situation in that task is selected. The number of points which have been assigned to that degree on the scale is assigned to the job. When the proper degree has been selected for each job factor, the point values for the listed degrees are totaled. This sum represents the final point value of the job in question.

In addition to the final point value, each task can also be judged, based upon the value of the individual factors. For example, if one crucial factor of a generally low-rated task has been rated exceptionally high, that task, too, will be audited.

4.2.2 The Ergonomics Audit System

After deciding which tasks to audit, the form and content of the audit system itself need to be determined. Our audit was conceived as a two-part system. The first part is a checklist, presenting the auditor with a set of ergonomic questions. Having answered the questions, the auditor uses the second part, a computer program, to compare the answers against ergonomic standards and to prepare an audit report detailing the inspector/system mismatches.

The audit's aim is to determine which aspects (task, operator, machine, environment) may impact inspector-system mismatches. The content of the audit checklist could use any convenient taxonomy of factors affecting human performance. Following Prabhu and Drury (1992) and Latorella and Drury (1992), the following taxonomy:

- **Information Requirements** - documents, communication
- **Equipment/Job Aids** - design issues, availability, standards
- **Environment** - visual, auditory, thermal
- **Physical Activity/Workspace** - access, posture, safety.

Although this taxonomy defines factors affecting human/system mismatches, it is not in the most convenient form for the auditor. To expedite auditing, it is preferable to turn to the generic task description found in **Table 4.1** and to restructure the audit to follow the sequence of inspection tasks. These can be grouped into a pre-inspection phase (Initiate), an inspection phase (access, search, decision, respond), and a post-inspection phase (repair, buy-back).

With this structure, it was possible to define more clearly the features necessary in the overall audit system. An audit system must have the following features:

- **is modular**, so as to include maximum coverage without unnecessary length. Inserting new modules to modify the checklist and program for a particular industry is easy
- **is self-explanatory**, so as to minimize training time for auditors
- **is based on standards from ergonomics/human factors**
- **has standards built into the analysis program**, rather than into the checklist questionnaire, to reduce any tendency to "bend" data in borderline cases
- **relies on measurements** and easily observable conditions to reduce judgment errors
- **is usable in different aviation environments**, e.g., large fixed wing aircraft,

general aviation aircraft, or rotary wing aircraft.

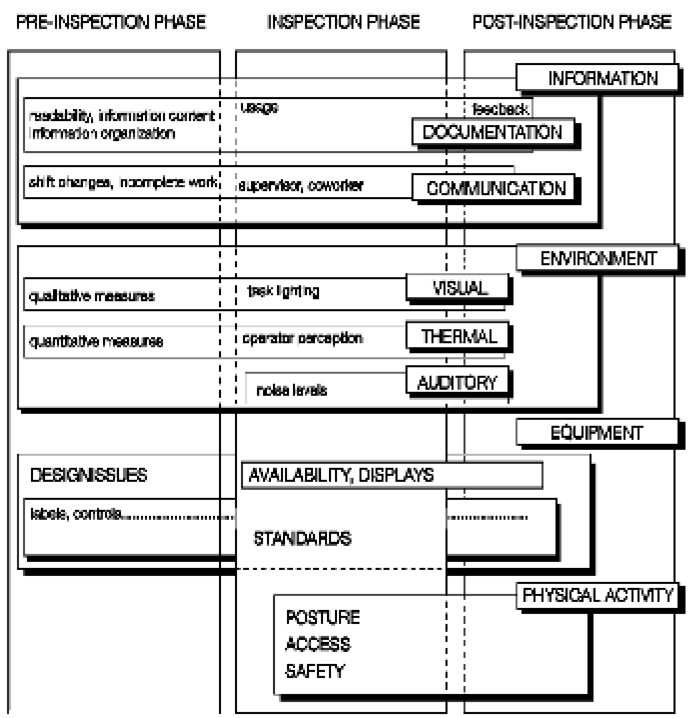
With these features in mind we designed the audit system described in the following section.

4.2.3 The Audit System Development

4.2.3.1 Audit Checklist

A checklist was produced from the taxonomy of factors and the three phases of the audit. The audit can be either a paper-based system or entered in the field on a portable computer, whichever is more convenient. There are two versions of the paper-based system available: a large version has detailed instructions and pictorial examples; a much shorter version is used when the auditor is sufficiently experienced to be able to work without these aids. **Figure 4.1** shows the checklist's structure. The four factors from the ergonomic taxonomy and the three phases are overlaid on the detailed issues to be evaluated.

Figure 4.1 Structure of the Checklist, showing its relationship to the four groups of factors and three phase defined in Section 4.2.1



A. Pre-Inspection Phase

In this phase, the auditor collects information on the ergonomic aspects of the task that are not expected to change during the task sequence. These are represented by questions on the following:

- documentation, communication during shift changes, etc.
- visual and thermal characteristics of the environment
- equipment design issues (**NDT** and access).

This information is gathered before the actual inspection to keep the auditor's effort (and any interference with the inspector) to a minimum as the task progresses.

B. Inspection Phase

During this phase, the auditor evaluates the main issues, i.e. information, environment, equipment and physical activity. However, the auditor's focus is the task at hand and the way this task is completed. The issues are the following:

- usage of documentation, communication between workers/supervisor
- task lighting, noise levels, operator perception of the thermal environment
- equipment availability and standards
- access, posture, safety.

C. Post-Inspection Phase

This phase evaluates the maintenance activities, i.e. repair and buy-back. Although using the same guidelines as the inspection task and following the same structure and sequence, some additional modules have been included to address issues specific to maintenance activity.

4.2.3.2 The Computer Program (ERGO) for Audit Analysis

Turbo Pascal 6.0 was chosen as the language for developing the audit program. It is a structured, high-level language with multiple overlapping windows, mouse support, a multifile editor, and an enhanced debugging facility.

The audit analysis program has a data input module and a data analysis module. These are further divided into several independent modules addressing specific issues of the preinspec-tion, inspection and the post-inspection stages, e.g., documents, communication, visual characteristics, access, and posture. The fundamental logic of both the programs is as follows:

- opening the data file
- accepting answers or values to the checklist questions
- updating the counter
- writing the answers to a data file
- accessing the data file
- comparing values with the correct value or answer
- setting flags and proceeding to the next data set if the two answers are unequal
- checking the position of all flags at the end of all data input
- printing recommendations or prescribing guidelines for all the flags set.

A simple manual accompanies the program, showing how to

- install the software onto a personal computer
- run the program
- create and view data files

- access data files for analysis
- create and view output files
- print data and output files
- abort from in within the program.

The manual has been written so that even novice computer users can install and run the program.

4.3 EVALUATION AND EVOLUTION

It is only possible to refine and develop a system such as this ergonomics audit program through continual testing in operational environments. Two airline partners were involved in designing, evaluating and developing this system. The first was a regional operation of passenger helicopters; the second, a major national airline. The requirements were initially perceived to be quite different for each environment, but a common audit system was eventually developed that is applicable wherever aircraft inspection is performed. The only difference among the different versions of the audit system is the choice of aircraft types in the examples and illustrations. Versions exist for airline jets, regional turboprop airliners (or corporate aircraft), light aircraft (general aviation), and rotary wing aircraft. It is worth repeating that the different versions exist solely to make the auditors more comfortable by letting them see familiar aircraft illustrated: the content of each checklist (and of the computer analysis program) is identical.

4.3.1 Sampling Plan Evaluation - The Point System

Before actually proceeding with the audit, it is imperative for the auditor to identify the task/tasks to be audited. The criticality of a task does not necessarily indicate the magnitude of its human factors mismatches. Those remain to be assessed by the audit checklist and the program itself. The Point Rating scheme identifies tasks where the probability of error occurrence is high and samples the likely problem areas.

4.3.1.1 Step 1. Selecting Factors

The basis of the sampling system developed was the experience and expertise of the employees who rate these tasks. We want to know whether the component of the screening method reflects the domain being tested and whether the components taken as a whole cover it in a representative fashion.

We employed a method of **"Multiple Judges"** to enhance their confidence in judgments of content validity. Eleven inspectors and three auditors were each asked to

- study the definition of the aircraft inspection domain
- generate a pool of possible factors influencing an inspection task
- refine that pool.

As a result of a survey study, the factors listed below were identified:

- **Mental demands:** the amount of information needed from documents, reference manuals, and communication with the supervisor and co-worker

- **Physical demands**: the amount of force/pressure to be exerted for task execution
- **Visual demands:** illumination levels required for the complete inspection
- **Access demands:** the space restrictions for carrying out the task
- **Postural demands:** the awkward postures adopted to access and inspect)
- **Temporal demands:** time stress during the inspection
- **Safety:** how safe the inspector feels during the inspection.

4.3.1.2 Step 2. Ranking the Factors

After having identified the seven factors, the inspectors were asked to rank order these factors in terms of their "degree of importance and criticality" with respect to the task. Ten inspectors with three years or more experience on C-check inspections were asked to rank these factors. The average ranking for the seven factors is as given below:

Most Important Safety

Mental demands

Visual demands

Access demands

Physical demands

Temporal demands

Least Important Postural demands.

A correlation analysis was conducted of these ten inspectors' rankings. The correlations of the individual subject readings with the average were relatively high, the lowest being 0.67. A non-parametric measure of overall correlation, **The Kendall Coefficient of Concordance (W),** measures the degree of association among inspectors had the value W = 0.674. This result was highly significant ($p < 0.001$), showing considerable agreement among inspectors.

4.3.1.3 Step 3: Weighting the Factors

It is possible to use the ranking values obtained above to determine weightings for the seven factors, using the Rank Order method (Guilford, 1954). In **Table 4.2,** the average ranks are shown in the first column. The second column gives the normalized ranks, assuming an underlying normal distribution of ranking responses by inspectors. Weights are then derived in the third column by dividing all the normalized ranks by the largest one (6.5). Thus, according to the inspectors' judgements, the least important factor (posture) should only receive just over half of the weight (0.51) of the most important factor (safety).

Table 4.2 Development of factor weightings from average rank values

FACTORS	MEAN RANK	NORMALIZED RANK	WEIGHTING
Safety	6.5	6.5	1.00

Mental	6.3	6.4	0.98
Visual	4.1	5.1	0.78
Access	4.0	4.9	0.75
Physical	2.8	4.6	0.71
Temporal	2.0	3.8	0.58
Posture	2.0	3.7	0.51

4.3.1.4 Step 4: Listing the Inspector Tasks

A comprehensive list of all the inspection tasks in a C-check were obtained from the airline partners operating fixed-wing and rotary-wing aircraft. For the fixed-wing aircraft, the airframe was segregated into six zones, depending upon the area under inspection:

- Fuselage
- Empennage
- Wings
- Wheel well and landing gear/cargo compartment
- Power plant
- Door and windows

A similar exercise was conducted for the rotary-wing aircraft's inspection tasks, where the natural classification was into phase inspections (Phase I through Phase V).

4.3.1.5 Step 5. Rating Tasks

For a particular zone selected, e.g., power plant, experienced inspectors were asked to rate a list of five tasks with respect to the seven factors indicated. For each task, the inspectors were asked to rate the factors on a scale from 1 to 5 as follows:

|_____|_____|_____|_____|

1 2 3 4 5

very easy very demanding

From these ratings and from the weights assigned earlier, sampling plans could be developed to concentrate auditing effort onto the most critical tasks.

4.3.2 Results of Sampling Plan

Three inspectors with ten or more years of experience with C-checks were chosen to rate the seven factors for each task listed under Power Plant Inspection and Wing Inspection. For each task, each factor rating is multiplied by its respective weight, and the values were summed over the seven factors to give one final score. The scores were then compared to each other to estimate the degree of criticality of each task. The final ranking of the tasks is presented in **Table**

4.3.

For the rotary-wing airline partner, three inspectors with six or more years experience with Phase inspections were chosen for a similar rating. The final ranking of the tasks is presented in **Table 4.4.**

From the data presented in Tables 4.3 and 4.4, it is apparent that differences among tasks are not large. Thus, while some tasks were found to have more critical ergonomic needs than others, none could be safely neglected.

Table 4.3 Final criticality ratings of power plant and wing inspection tasks

RANK	POWER PLANT TASKS	WING INSPECTION TASKS
1	Power plant inspection (15.04)	Tee Cap inspection (14.1)
2	Thruster-reverser drive link inspection (13.74)	Wing inspection (13.59)
3	Pylon inspection (13.17)	Aft spar wing control inspection (12.89)
4	Engine accessory inspection (12.16)	Flap hinge bracket penetrant inspection (10.97)
5	Power plant check (11.43)	Flap hinge bracket inspection (10.66)

Table 4.4 Final criticality ratings of inspection tasks on Sikorsky S58T and Bell 206L type aircraft

RANK	SIKORSKY S58T	BELL 206L
1	Phase I (18.87)	Phase III (20.23)
2	Phase V (14.46)	Phase IV (15.49)
3	Phase IV (13.94)	Phase II (15.42)
4	Phase III (13.71)	Phase I (13.16)
5	Phase II (13.47)	

The final result of these manipulations can again be tested for its reliability. If the inspectors are indeed judging consistently, then there should be a high degree of agreement among the final rankings of the tasks. Thus, the same inspectors were asked to rank the criticality of the tasks within each of the four sets ("fixed wing power plant" to "Bell 2062"), and these rankings were compared using the coefficient of concordance. All four values were significant at $p < 0.01$, with values as follows:

Fixed Wing, Power Plant	0.913
Fixed Wing, Wing Inspection	0.813
Rotary Wing, Sikorsky S58T	0.910
Rotary Wing, Bell 2062	0.900

These results in fact do show a high and significant level of agreement.

4.3.3 Audit Checklist

The Audit checklist evolved over three different versions. **Version 1.0** contained questions in 18 modules spread over the Pre-Inspection, Inspection, and Post-Inspection Phases. This version was evaluated at the sites of both airline partners. The need for graphics was identified because of their greater comprehension capabilities. Graphics were incorporated in Version 2.0. Version 2.0 retained the same structure as the previous checklist. A few questions were appended with self-explanatory diagrams while others were rephrased to reduce ambiguity. This checklist was then tested for reliability at two different sites.

4.3.3.1 Reliability of the Ergonomic Audit (Version 2.0)

The ergonomic audit was administered simultaneously by two trained auditors on the following three tasks, spanning two aircraft types:

- Audit 1 - Sikorsky S58T Phase III Main Rotor transmission inspection
- Audit 2 - Wing Inspection on a DC-9
- Audit 3 - Lavatory Inspection on a DC-9.

The differences between the two auditors were analyzed using the Cochran Q test, which is a strong test to determine whether the same treatment generates different responses between subjects. The value of the test statistic X2 for each test is shown in **Table 4.5**; all differences are significant at $p < 0.05$.

Table 4.5 Test for significance of differences between auditors

	TASK AUDITED	X^2
1	Audit 1 S58T Phase III Main Rotor inspection	7.14
2	Audit 2 DC-9 Wing inspection	5.00
3	Audit 3 DC-9 Lavatory inspection	5.00

Thus, results were different between the two auditors. Since the significant test did not indicate which questions had different responses between the auditors, these had to be determined by post-hoc investigations. As these differences were found, the audit program was redesigned to provide a checklist giving identical results for each auditor.

There are two ways to compare differences between the auditors: by module and by question type. First, the mismatches between the two auditors were determined for each of the 18 modules; these results are shown in **Figure 4.2.** The modules on Posture and Task Lighting showed the greatest number mismatches, but examination of these modules did not reveal a trend in the type or the number of mismatches.

In order to better understand these disparities, checklist questions were divided into three categories, dependent upon the type of question and, hence, upon possible errors in answering the question. Thus, any question on the checklist either result in either a Reading-Off Error, an Operator Perception Error, or an Auditor Judgment Error. Overall, 54% of the questions were reading-off type questions; 24% operator perception type; and 21% auditor judgement type. **Figure 4.3** shows the percentage of each error type inspectors made on each of the three tests.

As seen in **Figure 4.3,** most errors were due to **auditor judgement,** followed by **operator perception**. **Reading-off errors** contributed a very small percentage to the total errors.

Thus, in order to reduce the mismatch between auditors, auditor judgement errors have to be reduced to the minimum. This can be achieved by the following strategy:

- Have more explicit instructions assigned to auditor judgement type questions
- Reduce the number of "auditor judgement" type questions and increase the number of "read-off" type questions.
- Provide better training for auditors.

Figure 4.2 Frequency of mismatches for the three audits by modules

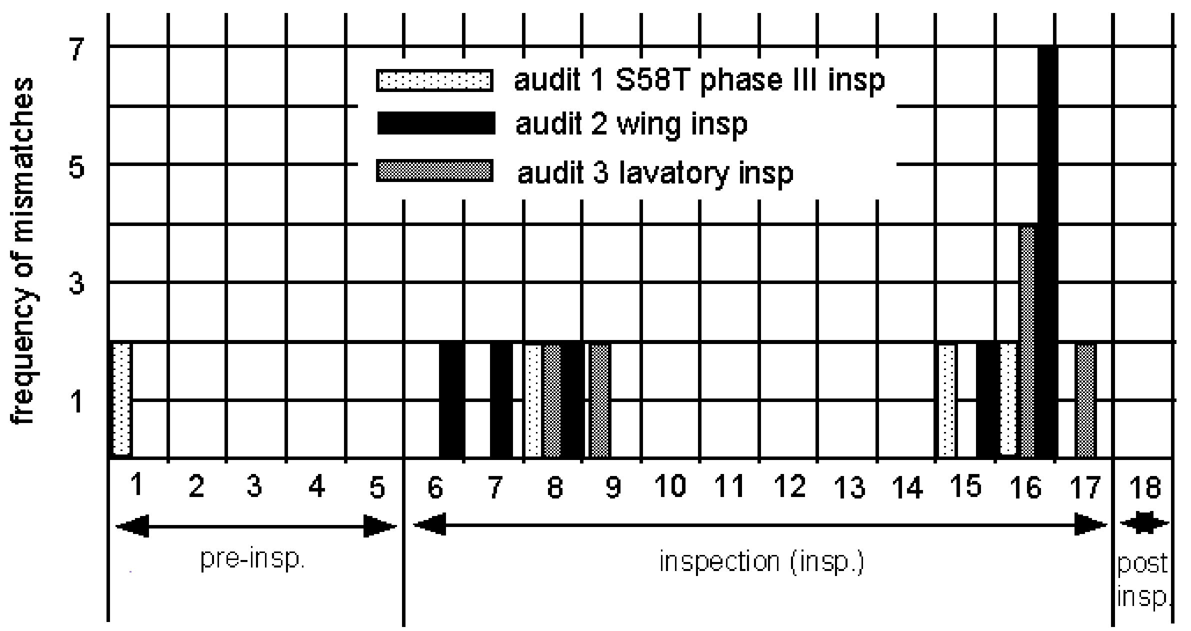
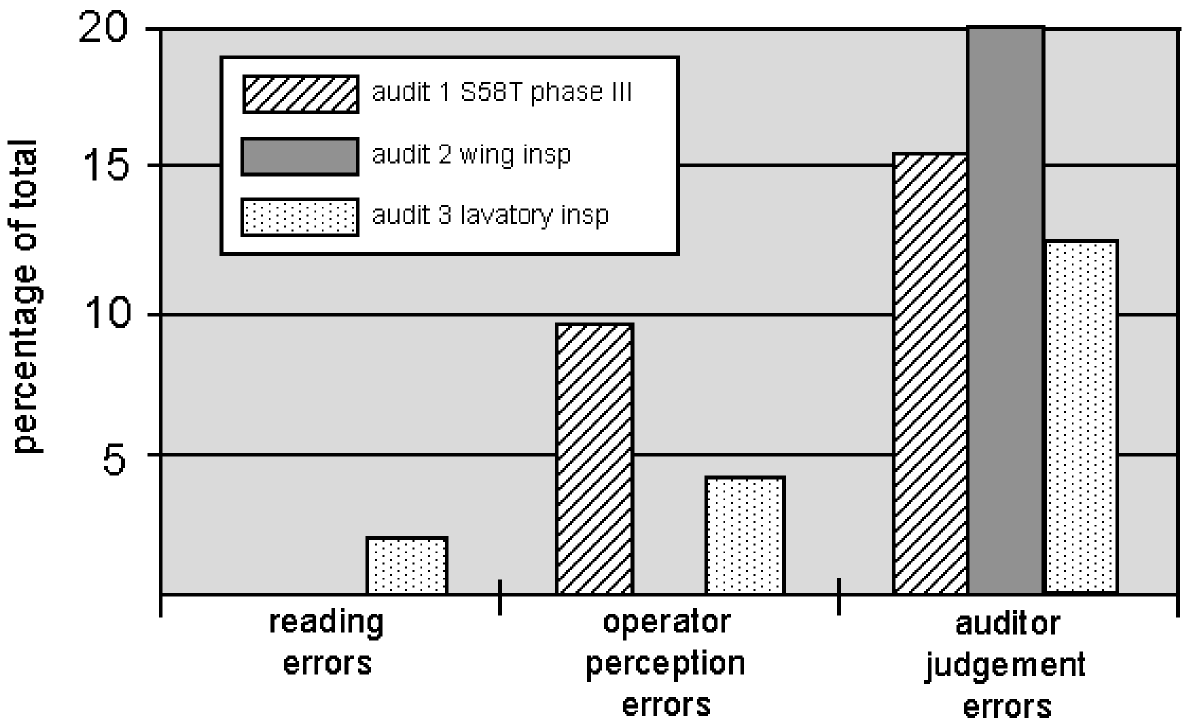


Figure 4.3 Percentage of each error type on each test



Version 3.0 of the audit checklist incorporated all of the above recommendations and was tested for reliability by having two auditors administer audits simultaneously on the task (Audit 4) of the Left Power Plant Inspection on a DC-9. The differences between the two auditors were analyzed using the Cochran Q test, referenced earlier. The value of the test statistic X2 was now not even significant at $p < 0.10$, showing that results did not change between the two auditors (**Table 4.6**). Thus, Version 3.0 of the audit was deemed to have proven reliable.

Table 4.6 X^2 Table to test for significance

AUDIT	TASK AUDITED	X^2
4	Audit 4 - Left Power Plant Inspection/DC-9	2.1

4.4 THE AUDIT SYSTEM IN PRACTICE

Both airline partners have used the training version of the checklist and the computer documentation produced, although each partner has used the audit system in a rather different way. The rotary-wing operation performed several audits, and the results were combined to guide management in implementing changes. From this compilation, it was determined that the major ergonomic needs were documentation redesign, task lighting, and access equipment redesign. Steps have now been taken to begin implementing changes, based upon the findings. The audit program will be used after implementation to measure the effectiveness of the changes.

Our other airline partner has incorporated the audit program into its on-going Quality Assurance program. A single auditor has been trained, and regularly uses the system to produce audit reports on specific inspection activities. An example of output from the program is Chapter 4 Appendix, obtained after an audit of a fixed-wing aircraft late in 1993. Names, dates, and numbers have been changed to preserve anonymity.

The audit evaluation takes the form of an auditor's memo to a supervisor, using heading information generated within the program. This format can readily be changed, as the output file is a simple text file suitable for input into any word processor. Also, the output does not simply identify a mismatch. It provides some guidance as to how corrections can be made, for example by giving recommended illumination levels or recommended air temperatures. The audit program is no substitute for a detailed ergonomic analysis, but it does provide a rapid tool for identifying error-likely situations. For more detailed recommendations, the FAA/AAM Human Factors Guide should be consulted.

Finally, the audit program takes about 30 minutes to administer. As this is less than the time typically required to type an audit report, the system is time-saving and cost-effective in addition to providing wider access to human factors techniques in aircraft inspection.

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CHAPTER FOUR APPENDIX - Example Output from Ergonomic Audit

TO **:Ms Supervisor**

FROM :A.N. Auditor

Task Description :APU Compartment Inspection.

Date :August 4, 1993

Time :3:00 am

Station :LHR

Hangar Bay :

Aircraft No. :A300

M/E No. :87-1831-1-0001

Q/A No. :24A76

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/DOCUMENTATION

A. Information readability

1. Typographic layout of the current workcard is inconsistent with other work cards. Maintain interdocument consistency in terms of:

a: Spatial organization b: Font type, Font size

c: Typographic cues (e.g., boldfacing, italics, etc.)

2. Make use of typographic cues. For spatial layout use Primary type cues like:

a: Vertical spacing b: Lateral positioning c: Paragraphing

d: Heading positioning

Within the spatial layout use secondary type cues like:

a: Bold-facing b: Italics c: Capital cueing d: Underlining, etc

3. Dot matrix printers with a 5X7 matrix of dot characters is minimally acceptable for reading purposes. If used, check for character specifications:

Minimum Character Height = 3.1mm to 4.2mm

Maximum Character Height = 4.5mm

Width/Height ratio = 3:4 - 4:5

IMPORTANT: Do not use lower case letters, since features can get easily confused.

4. Graphics/attachments illegible. Likely causes:

a: Photocopy deterioration   b: Microfiche copy deterioration

c: Blueprint copy deterioration

5. Standards are not prescribed. State "TIME" and "QUALITY" standards to ensure consistent print quality.

B. Information Content

Text

6. Feedforward information not provided to the inspector. Present information on

a: previous faults detected   b: locations of prior faults c: likely fault prone

areas for the specific task and current aircraft under inspection.

Graphics

7. Present information on body station positions in a graphical format. All spatial information should be presented in a diagrammatic form.

C. Information Organization

8. Incorrect sequencing of tasks in the workcard. Tasks need to be sequenced in the natural order in which the task would be carried out by MOST inspectors.

9. Avoid carryover of tasks across pages at ILLOGICAL points. Tasks should begin and end on the same page. For longer tasks, break into several subtasks with multiple sign-offs. Each subtask, should then begin and end on the same page.

10. Excessive number of tasks per action statement. More than 3 actions/step increases the probability of action slips.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/COMMUNICATION

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/VISUAL CHARACTERISTICS

1. Mercury Vapor lamps: "Poor" color rendition properties. Color rendition is the ability to distinguish true colors correctly. This is especially useful in detecting corrosion faults. For best results consider incandescent bulbs.

2. No "shades/shields" on illumination sources. This may cause "direct" or "disability" glare.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/ACCESS

ACCESS - STEP LADDERS

1. The height of the step ladder is 36.00 inches. The maximum height should be 27 inches.

ACCESS - TALL STEP LADDERS

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/DOCUMENTATION-PHYSICAL HANDLING & ENVIRONMENT FACILITY

1. The inspector does not sign off workcard after each subtask. This may lead to errors of omission.

2. Writing tools do not facilitate writing in all positions. Consider providing a workcard holder.

3. The inspector does not fill out discrepancy sheets/Non-Routine Repair sheets as soon as fault is detected. This may lead to errors of omission.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/COMMUNICATION

1. The inspector felt that verbal instructions from the supervisor were not explicit.

2. No performance feedback was given to the inspector conducting the task. Consider intermittent supervision by the supervisors to indicate when inspector was not performing up to standards.

3. The inspector was not encouraged to identify error likely situations in "Existing Designs".

4. The inspector was not encouraged to identify error likely situations in "Existing Procedures".

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/TASK LIGHTING

1. The average task illumination is 72.50 foot candle (fc) and the variance is 2718.75. The recommended task illumination should be 100.00 fc. The variance is exceptionally high.

2. Hand lamps deliver a maximum of 85 fc. of light. This illumination level is inadequate for "Detailed Inspection". Hand lamps also lack aiming control. Consider usage of Standing Lamps (Halogen 500 watts - 1200 fc.) or Portable lamps (Florescent 27 watts - 164 fc.).

3. Consider head lamp for hands free illumination; except in explosive environments. e.g., Fuel tank inspection.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/THERMAL CHARACTERISTICS

1. The current DBT is 31.00 degrees centigrade. The recommended temperature is between 20-26 degrees centigrade.

2. The current task has been identified as having MODERATE physical workload. The current air velocity is LOW (less than 1.5 m/s), and the WBGT is 29.00 cent. The recommended WBGT values for MODERATE w/load and LOW air velocity is 30 de.g., or less.

3. The current task has been identified as having MODERATE physical workload. The DBT is 29.00 cent. and the clo value for clothing is 0.58 clo. The recommended DBT values for MODERATE w/load and clo values between 0.5-0.75 are 18-22 degrees centigrade. Consider change in clothing.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/OPERATOR PERCEPTION OF THERMAL ENV.

1. The operator found the current workplace temperature to be slightly warm.

2. Operator wanted the workplace temperature to be cooler than the current temp.

3. The operator found the summer temperature at the workplace to be warm.

4. Operator wanted the summer temperature at the workplace to be cooler than the current temperature.

5. The operator found the winter temperature at the workplace to be cool.

6. Operator wanted the winter temperature at the workplace to be warmer than the current temperature.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/AUDITORY CHARACTERISTICS

1. The variance is high.

2. This task involves verbal communication. The average noise level is 65.00 dbA. The distance of communication is 20.00 feet. The noise level for communication at a distance of 10-20 feet should not exceed 50 dbA.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/ACCESS EQUIPMENT USAGE

1. Neither the correct access equipment nor the substitute access equipment was available.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/ACCESS - ACTIVITY

1. The operator felt that access was difficult.

2. Access equipment was repositioned too frequently. This consumes a lot of operator effort. Consider using multiple access equipments.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/POSTURE

The following extreme postures were observed during the current inspection task:

Urgent intervention is requested.

1. Arms in air, back bent and loading on one leg.

2. Arms in air, back twisted and loading on one leg.

3. Back bent and twisted and loading on one leg.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/SAFETY

1. No safety attachments provided when operator performs inspection at heights. Consider using safety screens on stair landings, rails, cages etc.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN POST-INSPECTION/FEEDBACK

1. Consider inclusion of standard information like ATA codes, station #, sup.#, employee #, etc. in the workcard. This considerably reduces the cognitive load on the inspector.

CHAPTER FIVE
INVESTIGATION OF ERGONOMIC FACTORS RELATED TO POSTURE AND FATIGUE IN THE INSPECTION ENVIRONMENT

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5.0 Abstract

Aircraft inspection tasks are often performed under extreme conditions which may cause increased operator stress, fatigue, and workload. Several factors, particularly restrictive spaces that cause extreme postures, have been identified as possible contributors to stress and fatigue in the aviation maintenance environment. These factors are dictated by design itself and by the access equipment employed. Following the development of a methodology for studying fatigue and restrictive spaces (Phase III), a set of four tasks from the C-check of a DC-9 were used to evaluate these effects. Inspectors were observed performing each task to collect postural data, and psychophysical scales were used to measure fatigue, postural discomfort, and workload. All showed that the same tasks have the greatest impact on the inspector. On the basis of those findings, improvements were generated and are now being implemented at the partner airline.

5.1 INTRODUCTION

Aircraft structures are designed as a compromise among aerodynamics, strength, weight, and access. Optimum access must be conceded in order to meet other requirements, thus requiring many aircraft inspection and maintenance tasks to be performed in non-optimum conditions which may lead to fatigue.

Ergonomic factors in aircraft inspection and maintenance tasks may cause extreme working conditions. One of the most noticeable deviations from ergonomically optimum conditions is that tasks must be performed in restricted spaces that force awkward postures. Literature reviewed during Phase III indicates that tasks possessing excessive postural demands, e.g., cramped positions and maintenance of awkward postures, can produce fatigue and ultimately affect both performance and well-being (see Corlett, 1983; Corlett and Bishop, 1978; Hunting, Grandjean, and Maeda, 1980; Van Wely, 1970; Westgaard and Aaras, 1984). The project reported in this paper arose from a task statement to propose a methodology to study extreme ergonomic conditions, particularly restrictive or confined spaces, and their effect(s) on human posture, performance, and stress.

Characteristics of the environment, operator, and task may produce fatigue and stress. We model to guide research in describing and predicting the effects of extreme ergonomic factors and associated postural, fatigue, and stress effects on performance and workload. We undertook on-site evaluation in order to 1) to measure and determine if increased stress and fatigue levels exist in the aviation maintenance and inspection environment; 2) to determine if techniques and methods used successfully to measure fatigue and workload in non-aviation environments could be applied to this environment; and 3) if increased levels of stress, fatigue, and workload were found, to provide ergonomic interventions to improve this environment.

5.2 RESTRICTIVE SPACE MODEL

The Restrictive Space Model **(Figure 5.1)** systematically describes a space or task area in terms of inputs, or ergonomic factors defining a physical or perceived space, and outputs allowing the effects of the space to be understood and predicted.

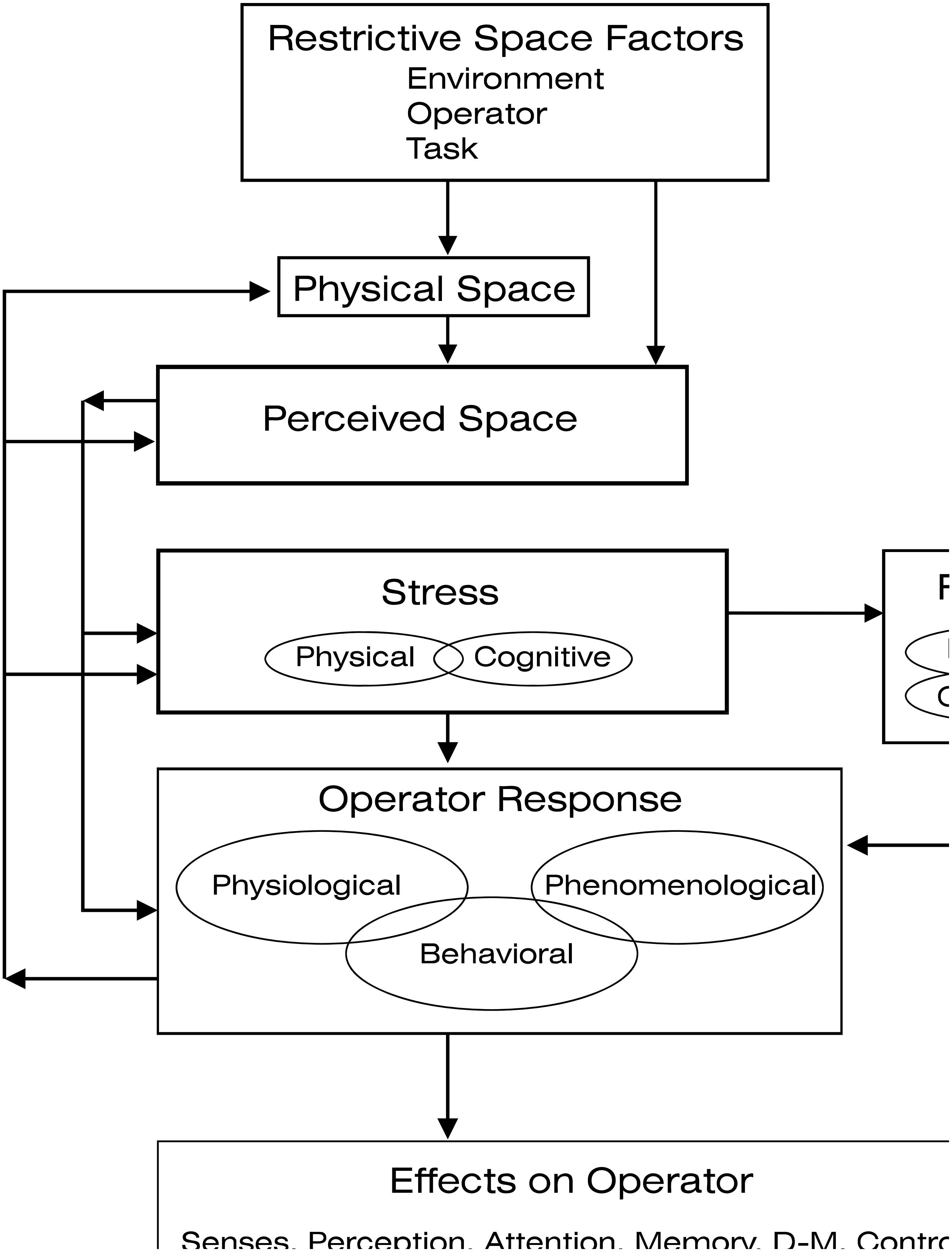
Restrictive Space Factors
Environment
Operator
Task
Physical Space
Perceived Space
Stress
Physical
Cognitive
Operator Response
Physiological
Phenomenological
Behavioral
Effects on Operator

Figure 5.1 Restrictive Space Model

5.2.1 Ergonomic Factors

In order to describe and eventually to predict the effects of operator response on performance and workload, we must understand the effects stress and fatigue have on the operator. During Phase III, ergonomic factors which may produce fatigue and ultimately effect performance and well-being were identified; these factors are listed in **Table 5.1** (Galaxy Scientific Corporation, 1993). This compilation of factors is not exhaustive. There are a number of other (lesser) environmental, task, and operator characteristics which could contribute to fatigue effects, e.g., temperature, gender, and age. However, the listed factors have been identified as being the most salient and prominent possible contributors to fatigue in the aviation inspection/maintenance environment. They provide a starting point to focus these investigations.

Table 5.1 Ergonomic Factors

Area/Volume of Workplace
Task Duration
Equipment/Tooling Used
Workplace Lighting
Social Factors, e.g., resource availability
Surface Condition of Adjacent Surfaces

5.2.1.1 Area/Volume of Workplace

Confined spaces normally associated with whole-body restrictions occur when an inspector enters an intervening structure or works within an area in which the entire body is confined to that specific area, e.g., cargo hold. However, restrictive spaces are also created in areas where the surrounding physical space is unlimited, but the immediate working area is restricted. These partial-body restrictions result in limited movement of a specific body part. For example, tasks aided by access devices such as steps or cherrypickers cause lower limb restriction, for the feet must reside within a limited area. Other examples include reaching arms through access holes and positioning various body parts in and around fixed aircraft components, e.g., inside a small access panel. These partial-body restrictions may occur in addition to whole-body restrictions. Interior inspection of the tail compartment demands that the inspector climb into the area (whole-body restriction) place the head and arms through narrow confines to check components (partial-body restriction).

Much research has examined the effects of restricted space on access tasks. *Access* consists of physically reaching the area to be inspected. Access activities involve controlling the movement of the body or body part(s) within a restrictive space. In aircraft maintenance/inspection this may be an unaided human task (e.g., area inspection of lower fuselage skin), aided by access devices (e.g., steps, scaffolding, cherrypickers), or require access through an intervening structure (e.g., inspection of wing fuel tank interiors through access holes). Normally, aircraft are designed to the anthropometric boundary, i.e. to the minimum allowable requirements based upon human body dimensions. However, designing to this boundary does not ensure (optimal) performance. Mathematical models indicate that the amount of space defines the accuracy requirements of a task. In turn, accuracy requirements may dictate the speed of performance.

Numerous investigations have found a speed/accuracy tradeoff in human performance; as accuracy requirements increase because of decreased space, performance slows (see Bottoms, 1982; Drury, Montazer, and Karwan, 1987; Fitts in Wickens, 1992). For example, the speed a hand can be moved through an access hole depends upon the hole's size. Further performance changes may depend upon the posture adopted while the body part is restricted. Wiker, Langolf, and Chaffin (1989) reviewed research which indicated that there are only minimal differences in manual performance for work heights up to shoulder level. However, position and movement performance decreased progressively when hands were used above shoulder level. The production of movement with pre-tensed muscles may serve to increase tremor and decrease maximum muscle contraction speed. Restricted entries and exits have been found to affect whole-body ingress and egress times (Drury, 1985; Krenek and Purswell, 1972; Roebuck and Levedahl, 1961), as well as subjective assessments of accessibility (Bottoms, Barber, and Chisholm, 1979).

These models indicate that the speed an inspector chooses increases until it reaches some limiting speed. The point at which increases in space no longer affect performance is the performance boundary (Drury, 1985). However, designing to this boundary does not ensure that increased operator stress, fatigue, or workload does not occur, merely that direct task performance is not affected.

Along with access, other aspects of the actual inspection task may be affected by a restricted space. Visual search requires the inspector's head to be at a certain location to control the eyes and visual angle. Thus, restricted areas frequently force inspectors to adopt awkward head, neck, and back angles induce stress and fatigue. Inspectors are forced to either search an area at less-than-optimum viewing angles or work indirectly, using a mirror. Although both methods can produce acceptable performance, inspector workload and stress are increased; performance is less efficient than under unrestricted conditions.

Restricted areas may also prohibit inspections from having any extraneous material easily accessible in the immediate working area (e.g., workcards on the illustration). This forces inspectors to make decisions without comparison standards, increasing memory load, or additional time to obtain information from the workcard, a manual, or a supervisor. Moreover, less-than-optimum viewing angles may further decrease sensitivity and increase the difficulty of decisions. Thus, restricted spaces can force the decision- making task to be more memory-intensive, more length, and more difficult.

Conversely, pressures for cursory decision- making may encourage the inspector to get out of the space quickly. Decision-making tasks exhibit a speed/accuracy tradeoff (SATO), with speedy performance associated with inaccurate decision-making. However, inspectors are highly motivated to perform accurately (Shepherd, Johnson, Drury, Taylor, and Berninger, 1991). Thus, we predict that while accurate decision-making performance may not be compromised by even the most extreme space conditions, workload and stress may increase.

The inspection task also requires that detected defects be marked and documented. As discussed above, restricted areas may not allow additional material such as non-routine repair forms in the workspace. The inspector must then remember all defects within an area, only later documenting on the appropriate forms. This situation can add to the high memory load requirements on inspectors and present the potential for an inspector to forget to note a defect.

Finally, extreme space conditions allow inspectors to adopt only a limited number of inefficient postures. Thus, their physical working capacity may be reduced in restrictive spaces, as indicated by research in the area of manual material handling (Davis and Ridd, 1981; Mital, 1986; Ridd, 1985; Rubin and Thompson, 1981; Stalhammer, Leskinen, Kuorink, Gautreau, and Troup, 1986). Under unlimited space conditions, operators are able to adopt efficient postures or switch postures and use other muscle groups, enabling primary muscle groups to be rested (Drury, 1985). However, the frequent breaks from restrictive areas common during maintenance/inspection activities allow relief from sustained task performance and allow the primary muscle groups to be rested.

5.2.1.2 Task Duration

Some inspection tasks and many repair tasks require mechanics to be in a confined or restricted area for prolonged periods. Increased task duration forces an inspector to spend longer periods of time in a restrictive area and could psychologically affect his or her perception of space. Habitability literature, concerned with the study of manned underwater vessels and space vehicles, indicates that internal space requirements vary as a function of duration (Blair, 1969; Price and Parker, 1971). Furthermore, Cameron (1973) indicates duration to be the primary variable associated with fatigue effects.

5.2.1.3 Equipment/Tooling

The equipment and tooling utilized during access and task performance can contribute to stress and fatigue effects and may further physically restrict the area. Furthermore, the equipment may not be designed optimally for a given task. For example, ratchets used to loosen/tighten a bolt may not have attachments which allow inspectors to reach an area without placing their arms in an awkward position, forcing them to create torque in an inefficient posture. Similarly, eddy-current devices used to inspect rivets have no convenient resting place, leading to a less-than-optimal relationship among the inspector, the probe, and the eddy-current display.

5.2.1.4 Workplace Lighting

Studies in aircraft inspection have shown that poor illumination and other adverse lighting conditions could be important reasons for eye strain or visual fatigue. Visual fatigue causes a deterioration in the efficiency of human performance during prolonged work. Thus, an adequate visual environment is crucial to ensure acceptable performance in aircraft inspection. In addition, poor lighting demands that inspectors adopt a certain posture for task performance by forcing a specific visual angle. Thus, restricted areas frequently force inspectors to adopt awkward head, neck, and back angles induce stress and fatigue. In addition, inadequate lighting requires inspectors always to hold their flashlight in one hand; likewise, awkward portable lighting forces them continually to struggle with and reposition the lighting (Reynolds and Drury, 1993).

5.2.1.5 Social Factors

Social aspects of the environment may also increase fatigue. As the number of people within a given area increases, the amount of space for any single person decreases. Uncomfortably close spacing among individuals may limit their individual environmental tolerance. When many individuals in the same area perform the same tasks, the available resources may become limited, and people may become frustrated, e.g., when specialized/portable lighting is not available). Also, when more people share the same space, there is an increased likelihood of physical interference among tasks.

5.1.1.6 Surface Condition

The surface condition of many work areas in an aircraft hangar has been noted to be poor: dirty, uneven, or rough. These surfaces cause inspectors either to limit the postures they are willing to adopt or force them to adopt inefficient postures. For example, operators may not sit in a certain area to avoid oil-soaked clothing; instead, they may stoop or crouch to perform the task. These surfaces also present a safety concern, at times causing inspectors to slip or trip. Furthermore, continued kneeling or laying on rough or uneven surfaces can cause recurring aches and pains.

In summary, the effects of restricted space and its associated posture effects have been hypothesized to be the largest contributor produce a fatigue response, possibly also affecting inspectors' workload and performance. The present evaluation focuses on this factor while simultaneously considering other factors within the aviation environment.

5.2.2 Physical and Perceived Spaces

Note: Sections 5.2.2 to 5.2.7 are included from the Phase III Volume I progress report as they form the basis for the studies undertaken.

The above factors can directly affect working conditions. The workspace has physical characteristics which can be easily defined and investigated, but the operator also perceives the physical space. Thus, the effective workspace is partially created by physical elements within a fixed space and partially by perceived elements. It is not necessarily constant, but depends upon an individual's constantly changing perceptions. The effects of this effective space must be inferred, as direct observation is not logically possible.

5.2.3 Stress

It is logical to model inspector's working conditions within a traditional stress framework, where extreme conditions act as a stressor. Context-dependent examination of the factors allows the specific stress-inducing situation to be defined. Determining subjects' perceptions assists in interpreting their behavior (Meister, 1981). Thus, field investigation is important for understanding the specific response to aircraft maintenance/inspection activities. In an effort to define stress operationally, the we employ the following definitions (Alluisi, 1982; Pratt and Barling, 1988):

Stressor - The environmental, operator, and task characteristics comprising the work area and impinging on the individual. In this context, both physical and perceived spaces are the stressors.

Stress - A state within the individual caused by the stressor's perceived magnitude. The existence and interaction of various environmental, operator, and task characteristics dictate the intensity of stress.

Aircraft inspection performance normally both physical and cognitive demands. Differentiating the stress these demands induce helps more clearly to define and understand individual's various stress responses. Physical stress is directly perceived by an individual's involved physical subsystems, e.g., biomechanical or physiological, due to a discrepancy between the environmental/task demands and the individual's physical ability to meet these demands. An individual perceives this type of stress through a specific, or localized, experience of discomfort. Thus, an individual's response can be specifically aimed at eliminating or alleviating the stressor, when possible. There also is an overall physiological response to bodily requirements. For example, space restriction may cause postural stress and discomfort in various muscle groups, resulting in increases in heart rate and blood pressure (Astrand and Rodahl, 1986).

Cognitive stress results from an individual's perception of the discrepancy between perceived environmental/task demands and the individual's perceived ability to meet those demands (Cox, 1990, 1985). Since this mismatch eventually determines the stress reaction, the operator's perceptions play a key role. This stress is experienced as negative emotion and unpleasantness (Cox, 1985; Sutherland and Cooper, 1988) and may be difficult to localize.

We hypothesize that whole-body confinements, as opposed to partial-body restrictions, are more apt to produce cognitive stress effects. Inspectors may feel that they have less control to adapt or to adapt to the perceived space. For example, when an inspector is totally enclosed in an area, there may be fewer opportunities to eliminate the stressor, e.g., through frequent rest breaks outside the space. Both whole-body and partial-body space restrictions are hypothesized to cause physical stress effects, particularly postural, due to the body positions which these restrictions demand. These physical stress effects most likely lead to cognitive stress effects if task completion is compromised.

In summary, the effects of stress on human performance provide the basis for investigation. These effects include increased arousal, increased processing speed, reductions in working memory, reduced attentional capacity and attentional narrowing, and changes in the speed and accuracy of performance (Hockey and Hamilton, 1983; Hockey, 1986; Reynolds and Drury, 1992; Wickens, 1992).

5.2.4 Fatigue

As discussed above, task performance under extreme conditions can result in both physical and cognitive stress; in turn, it can induce physical or cognitive fatigue. *Physical fatigue* may be defined as a state of reduced physical capacity (Kroemer, Kroemer, and Kroemer-Elbert, 1990). An individual can no longer continue to work because the involved physical subsystems are not capable of performing the necessary functions. For example, a posture can no longer be maintained due to exceeding the endurance limit of the muscles (see Rohmert, 1973).

Cognitive fatigue is normally associated with stress and may be broadly defined as a generalized response to stress over time. The effects may reside as a psychological state within the individual or extend to affect performance. Symptoms of fatigue include restricted field of attention; slowed or impaired perception; decreased motivation; cognitive subjective feelings of fatigue and task aversion; and decreased performance in the form of irregularities in timing, speed, and accuracy (Bartlett, 1953; Grandjean and Kogi, 1971).

5.2.5 Operator Response

An operator's response is a function of the perceived space and associated stress and fatigue effects. Operator response cannot generally be described by one variable, as it is manifested in various physiological, psychophysical, and behavioral patterns.

An individual may respond to or cope with a stressful situation in order to lessen the effect of or eliminate the stressor (Cox, 1985). A dependency may exist among the different modes of response: psychophysical, physiological, and behavioral. Any mode(s) of response may in turn elicit another mode(s) of response (Meister, 1981). For example, while performing maintenance or inspection in a cramped area of an aircraft, an initial physiological response to the postural demands such as lack of blood flow to the leg muscles. In turn, this response causes a behavioral response such as posture shifting and/or a subjective response perceived discomfort. A response may alleviate one component of the stress response while causing another. Continuing the example, while a change in posture may reduce the physiological response, the new posture may make the task more difficult to perform, causing feelings of frustration.

5.2.6 Effects on Operator

In order to describe, or possibly to predict, the effects of operator response on performance and workload, there is a need to understand the effects of stress and fatigue on the operator. These effects were cited previously in their respective sections (Sections 5.2.3 and 5.2.4). If performance is affected, it may be possible to specify the affected subsystem and why it is affected. For example, perception may be affected by the inability to obtain an adequate visual angle, *attention* may be distracted by discomfort due to postural stress, or *decision-making* may be speeded up in an effort to finish the task and eliminate the stressor, i.e. to leave the environment.

Table 5.2 Performance, workload, and stress defined within restrictive space framework

ZONE	PERFORMANCE	WORKLOAD	STRESS
0	None possible	*W* 0	*S* 0
1	Proportional to space	$W_{task + compensation(s)}$	$D_{task + compensation(s)} > H$
2	Acceptable	$W_{task + compensation(s)}$	$D_{task + compensation(s)} > H$
3	Acceptable	W_{task}	$D_{task} < HOC$

5.2.7 Framework to Measure the Effects on Performance/Workload

Performance and workload will ultimately be affected by any changes in operator function forced by working conditions and associated stress and fatigue. Drury (1985) advances a three-level framework attempt to describe task performance with respect to the working area. The following proposed framework includes an additional zone to better predict inspector stress, workload, and performance. This framework presents four zones that specifically define performance, workload, and stress (**Table 5.2**).

5.2.7.1 Zone 0 - Anthropometrically Restricted Zone

The task cannot be accomplished in Zone 0 because the working conditions or postures are too extreme for the operator to function. The boundary between Zone 0 and Zone 1 is normally determined by anthropometric data, i.e. by human dimensions. These minimum criteria are only used if space is a critical commodity such as in an aircraft. Under normal conditions, larger spaces are recommended. These type of data are limited because they are normally based on static sitting or standing. They do not account for normal working postures, do not allow for special equipment, and represent a young population. Hence, anthropometrically defined spaces underestimate minimum space requirements (Drury, 1985). There are computer-aided systems such as CREWCHIEF (McDaniel and Hofmann, 1990) that account for some of these limitations. However, Boeing, which has developed and utilizes a similar computer-aided human modeling system, admits that, "[these] systems [have] limits, and some mock-ups still will be required. `Human models...can't do all the interface work.'" (Underwood, 1993).

Even if `minimum allowance models' could ensure that individuals can work in a given space, they do not account for fatigue, workload, or stress effects.

5.2.7.2 Zone 1 - Performance Restricted Zone

Task performance is possible, in Zone 1, but performance is not optimum because ergonomic conditions still interfere with the task. This zone ranges from allowable access for task performance up to acceptable task performance. As conditions improve, performance increases. The total workload is equal to the workload associated with the task plus the workload associated with the operator compensations caused by the workspace. There is increased stress present in this zone, for the task demands exceed the operator capabilities. Workload and stress most likely decrease within the zone, as ergonomic demands decrease, the compensations should also decrease.

5.2.7.3 Zone 2 - Workload/Stress Restricted Zone

Task performance is acceptable, in Zone 2, at least in the short term. However, operators' workload and stress are increased because compensate for ergonomic conditions and/or extreme postures. As ergonomic conditions improve within this zone, operator compensation(s) or responses should decrease, causing the total workload and stress to decrease.

5.2.7.4 Zone 3 - Unrestricted Zone

Zone 3 allows acceptable task performance without additional operator compensation; thus, there is no additional workload or stress imposed by the working conditions.

5.3 ON-SITE EVALUATION AND ANALYSIS

Experimentation utilized the restrictive space model to assist in understanding and describing the relationships between the task conditions and the operator's compensations, fatigue, stress, and workload. The framework used categorizes the task spaces based upon the measured stress and workload effects.

The knowledge of the effects ergonomic factors have on the operator was applied within the methodology to develop the following:

1. A recognition guide, integrated within the ergonomic audit, allowing users to predict which tasks will have a performance decrement and/or stress increase due to posture.
2. A set of interventions keyed to task, operator, and environment factors reduce stress and fatigue.

The maintenance facility where data were obtained possesses four bays and services only DC-9's on all three shifts, i.e. day, afternoon, night. On-site evaluation was two-pronged and included analysis of 1) pre-existing conditions in terms of on-the-job injuries (OJI's) and 2) existing conditions in terms of direct and indirect data collection techniques.

5.3.1 Evaluation of Pre-Existing Conditions

Evaluation of pre-existing conditions can assist in determining if there is any need for ergonomic intervention and, if there is, to focus analysis towards the problem areas. In addition, it can guide the implementation process by emphasizing and prioritizing interventions. OJI's were reviewed in an effort to provide this information, as these data were already collected and thus easily accessible. OJI's represent an extreme human/system mismatch leading to an error severe enough to cause injury.

5.3.1.1 OJI Analysis

We reviewed OJI reports from 1/1/92 to 6/30/93. The procedure outlined by Drury and Brill (1983) was employed to identify accident patterns. Accident/injury data were separated in order to identify OJI's that occurred in the hangar and OJI's specifically related to restricted space. The OJI's identified space-related were then grouped based upon age, job, years on the job, area, activity being performed, days out, type of injury, and body part injured. Thus, we were able to develop a small number of repetitive scenarios or patterns.

5.3.1.2 Results

The percentage of space-related OJI's in the hangar was 20.4% (**Figure 5.2**). This finding indicates that ergonomic interventions, particularly those related to space, should be addressed. **Figure 5.2** also shows other data that were meaningful in this analysis. Most injuries were sprains to the lower limbs or back/neck, primarily occurring during repositioning, working, and access type activities, e.g., climbing and slip/trips. **Table 5.3** presents a summary of the most predominant scenarios.

Table 5.3 Summary of space-related hangar OJI's

- •Repositioning in cramped or dirty places, e.g., the fuel tank, tail interior, and bag bin, often causes sprains or strains
- •Head lacerations are associated with walking in the cabin or around the fuselage exterior
- •Kneeling causes knee bruises or strains
- •Lifting in confined spaces can result in back strain
- •Falls on stairs and access stands are common
- •Most injuries occur during access or maintenance subtasks

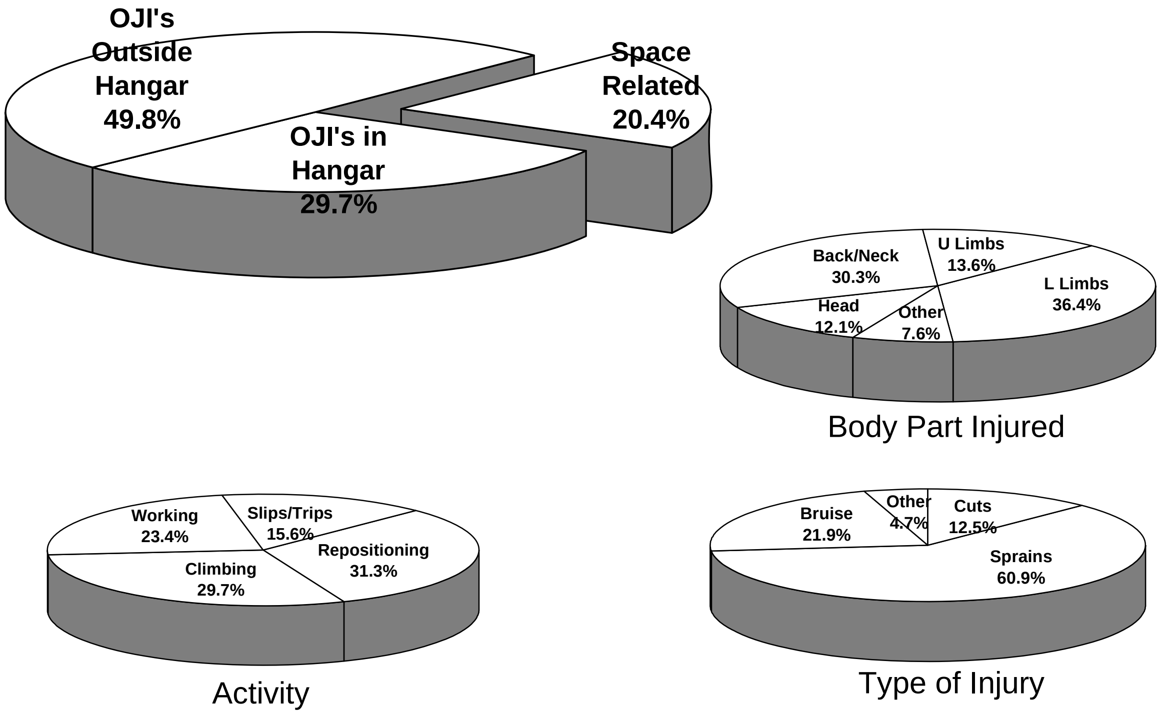

Figure 5.2 OJI Report Summary

5.3.2 Evaluation of Existing Conditions

Four inspection tasks were selected for analysis: aft cargo compartment, horizontal/vertical stabilizers, tail interior, and wheelwell/ main landing gear. These tasks provided a representative sample of tasks with regard to varying environmental conditions such as the amount of space, lighting. Both behavioral (direct recording) and psychophysical (indirect recording) data were collected to assess the effect of the aviation maintenance and inspection environment on inspector fatigue, discomfort, and workload.

5.3.2.1 Behavioral Measures

Whole-body postures were recorded through-out task performance. Positions of the upper limbs, lower limbs, and trunk were recorded continuously for two inspectors performing each task. In addition, detailed descriptions of each task. This included having human factors analysts work with inspectors during the completion of workcards. While obtaining task descriptions, we placed emphasis on documenting the ergonomic factors identified in Section 5.2 which create, or exacerbateing stress and fatigue effects.

5.3.2.2 Psychophysical Measures

Psychophysical techniques were used to measure fatigue, physical discomfort, and workload. These techniques are particularly attractive for field use because they are unrestrictive, require minimal instrumentation, are easy to use/administer, and provide valid and reliable results.

The Feeling Tone Checklist (FTC), utilized to measure fatigue effects over time, is an interval scale that has been found to be a valid and reliable measure of subjective feelings of fatigue (Pearson, 1957). The Body Part Discomfort Chart (BPD) was utilized to obtain postural discomfort data (Corlett and Bishop, 1976). This chart categorizes the body into a number of functional areas to allow the assessment of individual body areas. A 5-point ordinal scale was utilized to solicit operators' BPD ratings. The NASA - Task Load Index (TLX) is a multi-dimensional rating scale measuring six workload-related factors (mental demand, physical demand, temporal demand, performance, effort, and frustration) and their associated magnitudes to form a sensitive and diagnostic workload measure (Hart and Staveland, 1988).

5.3.2.3 Experimental Protocol

Postures were sampled every 30 seconds throughout each task. Data were obtained on two inspectors performing each task. The FTC and BPD was administered before and after task performance. In addition, the TLX was administered after task performance. The FTC, BPD, and TLX data were obtained on five experienced inspectors per task.

5.3.2.4 Results

An adapted version of the *Ovako Working Posture Analyzing System* (Louhevaara and Suurnakki, 1992) postural recording scheme was utilized to classify whole body postures during task performance. This system has been found to be valid and reliable (Karhu, Kansi, and Kuorinka, 1977, 1981). It categorizes whole-body postures into action categories based upon the severity of different postures, making it useful in determining which postures need to be addressed by workplace changes. **Table 5.4** lists the categorization scheme and corresponding Action Categories (AC). The postural data were categorized by action categories and averaged across inspectors for each task; results are presented in **Figure 5.3**. These data indicate that AC frequency is dependent upon task type ($2 = 140.23$, $p < 0.005$) and that inspectors adopted the largest percentage of extreme postures, i.e. AC2, AC3, and AC4, in the aft cargo and tail interior areas. However, there is a large percentage of extreme postures in the other areas. The most typical working postures for each task are listed in **Table 5.5** and illustrated in Figures **5.4**, **5.5**, **5.6**, **5.7.**

Table 5.4 OWAS Classification Table

	Upper				**Lower Limbs**					
Trunk	**Limbs**	2S	1S	2B	1B	K	W	S	L	C

Straight	2 Below				\\\\\\	\\\\\\			\\\\\\	\\\\\\
	1 Above				\\\\\\	\\\\\\			\\\\\\	\\\\\\
	2 Above				\\\\\\	\\\\\\			\\\\\\	\\\\\\
Bent	2 Below	\\\\\\	\\\\\\	\\\\\\	kk kk	kkkk	\\\\\\	\\\\\\	kk kk	kk kk
	1 Above	\\\\\\	\\\\\\	\\\\\\	kk kk	kkkk	kk kk	\\\\\\	kk kk	kk kk
	2 Above	kk kk	\\\\\\	kk kk	kk kk			\\\\\\		
Twisted	2 Below				kk kk					
	1 Above	\\\\\\					kk kk			
	2 Above	\\\\\\		\\\\\\						
Bent &	2 Below	\\\\\\	\\\\\\	\\\\\\				\\\\\\		
Twisted	1 Above	kk kk	\\\\\\	kk kk				\\\\\\		
	2 Above		\\\\\\	kk kk				\\\\\\		

S = Straight B = Bent K = Kneel W = Walk S = Sitting L = Laying C = Crawl

Action Category 1. The overall posture is ordinary and normal. No action is necessary. These postures are marked with a **blank square**.

Action Category 2. The load imposed by the overall posture is of some significance and slightly harmful. A better working posture should be sought in the near future. These postures are shown with a \\\\\\.

Action Category 3. The strain imposed by the overall posture is significant and distinctly harmful. A better working posture should be sought as soon as possible. These postures are marked with kkkk.

Action Category 4. The strain imposed by the overall posture is greatly significant and extremely harmful. A better working posture should be sought immediately. These postures are marked by **shading**.

Table 5.5 Typical working postures by task

Task	**% of Working Time**	**Action Categories**
STABILIZERS		
1.Legs Straight, Trunk Straight, 2 Arms Below Shoulders	9.3%	AC1
2.Kneeling or Crouched, Truck Bent and Twisted, and/or Arms Above Shoulders	14.1%	AC4
3.Leg(s) Straight, Trunk Straight, Arm(s) Above Shoulder	12.0%	AC1

4.Sitting or Laying, Trunk Bent and/or Twisted, Arms Below Shoulders	11.4%	AC2-AC4
TAIL INTERIOR		
1.Sitting, Trunk Straight, Arms Below Shoulder	21.1%	AC2
2.Sitting, Trunk Bent, Arms Below Shoulder	16.5%	AC3
3.Legs Straight, Trunk Bent or Twisted, Arm(s) Above Shoulder	21.9%	AC1-AC2
WHEELWELL/MAIN LANDING GEAR		
1.Leg(s) Straight, Trunk Bent and/or Twisted, and/or Arm(s) Above	19.0%	AC1-AC3
Shoulder	24.7%	AC3-AC4
2.Kneeling/Crouched, Trunk Bent and/or Twisted, and/or Arm(s) Above Shoulder	21.4%	AC1
3.Leg(s), Trunk, Arms Neutral	4.5%	AC1-AC2
4.One Leg Straight, Trunk Bent and/or Twisted, and/or Arms(s) Above Shoulder		
CARGO		
1.Kneeling, Trunk Bent and/or Twisted, Arms Below Shoulder	33.2%	AC3-AC4
2.Laying, Trunk Bent and/or Twisted, and/or Arm(s) Above Shoulder	11.3%	AC3-AC4
3.Sitting, Trunk Bent and/or Twisted, and/or Arm(s) Above Shoulder	13.4%	AC1-AC2

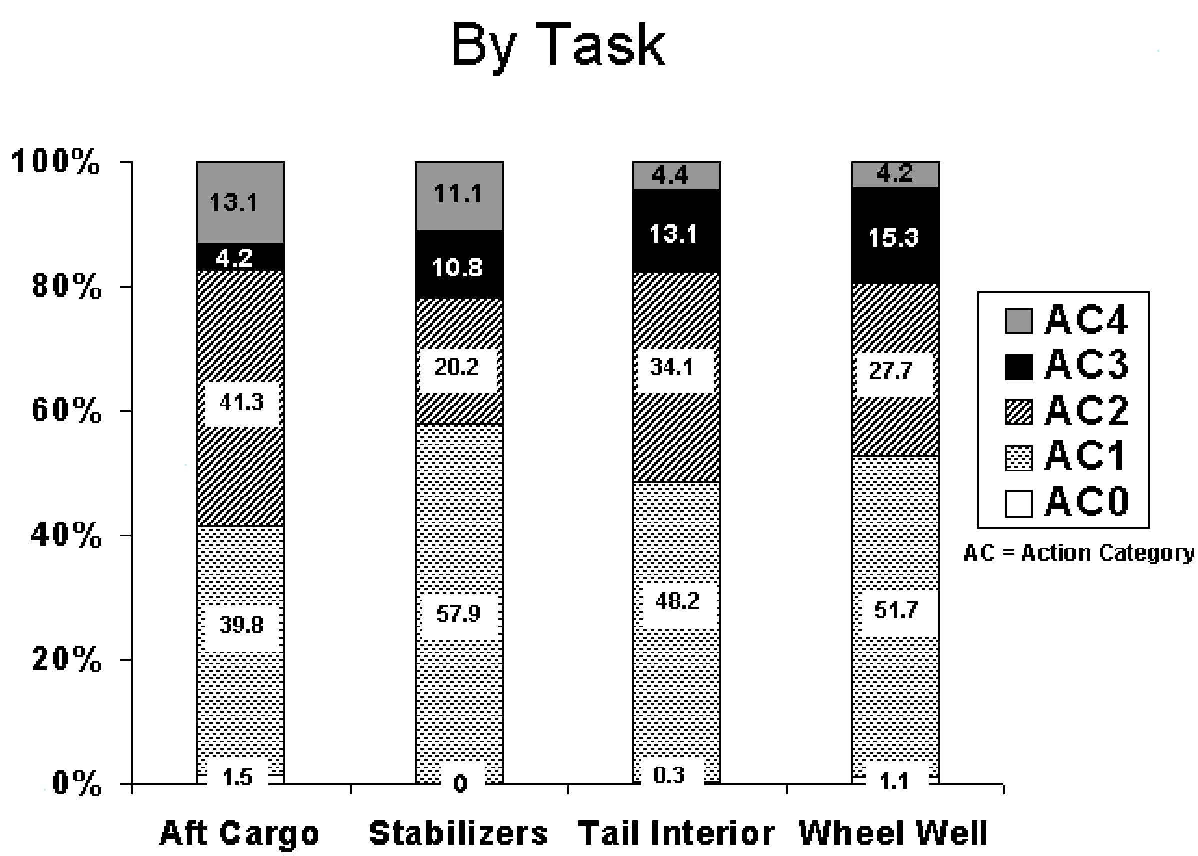

Figure 5.3 Posture Analysis

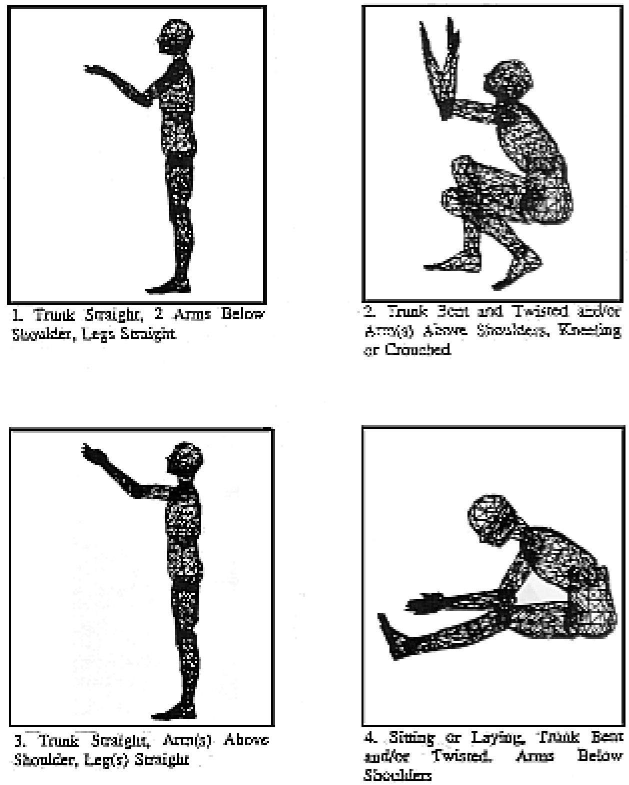

Figure 5.4 Stabilizer Postures

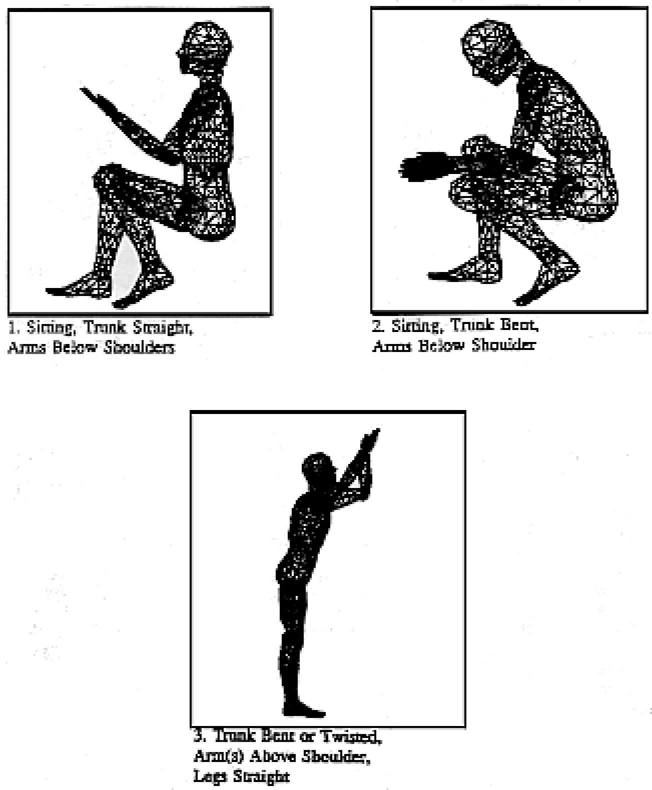

Figure 5.5 Tail Interior Postures

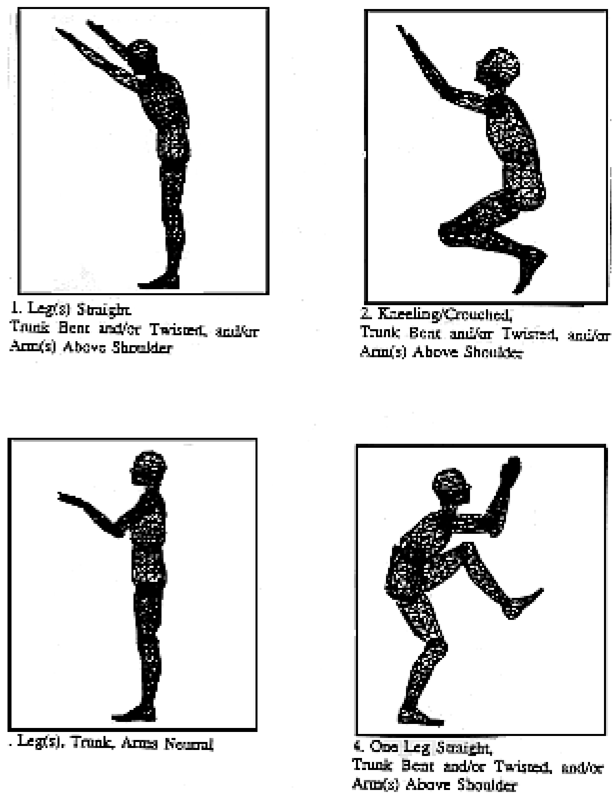

Figure 5.6 Wheelwell/Main Landing Gear

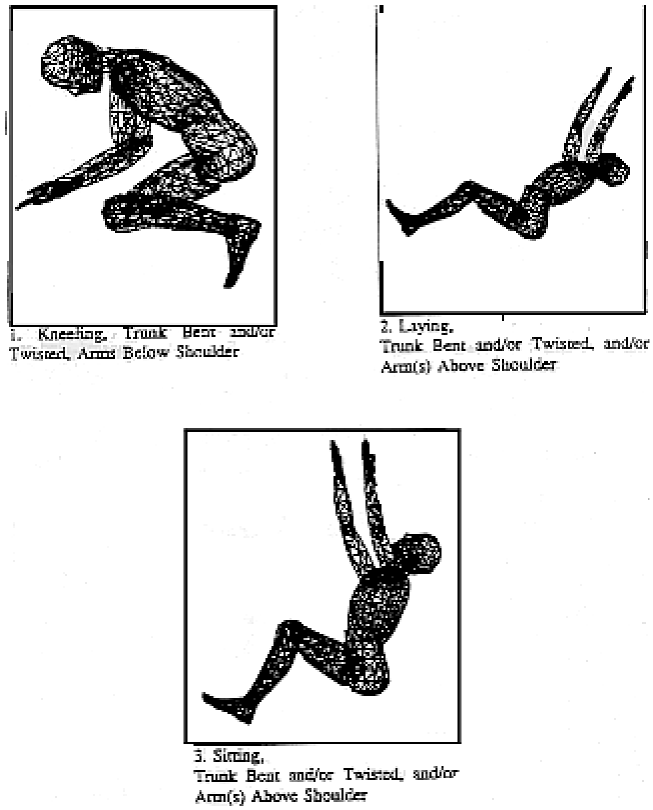

Figure 5.7 Cargo Postures

The BPD and FTC difference values (end of task - beginning of task) were averaged across inspectors and are presented in **Figures 5.8** and **5.9**. Inspectors experienced significant increases in body part discomfort in the tail interior ($t = 2.35$, $p < 0.05$). Likewise, inspectors indicated the most fatigue after inspecting the tail interior ($t = 3.17$, $p < 0.0.005$). Body part discomfort and fatigue were also judged as high in the aft cargo. The average fatigue value was skewed by one inspector who rated his fatigue to be less (**Figure 5.9**). The TLX data averaged across inspectors; results are presented in **Figure 5.10.** There was a significant difference among the overall workload levels ($F = 2.80$, $p = 0.074$), with workload being significantly greater in the tail interior. In addition, across all tasks, physical demand and performance were significantly greater than the other components in contributing to the overall workload level (Tukey critical value = 2.70__ = 0.05).

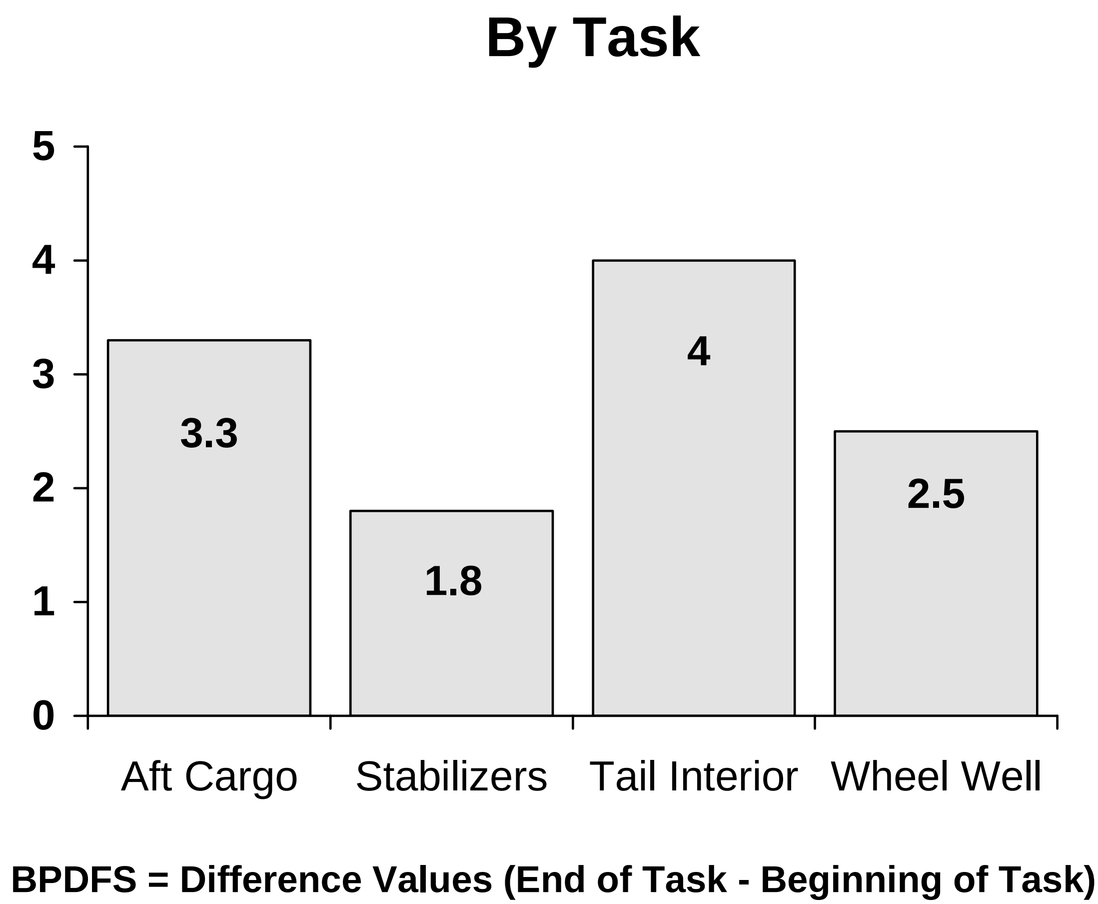

Figure 5.8 Body Part Discomfort Over Time

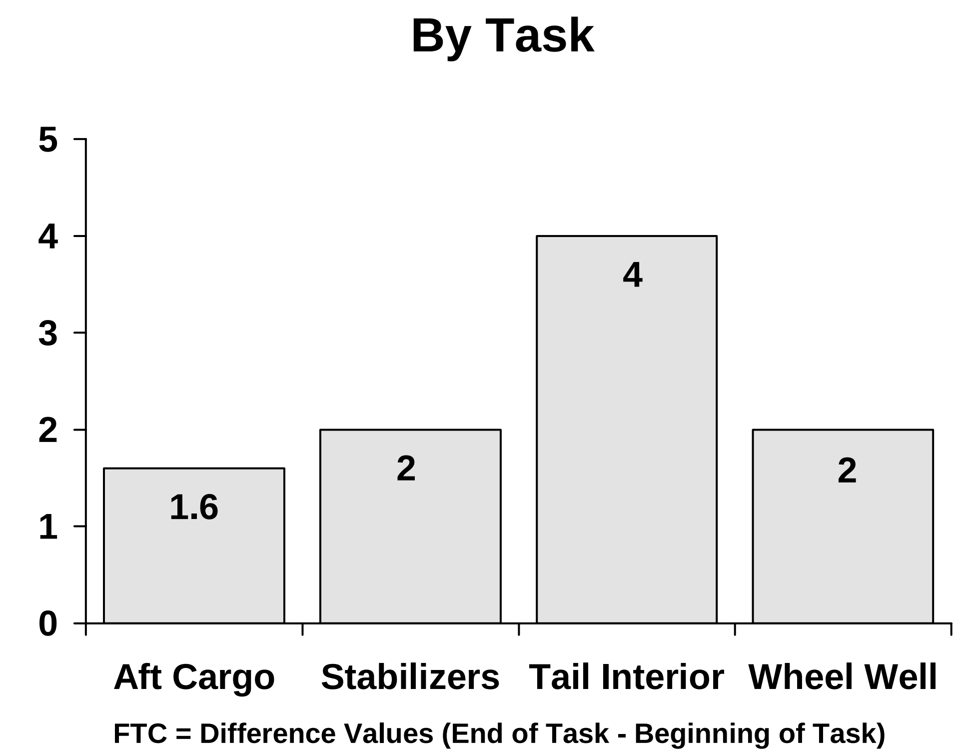

Figure 5.9 Fatigue Over Time

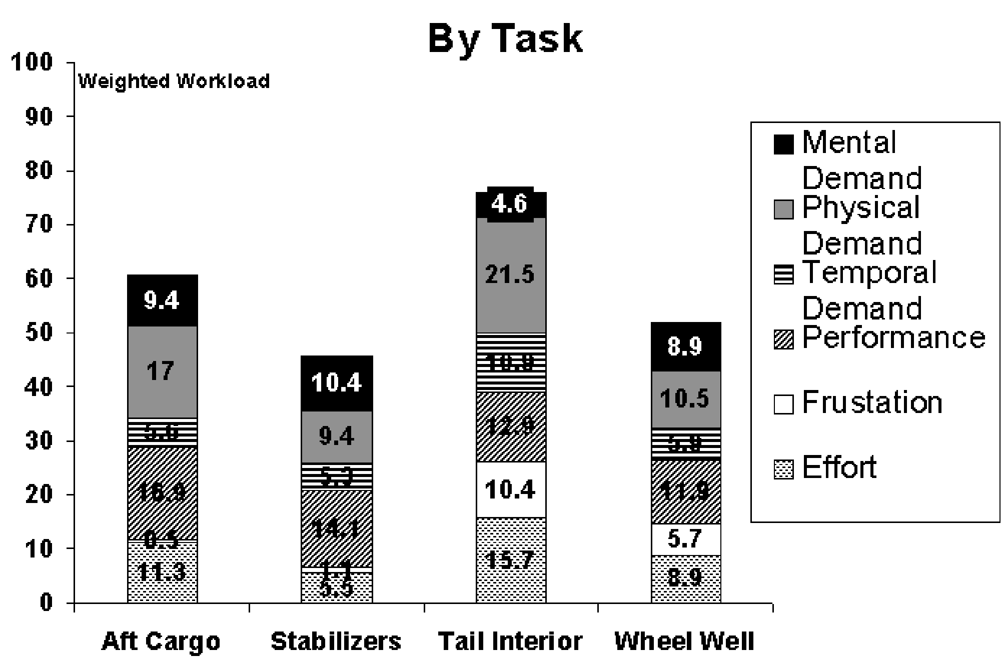

Figure 5.10 TLX Workload Data

5.4 FINDINGS

Although performance measures could not be obtained, as noted in previous work (Shepherd, Johnson, Drury, Taylor, and Berninger, 1991) as well as in this work, inspectors are highly motivated to perform accurately. We assume that inspectors were taking the steps necessary to ensure that their performance was not affected by the conditions. However, the above analysis and results indicate that inspectors often experience increased levels of stress, fatigue, and workload. Based upon these data, inspection work in the tail interior can be classified within Zone 2 of the framework (Section 5.2.7). That is, task performance is acceptable, but operators' workload and stress are increased because of their compensating for extreme conditions. Inspection of the stabilizers and wheelwell/MLG can be classified within Zone 3; acceptable task performance can be obtained without any significant increases in workload or stress imposed by the task conditions. Work in the aft cargo falls somewhere on the boundary between Zones 2 and 3. If more data were collected reduce variability in this real-world data, it is predicted that work in this area would be found to be in Zone 2.

The psychophysical data shows a consistent pattern of stress experienced during task performance in different areas. Generally, fatigue, body discomfort, and workload were judged higher in the aft cargo and tail interior areas, as compared to the other areas. There was some disassociation between the postural and the psychophysical data. The stabilizers and wheelwell/MLG were not rated as extremely fatiguing, although many extreme postures (AC3 and AC4) were noted while inspectors worked in these areas. This indicates that posture may be just one factor contributing to fatigue and that other factors such as space and lighting, in combination with extreme postures, play a role in eliciting fatigue. These results are to be as expected from the discussion in Section 5.2.1.

5.5 PRACTICAL INTERVENTIONS

Based upon the above evaluation, a posture/fatigue module has been developed and integrated into the ergonomic audit program (Koli, Drury, Cuneo, and Lofgren, Chapter 4 of this report). In addition, specific ergonomic interventions were provided for each task analyzed. These were generated from a logical analysis of factors contributing to fatigue in each area and the possible ergonomic interventions that could impact upon these factors. Furthermore, the techniques and tools used for this analysis can be applied and used in developing and guiding a comprehensive ergonomic program.

5.5.1 Ergonomic Audit Posture Module

A module has been developed and integrated into the ergonomic audit program that can be used to recognize extreme postural and spatial demands possibly causing fatigue and discomfort. This module should assist in eliminating mismatches, specifically these related to postural and spatial requirements, between the inspector's capabilities and the task demands.

5.5.2 Design Requirements/ Interventions

For each task, design requirements were stated. They are presented in Table 5.6. Design requirements are positive statements about what needs to be accomplished during redesign. These design requirements were geared towards eliminating or reducing extreme working postures (**Table 5.5** and **Figures 5.4, 5.5**, **5.6**, **5.7**) and improving the overall inspection environment. Notice that these are not solutions, but requirements. There may be several alternative solutions for each requirement. Formally stating design requirements can assist in generating solutions and reduce the probability of overlooking potential solutions (Drury, 1987). In addition, design requirements were prioritized according to the OJI's that occurred in each area. This assists in selecting interventions maximizing injury reduction for a given budget.

In the aft cargo area, due to the nature of the task, much of the kneeling and laying cannot be reduced. However, equipment would reduce much of the stress caused by extreme postures. In the stabilizers inspection task, the existing light levels (Table 5.6) should be increased to reduce visual fatigue caused when visual inspection is performed in non-optimum conditions (Reynolds and Drury, in press). In addition, the platform weight could be lowered so that the underside of the horizontal stabilizer could be inspected without inspectors having to kneel or crouch (**Table 5.5**, **Figure 5.4,** posture 2). Due to aircraft constraints, there can be limited structural and access changes in the tail interior. Thus, most of the solutions address the environment, in an attempt to improve these conditions. Access to the wheelwell could be improved by a new step design and eliminate the bending and reaching into the wheelwell **(Table 5.5,** and **Figure 5.6**, postures 1 and 4). Furthermore, a portable chair may be utilized to reduce crouching during MLG inspection (**Table 5.5**, and **Figure 5.6** posture 2).

5.5.3 Ergonomic Program

This evaluation has only addressed a small subset of ergonomic problems in the aviation maintenance environment, particularly those related to restricted space and posture. However, we also considered other factors during the evaluation and recommendation phases. This work has revealed the need for a comprehensive ergonomic program addressing all components of the aviation maintenance environment. Many issues were not addressed, e.g., safety concerns, but these issues could be evaluated and improved using proven ergonomic techniques and tools. The techniques applied in this project were found to be sensitive and could be adapted and utilized in further investigations of the aviation maintenance environment.

Ergonomic programs have been developed for manufacturing environments with great success (see, Reynolds and Drury, in press). These programs are based upon the idea of continuous evaluation and intervention, using the tools and techniques applied above, to improve the fit between human and system, and hence to reduce error-causing mismatches. In the 1994 plan, such a program is being implemented as a SUNY/FAA demonstration project.

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CHAPTER SIX
HYPERMEDIA INFORMATION SYSTEM

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6.0 INTRODUCTION

The aviation industry manages large quantities of documentation for purposes including training, research, maintenance, and safety inspection. Paper or microfiche documents include fault isolation manuals, maintenance manuals, federal aviation regulations, and research reports. Timely and convenient access to these documents is important, but currently document access can be quite cumbersome. For example, safety inspectors and aviation maintenance technicians must carry literally stacks of documents to the flightline when they inspect or work on an aircraft. Finding the desired information in cumbersome documents is not always easy; therefore, the results are not always accurate. Improvements in the way aviation personnel access information will lead to more reliable and more cost-effective aircraft maintenance.

Toward this end, the Federal Aviation Administration (FAA) Office of Aviation Medicine (AAM) Human Factors in Aviation Maintenance research program is studying the challenges associated with creating, accessing, and maintaining digital documentation using a Hypermedia Information System (HIS). This paper discusses the current state of the HIS, including the interface features, integration into a job aiding system, and future plans.

6.1 THE HYPERMEDIA INFORMATION SYSTEM FEATURES

The goal of the AAM Hypermedia Information System research program is to use hypermedia technology to improve access to aviation information. Hypermedia technology makes it possible to establish links between a document and other documents, graphics, animation, video, and audio. This makes a hypermedia document far more powerful and meaningful than a digital document that is strictly text. With hypermedia technology, information can be stored, searched, and retrieved by referential links for fast and intuitive access. This reduces the time spent looking for information and allows a more thorough, meaningful search. Hypermedia technology allows users to make faster and more intelligent decisions. Naturally, the technology offers other benefits such as reduced costs for inspecting and maintaining aircraft. For more information on hypermedia, see Howell, 1992, and FAA/AAM & GSC, 1993b.

Initial research program efforts concentrated on demonstrating the feasibility of a hypermedia system for aviation personnel. Team members designed a digital library system and implemented rudimentary tools for storing the information. The bulk of the implementation effort was focused on information retrieval tools and the hypermedia reader interface. Federal Aviation Administration research reports were used as a testbed for creating the digital library. This proof-of-concept hypermedia viewer (FAA/AAM & GSC, 1993b) proved to be a flexible, powerful way for researchers to view hypermedia documents. The HIS can be used solely as a tool to access information, as well as integrated with training and job-aiding systems (Johnson and Norton, 1992).

Both the viewer and the library were distributed on compact disc, read-only memory (CD-ROM) to the aviation maintenance community in early 1993. As with many proof-of-concept systems, this one was geared toward a specific application area. The viewer interface was tailored to the FAA research reports, making its broad-scale applicability limited. Over the last year, research has continued to make the tools more generic and enhance their functionality. The digital library containing FAA research reports was expanded to include new reports. Additionally, two new libraries were created: one contains the Federal Aviation Regulations; the other, the Inspector's Airworthiness Handbook. The work described in this chapter will be produced and distributed on CD-ROM in early 1994.

The HIS reader interface maintains a book paradigm and consists a navigation component and a viewing component. The navigation component combines the familiarity of traditional book navigation, e.g., a table of contents, with the power of hypermedia searching. The viewing component allows the reader[1] to read, print, and manipulate the various media that make up the library.

6.1.1 Navigation

A traditional paper book provides several navigation methods, including a table of contents, an index, and simple page turning. Likewise, the HIS supports a variety of access paths into and within a document. Some readers seek specific topics of interest and appreciate a powerful method to browse through a complex document. These readers find the hierarchical Outline Viewer and powerful searching capabilities useful. Other readers may seek quick references to standard information. Hot Links and Bookmarks provide mechanisms for these readers to quickly access frequently referenced places in a document.

6.1.1.1 The Bookshelf

The first HIS component the reader encounters is the Bookshelf (**Figure 6.1**). The Bookshelf graphically depicts libraries available to the reader. The reader selects book icon to choose a library. To change libraries, the reader returns to the Bookshelf and selects another book icon. Bookshelf icons can be customized to fit a specific application.

6.1.1.2 The Outline Viewer

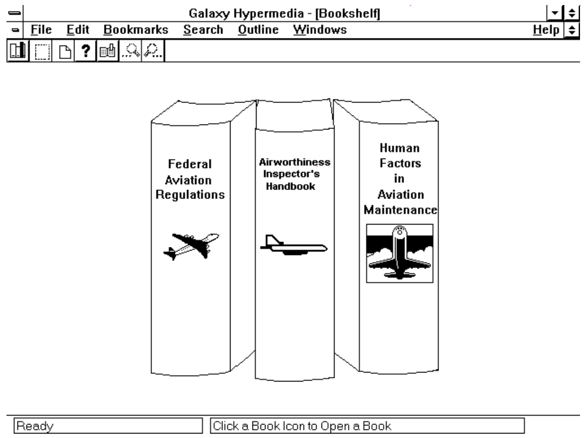

Figure 6.1 The HIS Bookshelf

Once a reader chooses a library from the Bookshelf, the Outline Viewer appears to display the complete outline for the library. The outline is similar to a Table of Contents and contains the Topics defined for the library's documents. A hypermedia author[2] specifies Topics within the original digital documents and assigns a hierarchical order to them. By using the HIS Outline Viewer, a reader is able to browse the outline of all documents in the library and to expand and collapse the Topics **(Figure 6.2)**. Once a reader finds and selects a Topic of interest, the part of the document associated with the Topic appears **(Figure 6.3**).

6.1.1.3 Hot Links

The HIS supports a variety of Hot Links a reader can use to navigate through the library. The Hot Links include both inter- and intra-document links to text, as well as links to graphics, animation, video, audio, definitions, and other executable programs. Hot Links are denoted by a rectangular box surrounding red text (**Figure 6.3**)

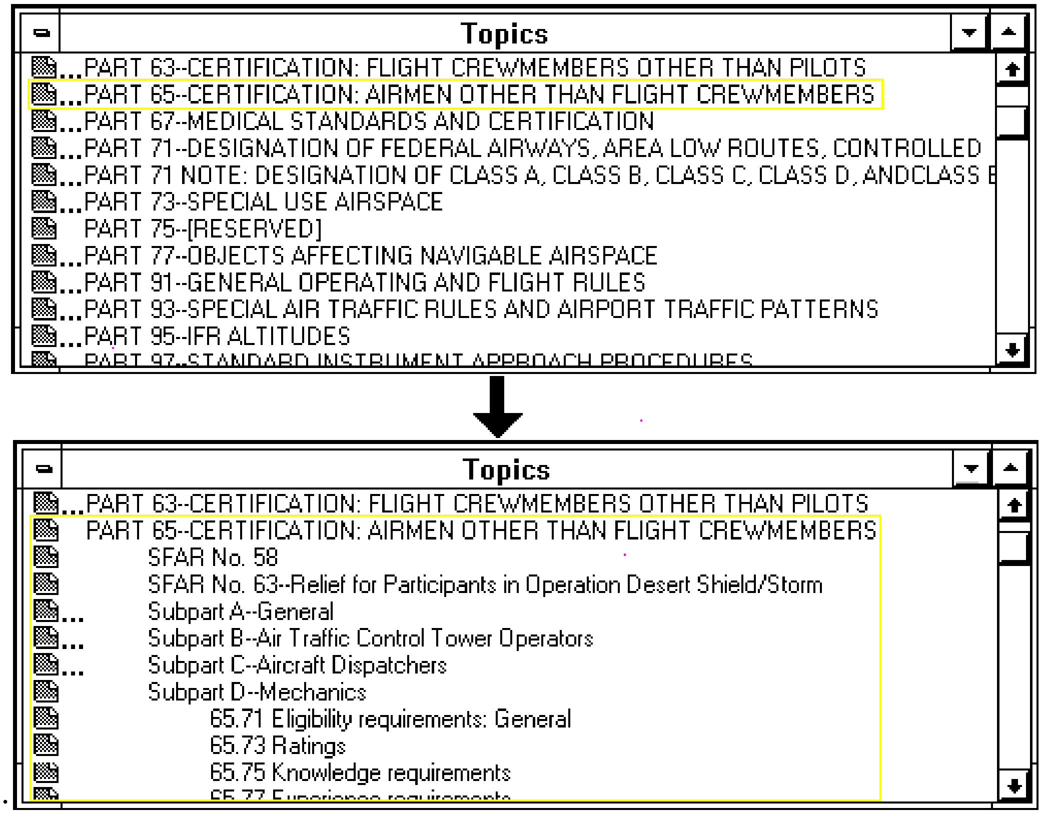

Figure 6.2 Collapsed and Expanded Topics

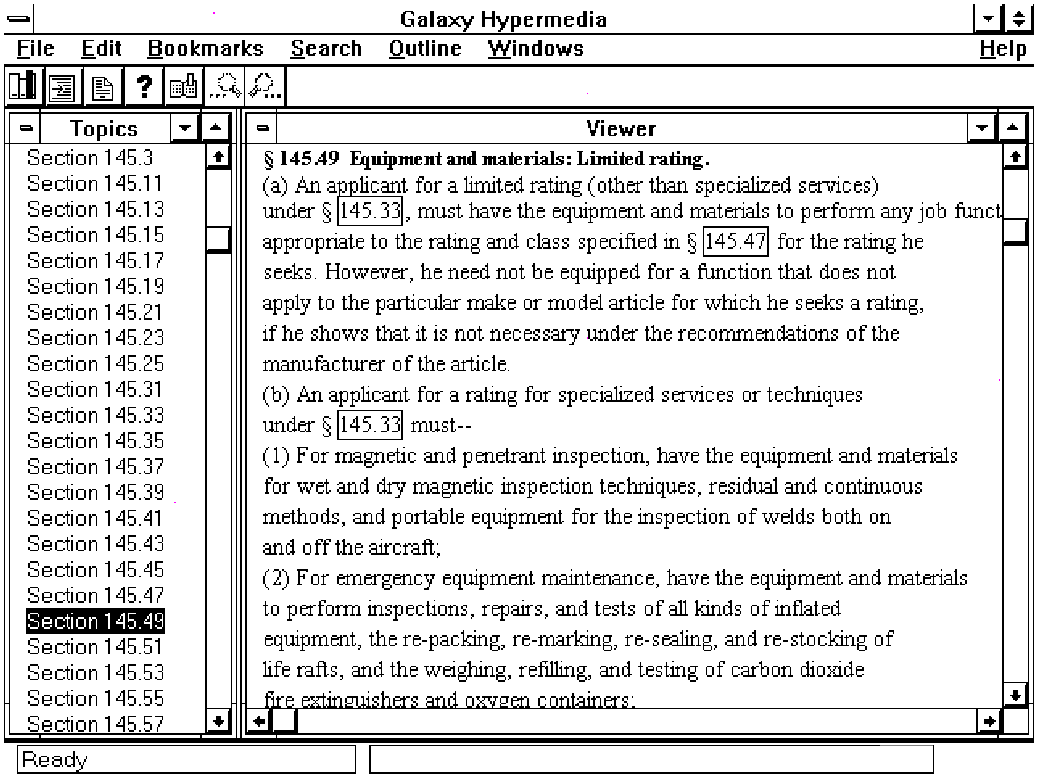

Figure 6.3 The Outline and Document Viewers

6.1.1.4 Searching

One of the most powerful features of a hypermedia system is its ability to quickly locate specific information in large amounts of text without forcing the reader to scan each line. A reader searches by typing a query, as shown in **Figure 6.4**. The HIS then rapidly searches all documents in the library. The HIS then displays a list of Topics satisfying the query, also shown in **Figure 6.4**. The reader can select one of the Topics to view. When the selected Topic's text is loaded, the search hits are highlighted, as shown in **Figure 6.5.** To see other search hits, the reader can either scroll through the text or use the magnifying glass icons in the icon bar (**Figure 6.5**) to go to the previous or next occurrence.

The HIS supports four types of searching: term, wildcard, phrase, and Boolean. A term search is a search for a specific word such as aviation that is not a stopword. A stopword is a word occurring so frequently in the document that it is not important, such as *the* or *and*. Every Topic containing the search term is listed in the Search Query Dialogue Box.

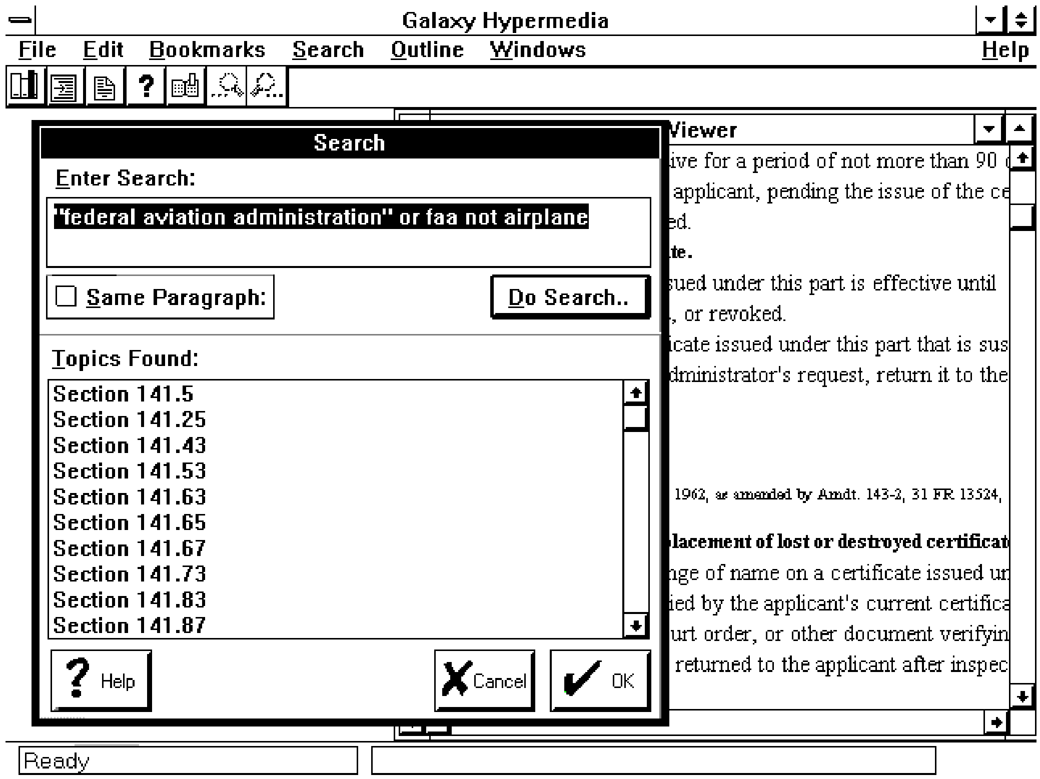

Figure 6.4 Search Query Dialogue Box

A wildcard search allows the reader to look for variations of a term such as administrate, administration, administer. The reader can append a term or partial term with either an asterisk (*) wildcard or a question mark (?) wildcard. The asterisk represents zero or more characters, and the question mark represents zero or one character.

A phrase searching enables the reader to specify the order and adjacency of multiple search terms. For example, phrase searching for "federal aviation administration" only displays places where that exact phrase appears. The reader specifies a phrase search by placing quotes around the target phrase.

A Boolean search combines any/all of the above types with Boolean operators (AND, OR, NOT), as in "federal aviation administration" or faa not airplane. In this example, the search would return a list of all Topics containing either *federal aviation administration* or *faa*, but not containing *airplane*.

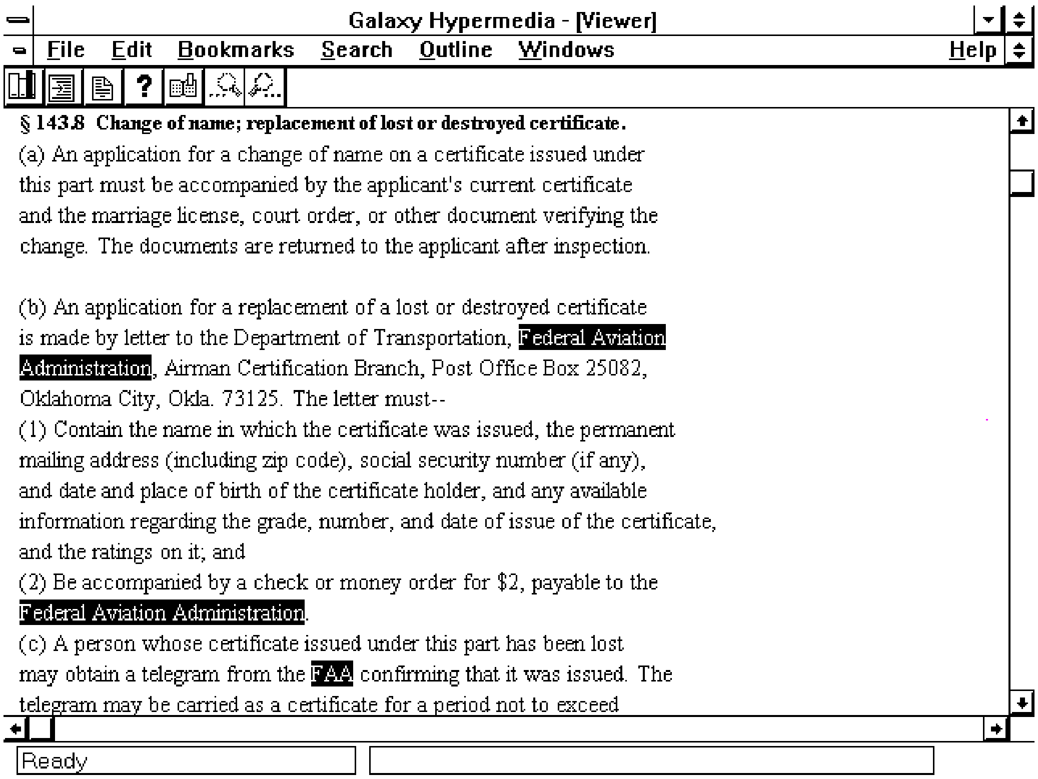

Figure 6.5 Search Hits

6.1.1.5 Bookmarks

It is sometimes desirable for a reader to mark a place in a document. The HIS provides a bookmarking capability and enables a reader to create multiple Bookmarks for a document. When creating a Bookmark, the HIS uses the current Topic as the Bookmark's target destination. To use a previously created Bookmark, the reader chooses one from the list of active Bookmarks (**Figure 6.6**). The Topic containing the Bookmark does not have to be in the current library; the HIS automatically switches libraries, if necessary.

6.1.2 Viewing

The HIS provides three distinct tools viewing the various media comprising a hypermedia library. The Document Viewer has multiple entry mechanisms: the Outline Viewer, the Search Query Dialogue Box, Bookmarks, and Hot Links. The Graphics Viewer and the Multimedia Viewer are accessible only through Hot Links.

6.1.2.1 The Document Viewer

The Document Viewer, shown in **Figures 6.3** and **6.5,** allows a reader to scroll through and read a hypermedia document, as well as to investigate search hits. Text formatting such as boldface, italics, underlining, and multiple font sizes and typefaces, enables the on-line document closely to resemble the original. Any headers and footers are also displayed.

6.1.2.2 The Graphics Viewer

Readers use the Graphics Viewer to view and print graphics. It appears when a reader clicks on a hot word that links to a static graphic image. Supported graphics formats include, among others, bitmap (BMP), encapsulated postscript (EPS), graphics interchange file (GIF), target image file format (TIFF), and Joint Photographic Experts Group (JPEG). The Graphics Viewer determines the graphics file's format and displays it appropriately; it offers seamless incorporation.

Figure 6.6 Bookmarks

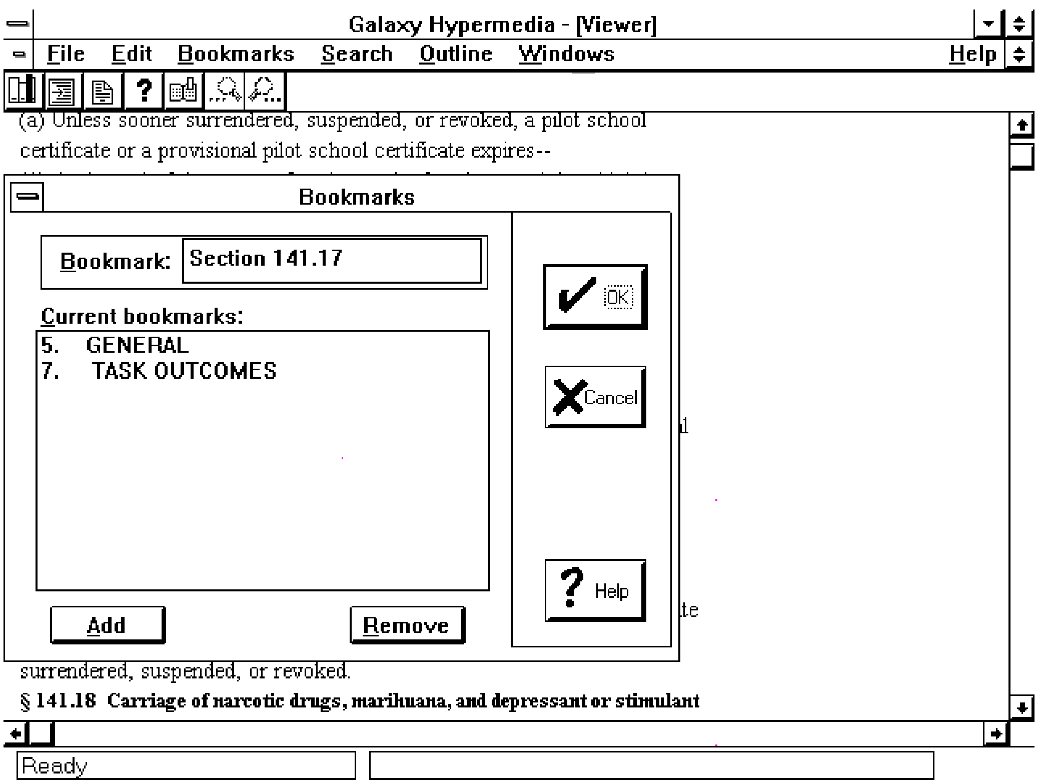

Figure 6.5 Search Hits

6.1.2.3 The Multimedia Viewer

More innovative types of media are now available for computer presentation (e.g., sound, video, animation, etc.). The Multimedia Viewer is provided for such media. The Multimedia Viewer is also seamless, determining the type of media when the reader selects a Hot Link to a media source and playing it appropriately. The HIS currently supports all MCI-supported media, including animation, video, **cd**-audio, and audio-video interleave.

6.2 HYPERMEDIA DOCUMENT CREATION

Because a hypermedia document is more than just a digital version of a paper document, it is necessary to transform a document from its original form into a form containing information for the HIS. This information runs the gamut from basic text format such as which font to use to links to other documents, graphics, animation, or other software programs. The HIS currently provides support for the following document types: WordPerfect, Standard Generalized Markup Language (SGML) that conforms to the Air Transport Association (ATA) Specification 100, and **ANSI**. The transformation process for each type is described briefly below.

For document types such as WordPerfect, the transformation process is partially automated. It is possible to include WordPerfect formatting such as boldface, italics, fonts, headers, etc., with an in-house filter that converts inherent WordPerfect commands into commands that the HIS understands. A similar filter could be created for other word processor formats such as Microsoft Word and would behave similarly. The hypermedia author then adds hypermedia-specific information such as Topics and Hot Links.

The transformation process for **SGML** documents that conform to ATA Spec 100, such as the Boeing 757 Aircraft Maintenance Manual, is completely automated. The SGML language is used to mark up documents by inserting tags in the text. Basically, these tags describe the document's structure, such as which text is chapter titles (Topics), which is references (Hot Links), which is paragraphs, etc. The hypermedia research project has developed a translation program to convert SGML tags into their HIS counterparts. This makes documentation transformation a smooth process, with no need for intervention by an author.

An **ANSI** document requires the most cumbersome transformation process. Since an ANSI document is flat text with no fonts, boldface, links, etc., it is the hypermedia author's responsibility to provide these details. Fortunately, an authoring system is under development to make this task intuitive. With this authoring system, a computer novice will be able to turn a digital document into a hypermedia document easily. Once a document is displayed in the HIS, an author can put the Document Viewer into "author mode." By using the mouse to highlight text, the author can use menu options to specify the text's appearance (bold, italics, etc.) or function (link to graphics, link to text, etc.). The information the author provides is part of the hypermedia document, even after the author exits from the HIS.

6.3 REAL-WORLD HIS APPLICATION

Now that the HIS itself has been described in detail, it is beneficial to describe a situation in which it is being used. The HIS has proven its ability to support all facets of the aviation community. The previous version of the HIS on CD-ROM addressed the needs of researchers. It was also successfully integrated into several maintenance training systems. During the last year, the current HIS (described above) was incorporated into a job aid for Aviation Safety Inspectors.

The Performance Enhancement System (PENS) (see FAA/AAM & GSC, 1993a) applies pen computer and hypermedia technology to provide real-time job aiding and information retrieval for Aviation Safety Inspectors. Aviation Safety Inspectors must have access to large amounts of information, including Federal Aviation Regulations, Airworthiness Directives, and Advisory Circulars. The Federal Aviation Regulations and the Inspector's Airworthiness Handbook have been put into a library for inspectors' use. As the inspectors use PENS, they can directly access the HIS to reference and search for information. The initial PENS system is being distributed for use and evaluation to Aviation Safety Inspectors in nine U.S. locations. During the formal evaluation, feedback provided regarding the HIS will be used to make future PENS enhancements. Initial, informal feedback indicates that inspectors find it extremely valuable to have access to the documents through the HIS. Inspectors are looking forward to having other documents such as the Airworthiness Directives incorporated into the system.

6.4 FUTURE DIRECTIONS

As demand continues to increase, the HIS will continue to evolve. Specifically, the goals for developing the HIS further include the following:

- Complete the development of easy-to-use authoring tools
- Support a wider variety of document types
- Increase the document base to include other aviation documents
- Enhance the searching mechanism to provide "smarter" searching
- Support embedded graphics and tables.

The following sections describe plans to enhance the HIS in support of these goals.

6.4.1 Authoring Tools

Given that it is necessary for an author to transform a digital document into a hypermedia document, it is desirable to make the process for doing so as easy and intuitive as possible. As mentioned previously, development is under way to provide such an authoring system. Anything the author needs to add, such as Hot Links and Topics, will be added in a WYSIWYG ("what you see is what you get") environment. The author will be able to modify text, e.g., to correct spelling errors, and even to type a document from scratch. This powerful authoring environment will enable virtually anyone to create a hypermedia document.

6.4.2 Extended Document Types

It is also necessary to provide up-front support for existing source documents in formats other than WordPerfect, **SGML**, and **ANSI**. Another goal is to develop filters for other word processing formats and documentation standards. These other formats and standards might include Microsoft Word and Interactive Electronic Technical Manual (IETM) specifications.

6.4.3 Increased Document Base

This past year's work has already seen an increase in the supported document base for the HIS to include the Federal Aviation Regulations (FARs), the Airworthiness Inspector's Handbook, and recent research publications of the FAA/ AAM & GSC. This work is just the tip of the iceberg so far as the HIS' documentation base is concerned. Next year, the Human Factors Guide that is currently in development under the Human Factors in Aviation Maintenance research program will be transformed into an HIS-accessible hypermedia document. Also, Aviation Safety Inspectors participating in the PENS project are requesting Advisory Circulars and Airworthiness Directives.

6.4.4 Enhanced Searching

Searching is a powerful means of navigating a hypermedia document, enabling a reader to access interesting information directly. By combining terms and phrases with Boolean operators, a reader can refine a search that is too broad. However, it is still possible for a reader to end up with search hits that are irrelevant or only vaguely related to the actual topic(s) of interest. Future research will investigate several potential solutions to this problem. A relevancy measure is one way to prevent a reader from needlessly examining irrelevant hits by indicating the relative relevance of a search hit to the topic in which it is found.

A relevancy measure may not always be useful, such as in situations when multiple hits have similar relevance. A thesaurus will assist the reader to focus a search. The thesaurus can be customized by library; "plane" may have "air-plane" as a synonym in an aviation library and "shave" in a carpentry library.

6.4.5 Embedded Graphics

The HIS allows an author to present text to a reader in the Document Viewer and to provide Hot Links to graphics. Graphics are then displayed via the Graphics Viewer. The Graphics Viewer may not be desirable for some types of documents. For example, a document containing pages with numerous icons, figures, or small tables might be clumsy if it requires frequent opening and closing of graphics files via the Graphics Viewer. To accommodate this type of document, the HIS will add support for scrollable embedded graphics and tables. This also allows a reader to print text and graphics together, instead of having to print them from their separate viewers.

6.5 SUMMARY

The AAM Hypermedia Information System (HIS) research program continues to meet the challenges of improving aviation information access successfully. The HIS that has been developed allows a reader to navigate through huge amounts information quickly and easily. By supporting projects such as PENS and by creating hypermedia documents such as the FARs, the Airworthiness Inspector's Handbook, and research publications of the FAA/AAM & GSC, the HIS has proven its ability to support all facets of the aviation community. The HIS is flexible in its support of multiple document/graphic types and standards and in its ability to accommodate new types of media. With the advent of an authoring system that will enable virtually anyone to put documents into the HIS, demand for the HIS will only increase.

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CHAPTER SEVEN
CORRELATES OF INDIVIDUAL DIFFERENCES IN NONDESTRUCTIVE INSPECTION PERFORMANCE

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Galaxy Scientific Corporation

7.0 INTRODUCTION

Aviation maintenance requires a high level of quality assurance, with reliable nondestructive inspection (NDI) a critical component in this (FAA/ AAM & GSC, 1993). The Air Force and the nuclear power industry conducted a recent review of studies and programs in the area of NDI reliability. The review revealed a repeated finding: large individual differences existed among inspectors in their NDI proficiency (FAA/AAM & GSC, 1993). The few studies the review cited that attempted to determine possible reasons for differences in NDI proficiency were generally unsuccessful.

The Sandia Corporation has recently completed an FAA-funded field study, somewhat comparable to the Air Force's "Have Cracks, Will Travel" study, to provide information on the mag-nitude of differences among NDI inspectors in commercial aviation (Spencer et al., 1992). Although the results of this study have not been published, preliminary data suggest that sizable individual differences exist in the commercial field as well (Schurman, 1994).

As noted in the above review report, laboratory and field studies of individual differences in the areas of inspection and vigilance, opinions of experts in the NDI field, and interviews with NDI inspectors and training supervisors have suggested a number of variables, measures of which would appear to be potentially relevant to NDI selection and/or proficiency. A number of these variables (e.g., concentration/attention, patience, temperament, motivation, mechanical aptitude) also corresponded to those suggested by Southwest Research Institute in their recommendations to the Air Force of selection measures to improve technician proficiency (Schroeder, Dunavant, and Godwin, 1988). The variables suggested by these various sources can be roughly separated into the following categories:

- Boredom Susceptibility
- Concentration/Attentiveness/Distractibility
- Extroversion/Impulsivity
- Motivation/Perseverance
- Decision Making/Judgement
- Mechanical/Electronics Aptitude
- Need for Autonomy.

A principal intent of the study reported here was to determine the relationship between selected tests and measures derived from the above categories and performance on an NDI task. A second intent was to investigate whether sustained performance during a simulated one-day shift resulted in any significant decline in performance and to examine possible interaction effects between performance changes and the above-mentioned individual differences variables.

This study employed a computer-simulated NDI eddy-current task developed by Drury and his colleagues at the State University of New York (SUNY) at Buffalo. The task is described in studies by Drury, Prabhu, Gramopadhye, and Latorella, (1991) and Latorella, Gramopadhye, Prabhu, Drury, Smith, and Shanahan, (1992). In essence, the task utilized a SUN SPARC workstation and incorporated a standard keyboard and optical three-button mouse as input devices. As Latorella et al. (1992) emphasized, the aim in developing this task was neither to develop a simulator for training on actual NDI tasks nor to develop a task to measure absolute values of the probability of detecting particular types and sizes of faults. Their aim was to devise a task closely approximating the characteristics and requirements of eddy-current inspection tasks to enable laboratory investigation of factors possibly influencing NDI performance.

Neither of the two previous studies using this task was concerned with extensive evaluation of possible predictor measures or with possible fatigue effects resulting from sustained performance over successive task sessions. Few studies of inspection have examined performance over a long enough period of time to assess fatigue effects. Wiener (1984) concluded that the literature does not allow conclusions as to whether or not there are time decrements in inspection performance. An earlier review suggested such fatigue effects, but most, if not all, of the "inspection" studies reviewed were actually vigilance studies using paced tasks, with brief stimuli presented over relatively short sessions (Poulton, 1973). Drury (1992) found only one study of "shop" inspection in which a gradual fall in performance was reported, and that occurred over a two-hour period. There is little evidence relative to expected performance change over the simulated day shift incorporated in the present study.

The total procedure of this study, including the test and selection measures used, was tested in a pilot study reported on previously (FAA/AAM & GSC, in press). Since the purpose of the pilot study was to examine the overall feasibility of the approach used and to identify possible problems with the procedure, minimal reference will be made to this earlier study.

7.1 METHODOLOGY

7.1.1 Subjects

A total of 28 subjects, 15 males and 13 females, participated in the study. All were right-handed, had normal near visual acuity (as determined from an Orthorater screening test), reported normal hearing, and were between 18 to 29 years of age. All had graduated from high school, with most being full- or part-time employees concurrently attending a community college, technical school, or four-year college or university. Subjects were obtained through an existing Federal Aviation Administration (FAA) subject contract and were paid $10.00 an hour for their participation.

No subject was an aircraft mechanic or inspector and none had prior training or experience in aircraft maintenance or inspection. This ensured a wider range of individual differences than was likely if subjects had been selected from the maintenance/inspection population. The inclusion of college students appeared justifiable on the basis of several recent studies of inspection performance using both students and inspectors (Gallway, 1982; Gallway and Drury, 1986). The former study was reasonably similar to the present one in that it involved selection tests and inspection performance. Neither study found any significant differences between students and inspectors.

7.1.2 Apparatus

The basic apparatus for this study consisted of a SUN SPARC Model 4/50GX-16-P43 workstation, 19-inch color monitor, and a 3-button optical mouse. Since the nature of the task and its physical characteristics have been described in detail previously (Drury et al., 1991; Latorella et al., 1992), only aspects relevant to the present study will be reviewed here.

The display consisted of four basic task elements (windows). These are shown in **Figure 7.1** and are described below.

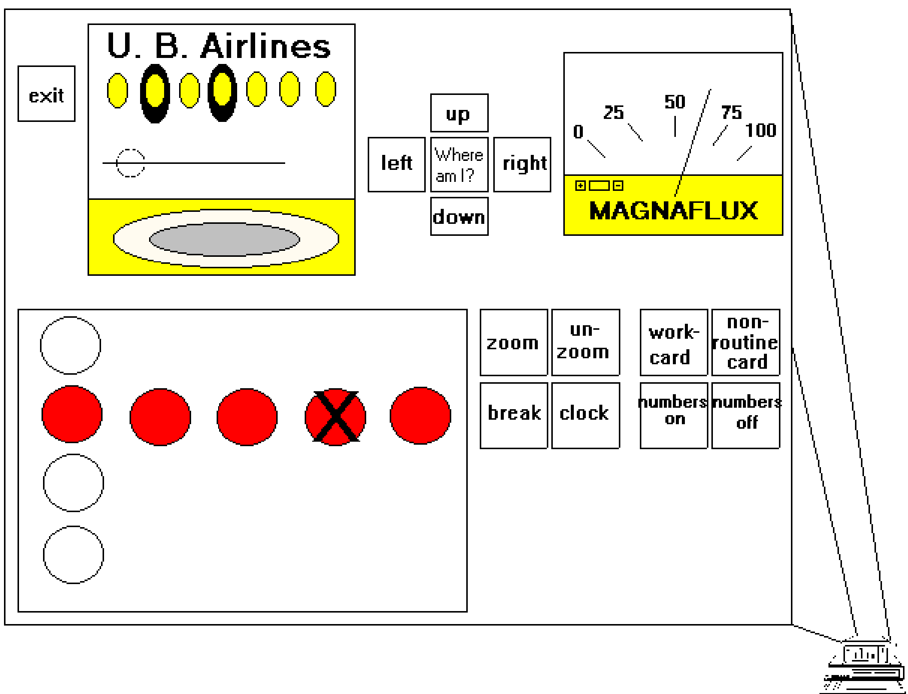

Figure 7.1 NDI Task Simulation (Drury et al., 1992)

7.1.2.1 Inspection Window

The lower left portion of the screen was the inspection window displaying the rivets to be inspected. Although it is possible to present a subject with multiple six-rivet rows, this study used a single row. The subject used the optical mouse to move the cursor around each rivet's circumference. The subject could examine the rivet until deciding if it was cracked. When the subject decided that a rivet was cracked, he or she pressed the right mouse button. A red cross appeared over this rivet, and "rivet marked bad" appeared on the screen. If the subject decided the rivet was not defective, he or she pressed the middle button. "Rivet marked good" then appeared on the screen. A subject could correct a mistake by pressing the appropriate button.

When a subject had inspected all six rivets, he or she pressed the left mouse button on the directional block labeled "right." A black marker ring circled the last rivet inspected, and the next six rivets in the row appeared in the inspection window.

7.1.2.2 Macro-View and Directionals

A macro-view in the upper left portion of the screen displayed a side view of the aircraft fuselage and the row of rivets being inspected. Since only a small portion of this row was being inspected at any given time, the subject could move the cursor over the words "Where am I" and a momentary circle then appeared over the portion of the rivet row currently being examined.

7.1.2.3 Eddy-Current Meter

The upper right portion of the screen contained a simulated analog meter serving as the eddy-current output indicator. Meter deflections beyond a set point produced an audible alarm and a red flash on an indicator light. The following actions caused meter deflections:

- touching a rivet's edge with the cursor or moving the cursor onto a rivet
- passing the cursor over a crack (All cracks were invisible and of varying length.)
- passing the cursor over or near simulated corrosion, scratches, or paint chips (These were simulated by 2 mm jagged lines at random locations adjacent to a rivet. Not all rivets contained such "noise," and no rivet contained more than one such noise spot.)

7.1.2.4 Lower Right Window

The subject could use this area of the display to exercise a number of options (e.g., to "zoom" for a closer look at a rivet being inspected, to stop the task for a break, or to display elapsed time). The only feature used in this study caused a number to appear on each rivet. The experimenter only used this feature during training feedback sessions to enable subjects to locate and re-check rivets incorrectly classified.

7.1.3 Predictors and/or Task Correlates

As previously noted, the earlier review report (FAA/AAM & GSC, 1993) identified a number of variables, measures of which appear potentially relevant to NDI selection and/or proficiency. These variables could be roughly separated into the following categories:

- Boredom Susceptibility
- Concentration/Attentiveness/Distractibi-lity
- Extroversion/Impulsivity
- Motivation/Perseverance
- Decision Making/Judgement

- Mechanical Aptitude
- Need for Autonomy.

The following sections describe the tests and scales, derived from the above categories, examined for their relationship to performance on the NDI task.

7.1.3.1 Subjective Rating Scale (SRS)

The Subjective Rating Scale (SRS) is a simple self-rating scale the author has used in several previous studies (Thackray, Bailey, and Touchstone, 1977; Thackray and Touchstone, 1991) to assess current feeling levels. Measures generally are taken before and after periods of task performance. The basic instrument consists of five 9-point scales measuring the dimensions of attentiveness, tiredness, strain, interest, and annoyance. Two additional scales measuring perceived effort and perceived difficulty were used in the more recent study by Thackray and Touchstone (1991) and included here as well. The SRS was extensively examined in the early Thackray, Bailey, and Touchstone (1977) study. In that study, subjects falling at the extremes of rated interest following performance of a simulated radar monitoring task were compared on several performance and subjective variables. In general, those who rated the task as quite boring showed the greatest decline in rated attentiveness and the largest performance decrement.

7.1.3.2 Bennett Mechanical Comprehension Test

One recommendation of the Southwest Research Institute study of ways to improve NDI technician proficiency was to select individuals who score high on mechanical/electronics aptitude (Schroeder, Dunavant, and Godwin, 1988). This recommendation is echoed by NDI instructors who express their belief that individuals with above average mechanical aptitude make better inspectors (FAA/AAM & GSC, 1993). For these reasons, the Bennett Mechanical Comprehension Test was included in the test battery. This test measures ability to perceive and understand relationships of physical forces and mechanical elements in practical situations. This ability may be regarded as a measure of one aspect of intelligence, if intelligence is broadly defined (Bennett, 1969). This test has been validated on various groups of aircraft employees such as shop trainees and aircraft factory employees in mechanical jobs (Bennett, 1969). The performance criteria for the validation studies were generally job ratings, with validity coefficients (*r*'s) ranging from .52 to .62.

7.1.3.3 Typical Experiences Inventory

The ability to resist distraction, if it can be measured, would appear to have at least face validity in selecting inspectors (Wiener, 1975). The Typical Experiences Inventory was developed for use in several previous studies (Pearson and Thackray, 1970; Thackray, Jones, and Touchstone, 1973). This scale consists of a series of statements designed to measure ability to work under conditions of (a) time stress, (b) threat of failure, (c) distraction, (d) social stress, and (e) physical stress. In Thackray et al. (1973), two groups of subjects were selected who scored either high or low on the distractibility subscale of this inventory. High scorers showed significantly greater lapses of attention during performance of a repetitive task than did low scorers. Because of these findings, it was decided to examine the relationship of scores on this subscale to possible performance decrement on the NDI task.

7.1.3.4 Arithmetic, Digit Span, and Digit Symbol Tests of the Wechsler Adult Intelligence Scale (WAIS)

Scores on these three WAIS subtests have been shown in numerous factor analytic studies to measure a factor that has been variously named "Freedom from Distractibility", "Attention-Concentration", or "Concentration-Speed" (e.g., Goodenough and Karp, 1961; Karp, 1963). Some or all of these WAIS subtests have been found to relate significantly to inspection performance (Gallwey, 1982; Wang and Drury, 1989). Consequently, these tests were included as another measure of attention/concentration or, conversely, distractibility.

7.1.3.5 Eysenck Personality Inventory (EPI)

The Eysenck Personality Inventory (EPI) is a short inventory measuring extroversion and neuroticism. The extroversion dimension has been studied extensively in the context of vigilance research because of Eysenck's (1967) hypothesis that extroverts should have more frequent lapses of attention and hence more omission errors than introverts. Reviews of the use of this personality dimension in vigilance research (Berch and Kantor, 1984; Wiener, 1975) have lent some support to the belief that extroverts generally do not perform as well on vigilance tasks as do introverts. Much less research has been conducted on personality variables in the area of inspection, and no studies of extroversion and inspection performance had been conducted at the time of Wiener's 1975 review. Since then, the author is aware of only one inspection study that has incorporated a measure of extroversion. Using a visual search task, Gallwey (1982) found that introverts, as measured by the EPI scale, had fewer search errors.

Koelega (1992) conducted a recent meta-analysis of vigilance studies over a 30-year period and concluded that evidence for the superiority of introverts is considerably less than previously believed. Koelega feels that there is enough consistency in the findings to warrant continued research. Because of this, it was decided to include extroversion as measured by the EPI in the present study.

7.1.3.6 Boredom Proneness Scale (Life Experiences Scale)

NDI inspection is typically repetitive and frequently considered boring and monotonous (Schroeder, Dunavant, and Godwin, 1988). While the evidence relating experienced boredom to poor performance is somewhat tenuous, at least one study demonstrated a significant relationship of reported boredom and monotony to vigilance performance. As noted earlier, subjects falling at the extremes of rated boredom following a simulated radar monitoring task showed the greatest decline in rated attentiveness and the largest decrement in performance (Thackray et al., 1977).

Boredom in the above study was measured following task performance and thus can be considered a "state" assessment of boredom. Farmer and Sundberg (1986) developed the only scale specifically developed to assess the general construct of boredom proneness (i.e. a "trait" measure of boredom susceptibility). To the author's knowledge, this scale has not been used in studies of inspection performance. For this reason, it was included in the present study. In order to disguise the scale's intent, it was relabeled "Life Experiences Scale."

7.1.3.7 Matching Familiar Figures Test (MFFT)

The Matching Familiar Figures Test (MFFT), developed by Kagan and his associates (Kagan, Rosman, Day, Albert and Phillips, 1964), consists of a series of 12 "stimulus" pictures, each of which is associated with 8 "response" pictures. Except for one correct picture in each response set, all differ from the stimulus picture in some minute detail. Subjects point to the picture they believe to be correct in each set and continue until identifying the correct one. Both the time to first response and the number of errors are scored. According to the test's authors, the MFFT measures a cognitive style known as reflection-impulsivity. Those who make quick, inaccurate decisions on the test are said to have an impulsive cognitive style; those who make slow, accurate decisions are said to have a reflective cognitive style.

This test has been used to measure the tendency of subjects performing inspections tasks to opt for speed or accuracy in their speed/accuracy tradeoff (Drury, Gramopadhye, Latorella, Patel, Prabhu, and Reynolds, 1992). Presumably, impulsive subjects tend to opt for speed at the expense of accuracy; conversely, reflective subjects would opt for accuracy at the expense of speed. A recent study found scores on the MFFT to be significantly related to several measures of inspection performance (Latorella et al., 1992). Since the task used in this latter study was the NDI simulation developed by them and used in the present study, it seemed desirable to investigate further the relationship of MFFT scores to performance on this task.

7.1.3.8 Internal-External Locus of Control Scale

Rotter's (1966) Internal-External (I-E) Locus of Control Scale was developed to measure differences among individuals in the extent to which they believe that rewards and reinforcements in life experiences are contingent on or independent of their own behavior. The internal person believes that rewards are contingent on his or her own effort, attributes, or capacities; the external person believes that life's rewards result largely from luck, chance, fate, or forces outside of his or her control.

In a study of vigilance performance, Sanders, Halcomb, Fray, and Owen (1976) hypothesized that "internals," constantly striving for mastery of a situation and exhibiting a belief in their own ability to determine the outcome of their efforts, would perform better on a vigilance task than would "externals." The results supported this hypothesis in that internals, relative to externals, missed significantly fewer signals. Also, internals continued to progress in the monitoring task with a very small decline in performance; externals showed a consistent performance decrement.

Because the Rotter scale has apparently not been used previously in inspection research, it seemed important to determine whether relationships similar to those found in vigilance would apply to inspection performance.

7.1.3.9 Jackson Personality Research Form (PRF)

The Jackson Personality Research Form (Jackson, 1974) is a widely used test designed to yield a set of scores for personality traits broadly relevant to the functioning of individuals in a wide variety of situations. It is a personality test that focuses primarily upon normal functioning, rather than psychopathology.

The Form E used in this study consists of sixteen scales, of which seven were employed in this study. The included scales were (a) Achievement, (b) Endurance, (c) Understanding, (d) Cognitive Structure, (e) Autonomy, (f) Change, and (g) Impulsivity. A brief description of each scale and the reason(s) for its inclusion follows.

- *Achievement*. A measure of the willingness to put forth considerable effort to accomplish difficult tasks. This was included as a possible measure of intrinsic motivation or perseverance in task performance, mentioned earlier in the review report as a desirable quality for NDI technicians.
- *Endurance.* A measure of the willingness to work long hours and to be patient and unrelenting in work habits. This trait appears somewhat related to the above measure, and, in fact, loads on the same factor in a factor analysis of the test. It was included for the same reasons as the Achievement trait.
- *Understanding.* A measure of intellectual curiosity and the desire to understand many areas of knowledge. This was included because it was felt that it might correlate negatively with performance on a task as constrained and repetitive as eddy-current testing.
- *Cognitive Structure.* A measure of the need to make meticulous decisions based upon definite knowledge with a dislike of ambiguity and uncertainty. It was felt that this trait might be positively related to search time, i.e. the time spent in searching each rivet for possible faults.
- *Autonomy.* A measure of the need to be independent and not to be tied down, restrained, confined, or restricted in any way. This trait was mentioned in the previous review report as characterizing the most proficient inspectors (FAA/AAM & GSC, 1993). This trait was also identified by some NDI instructors interviewed.
- *Change.* A measure of liking for new and different experiences, with a dislike and avoidance of routine activities. Inclusion of this trait is self-evident, since NDI tasks are quite often referred to as boring and monotonous.
- *Impulsivity.* A measure of the tendency to act on the "spur of the moment" and without deliberation. This was included as an additional measure of impulsivity to be compared with the impulsivity measure derived from the MFFT.

7.1.3.10 Figure Preference Test

The Figure Preference Test was a paired comparison version of the Munsinger and Kessen (1964) test of preference for complex versus simple perceptual stimuli. Subjects chose which figure of each pair they prefer from a set of 66 pairs of figure drawings differing in complexity.

A recent study of industrial workers determined that preference for simple stimuli on this test was related to preference for repetitive, unchanging work requiring a constant focus of attention (Rzepa, 1984). Because of the apparent similarity of NDI inspection to tasks of this type, it was decided to add the Figure Preference Test to the battery of predictors.

7.1.3.11 Summary of Tests and Measures

The tests and measures described above were included because it was felt that each might serve to measure some aspect of the variables mentioned under Section 7.1.3 as predictors and/or correlates of NDI performance. A number of these tests and measures are similiar and may indeed measure the same trait, aptitude, or ability. However, one cannot always tell from test titles and descriptors whether they measure similar things; some were included to determine empirically the extent of their interrelationships, or lack thereof.

7.1.4 Procedure

Each subject was tested over two successive days. The morning of the first day was devoted to administration of the various tests and measures; during the afternoon, subjects practiced using the mouse, were required to read and be tested on a document describing eddy-current testing and the need for it, and practiced the NDI simulation task. Afternoon training procedures were essentially the same as those used in the earlier pilot study.

Training in using the mouse was provided by a display program consisting of a enlarged picture of a rivet head with a training circle surrounding it. The subject practiced using the mouse and cursor to circle the rivet while staying within the circle. After each pre-selected block of training trials, each subject received feedback on the average times required to circle the rivet and the average number of times the cursor head touched the rivet or went outside the circle. Training continued until the subject reached a consistent level of performance. This usually required 15 to 30 minutes of practice.

Task training began with a short (20-rivet) demonstration session in which the basic elements of the NDI task were explained. This was followed by three training sessions each 60 rivets long. Thirty percent of the rivets in each of the three training sessions contained faults (cracks). In addition, the second and third sessions also contained small, but visible (2 mm), "noise" spots at various locations at or near a rivet. The frequency of "noisy rivets" was also thirty percent. The location of faults and noise was randomly assigned for each task session (both training and subsequent test tasks). Performance feedback was automatically provided after each block of 10 rivets. In the first session, training circles around each rivet assisted the subject to keep the cursor in the appropriate region while circling the rivets; no training circles were used in the second and third sessions.

On the morning of the second day, subjects performed a short (20-rivet) "refresher" version of the NDI task and then two lengthy (180-rivet) test sessions. These sessions were self-paced, and test durations for each subject varied from a minimum of about 60 minutes to the maximum allowable duration of 90 minutes. There was a fixed 15-minute rest break between sessions, although subjects were told that they could take short (10-20 second) "stretch" breaks as needed during any session. Following a 60-minute lunch break, this same procedure (two 180-rivet sessions), minus the short practice session, was followed in the afternoon. No feedback was provided following test sessions, and the frequency of both faults and noise was held at 30 percent each.

Subjective rating scales were administered at various times during the course of both days.

At the end of the second day, subjects were debriefed and questioned about their various attitudes and approaches to the NDI task.

7.2 RESULTS

7.2.1 Task Performance

7.2.1.1 Performance Measures: Reliability, Intercorrelations, and General Observations

As mentioned earlier, 30 percent of the rivets in each 180-rivet session contained cracks (faults). Of the two types of error (failing to detect a faulty rivet or calling a good rivet bad), missed faults were by far the most common. On the average, approximately 23 percent of faulty rivets were missed, while only about 2 percent of good rivets were marked faulty. These mean error rates, incidently, are remarkably close to those noted in preliminary analyses of the recently completed Sandia/FAA field study (Schurman, 1993). Comparisons of the sum of the first two sessions with the sum of the last two sessions yielded correlations (reliability estimates) of $r=.84$, $p<.01$ and $r=.82$, $p<.01$ for false alarms and missed faults, respectively. Total errors (false alarms plus missed faults) correlated $r=.51$, $p<.01$ with false alarms and $r=.91$, $p<.01$ with missed faults. Since false alarms and missed faults were essentially uncorrelated ($r=.09$), missed faults accounted for most of the variance in total errors.

The remaining measure of performance, mean time per rivet, measured speed of inspection; it represented the mean time a subject examined rivet before arriving at a decision. A negative correlation of missed faults with mean time per rivet would suggest that subjects traded speed for accuracy. However, the obtained correlation of missed faults with speed, although negative, failed to reach statistical significance ($r= -.22$, $p>.05$).

7.2.1.2 Performance Change Across Periods and Sessions

One of the purposes of this study was to examine the data for evidence of progressive changes across periods and sessions. Such data might suggest a fatigue effect. Changes indicative of fatigue were suggested from the findings of the earlier pilot study. **Tables 7.1** and **7.2** show mean percentages across sessions of missed faults and false alarms, respectively. To allow intra-session comparisons of performance not separated by rest breaks, each session was divided into two 90-rivet segments, referred to as periods in the tables. Although each session contained an equal number of total faults, arbitrarily breaking each into halves resulted in slightly differing proportions of faults in the first and second halves of the four sessions. Consequently, the data shown in **Tables 7.1** and **7.2** show percentage data, and all subsequent analyses of variance were conducted on these data.

Table 7.1 Mean percent of faults missed across periods and sessions

	Period		
Session	**1**	**2**	**Session Means**
1	15.4	23.8	19.6
2	25.0	24.4	24.7
3	24.0	25.3	24.6
4	19.6	28.6	24.1
Period Means	21.0	25.5	23.2

Table 7.2 Mean percent of false alarms across periods and sessions

	Period		
Session	**1**	**2**	**Session Mean**
1	0.8	0.5	0.6
2	1.3	3.1	2.2
3	1.9	2.8	2.3
4	3.1	4.2	3.7
Period Means	1.8	2.7	2.2

Both tables reveal generally poorer performance in the second period of each session, but only false alarms showed a systematic increase across sessions. Repeated measures of analyses of variance (ANOVAs) conducted on the two error measures revealed the differences between periods to be significant for both missed faults and false alarms ($F(1/26)=9.88$, $p<.01$ and $F(1/26)=7.29$, $p<.01$), respectively. Differences between sessions were significant for false alarms ($F(3/78)=5.14$, $p<.01$), but not significant at the .05 level for missed faults. The interaction of session by period was significant for both missed faults ($F(3/78)=4.43$, $p<.01$) and false alarms ($F(3/78)=3.02$, $p<.05$), although in neither case did the patterns of cell mean differences lead to meaningful conclusions. Because the pilot study had suggested the possibility of sex (gender) differences in performance, the analyses included gender as a between-subject variable. Neither analysis revealed any significant main effects or interactions attributable to gender. Consequently, the tables show only combined data of both sexes.

Mean times per rivet across the four sessions were 23.6, 21.9, 21.6, and 19.6 seconds, respectively. Analysis of variance revealed this decline to be significant ($F(3/78)=8.96$, $p<.01$). There were no significant differences between males and females, and the interaction of gender and sessions was nonsignificant ($p>.05$). Comparisons of changes within sessions (periods) were not considered to add any additional useful information, and none were made.

Some comments regarding the increase in false alarms both within and between sessions is in order. A possible increase in fatigue within a session seems a plausible explanation for the increase in missed faults. Subjects presumably became less attentive and more careless. However, it is somewhat puzzling to see how increasing tiredness could also result in increases in false alarms. False alarms should logically occur only when a meter indication resulting from "noise" is wrongly attributed to a crack. In this task, however, most erroneous meter indications seemed to result from a subject passing too close to a rivet's edge. The time spent examining each rivet steadily decreased across sessions, and this could indicate less-careful examination of individual rivets. Less-careful examination would likely increase the number of times a rivet was touched, with the resulting meter deflections misinterpreted as faults.

7.2.2 Rating Scale Variables

7.2.2.1 Pre- to Post-Task Changes

Measures of attentiveness, tiredness, strain, interest, and annoyance were obtained for each subject at the beginning and end of the morning and afternoon sessions of the second day. In addition, items relating to perceived task difficulty and effort required to maintain alertness were also administered at the end of the morning and afternoon sessions of this second day. Mean pre- and post-task values for each rating variable are shown in **Table 7.3**.

Table 7.3 Mean pre- and post-session ratings

Variable	Mn Pre-Session Ratings	Mn Post-Session Ratings
Attentiveness	6.8	5.3
Tiredness	4.6	5.6
Strain	3.7	4.7
Interest	5.8	4.2
Annoyance	1.3	2.1
Effort	3.5	4.8
Difficulty	2.3	3.2

Separate ANOVAs revealed significant pre- to post-task decreases in attentiveness

($F(1/27)=37.15$, $p<.01$) and interest ($F(1/27)=48.83$, $p<.01$), along with significant increases in tiredness ($F(1/27)=30.39$, $p<.01$), strain ($F(1/27)=15.75$, $p<.01$), and annoyance ($F(1/27)=11.77$, $p<.01$). Ratings of task difficulty increased significantly from the beginning to the end of the sessions ($F(1/27)=8.27$, $p<.01$) as did the ratings of effort required to remain attentive ($F(1/27)=22.39$, $p<.01$).

Verbal labels associated with numerical values on the rating scales revealed that none of the feeling states represented extreme levels. Subjects typically began each session feeling moderately attentive, moderately relaxed, moderately interested, not annoyed, and having about their normal energy level. Each variable was rated on a 9-point scale, with 5 representing the midpoint or middle value. Post-session levels for most variables were near this midpoint value. Pre- to post-session changes for all variables were relatively small, representing minor shifts in feeling state from pre-session levels. For difficulty and effort, subjects initially perceived the task to be slightly difficult, requiring slight effort. Ratings of perceived difficulty and effort at the end of the sessions, although increasing significantly for both variables, revealed relatively minor changes in each variable.

7.2.2.2 Correlations of Rating Scale Data with Performance

To investigate the relationships, if any, between rating scale data and performance, difference scores (post minus pre levels) were obtained for each subject for each rating scale variable. These were separately correlated with missed faults, false alarms, and mean time/rivet. No correlation reached significance ($p>.05$), with the exception of an association of attentiveness change with missed faults ($r=-.40$, $p<.05$). This relationship, as explained in the next section, was apparently the result of differences in initial rather than final levels of attentiveness.

7.2.2.3 Analyses of Variance of Rating Scale Data and Performance

In addition to the correlational analyses, separate ANOVAs were conducted to compare rating scale changes for extreme groups of subjects (the best and the worst 9 subjects) formed on the basis of total scores on each performance variable. It was felt that eliminating subjects in the middle range of score distributions might provide a more sensitive approach to analyzing relationships. Only one of the ANOVAs, however, suggested a possible relationship of performance scores to ratings; this was an interaction between interest change and missed faults ($F(1/16)=3.88$, $p<.06$). Examination of mean values revealed that subjects in the poorest group showed a greater decline in interest during performance than did those in the better group. The analysis comparing the best and worst groups' missed faults with attentiveness change yielded an interaction effect that, like that shown above for interest change, approached significance ($F(1/16)=3.71$, $p<.07$). Examination of the mean values, however, revealed the reason for the significant correlation reported in Section 7.2.2.2. While the best and worst groups had similar post-session ratings of attentiveness, better performers had a higher initial level of attentiveness, thus showing a greater pre to post change than did the poorer performers.

7.2.3 Predictor Variables and Performance

A large number of exploratory analyses were conducted using discriminant function analysis and factor analysis. In general, the clearest relationships were found using factor analysis. A principal components analysis using varimax rotation and solved for four factors seemed to yield the best, most interpretable relationships. Loadings of each predictor variable on the four factors are shown in **Table 7.4**. A cut-off criterion of .60 was used to select those variables contributing to factor interpretation.

This means that a variable would have to explain at least 36 percent of a factor's variance for it to be included in a factor's interpretation. The factors were identified with the labels listed below.

Table 7.4 Loadings of each predictor variable on the four factors

	Factor			
Variable	**1**	**2**	**3**	**4**
Typ Exp Inventory	-0.046	0.473	-0.128	-0.276
Bennett Mech Test	-0.209	0.103	-0.257	0.612
LES Boredom Prone	0.358	0.378	-0.582	-0.052
Match Fam Fig Error	-0.257	-0.722	0.096	-0.291
Match Fam Fig Time	-0.075	-0.049	-0.639	0.222
Eysenck Extroversion	0.644	-0.398	0.222	0.203
WAIS Dig Symbol	0.208	0.175	0.697	-0.156
WAIS Dig Span	0.114	0.105	0.106	0.828
WAIS Arithmetic	0.057	0.600	0.129	0.500
PRF Achievement	-0.553	-0.308	-0.029	0.241
PRF Autonomy	0.059	0.738	0.213	0.028
PRF Change	0.075	0.073	0.754	0.296
PRF Cog Structure	-0.807	0.016	-0.186	0.051
PRF Endurance	-0.717	-0.282	0.055	-0.084
PRF Impulsivity	0.741	-0.250	0.170	0.074
PRF Understanding	-0.143	0.644	0.075	0.152
Rotter I-E Scale	0.584	0.085	-0.491	-0.026
Fig Preference	0.105	0.016	0.359	0.282

Factor 1 - Impulsive/Impatient: This is one of the easier factors to identify. The tests loading positively on this factor (EPI Extroversion and PRF Impulsivity) suggest an impulsive personality style, while tests loading negatively (PRF Endurance and PRF Cognitive

Structure) suggest impatience, unwillingness to work long hours, and a lack of meticulousness.

Factor 2 - Reflective/Analytical: Kagan and associates (Kagan et al., 1964) report that low scores on the MFFT error measure relate to a reflective personality style; high scores on the PRF Understanding scale also suggest a reflective, analytical style. Positive loadings on the WAIS Arithmetic scale are related to concentration/attentiveness (Goodenough and Karp, 1961; Karp, 1963), and high scores on the PRF Autonomy scale suggest self-reliance. While not forming an entirely consistent pattern, this factor seems best to typify a reflective/analytical dimension.

Factor 3 - Rapid/Adaptable: Positive loadings on the WAIS Digit Symbol and negative loadings on the MFFT Time measure suggest an ability to perform new tasks rapidly. High loadings on the PRF Change scale suggest a dislike of routine and an ability to adapt readily to new and different experiences. While aspects of this factor may seem to resemble Factor 1, the loadings are quite different. It appears that Factor 3 represents more of a risk-taking, adventurous dimension than the impulsive, impatient dimension of Factor 1. Taken together, Factor 3 appears to reflect a rapid/adaptable personality dimension.

Factor 4 - Mechanical Aptitude: This factor appears to stand alone as an ability factor; the other factors represent personality dimensions. Only two tests load substantially on this factor: the Bennett Mechanical Comprehension Test and the WAIS Digit Span scale. The former seems to define the factor, while the latter suggests an important attentional component.

Pearson product moment correlations between each factor score and the various performance criterion measures, however, showed only two of the factors to be significantly related to performance. Factor 4 was negatively correlated with missed faults ($r=-.38$, $p<.05$) and with false alarms ($r=-.51$, $p<.01$). Factor 1 was negatively correlated with mean time/rivet ($r=-.48$, $p<.05$). A summary interpretation of these relationships is that good task performance (low numbers of missed faults and false alarms) is related to both mechanical aptitude and concentration/atten-tiveness. Speed of inspection is related to both impulsivity/impatience and an unwillingness to devote long periods of time to work.

7.2.4 Gender, Liking for Inspection, and Educational Level

At the end of the last performance session, each subject was debriefed and asked whether or not he or she might like inspection work or could visualize himself or herself as an inspector. The answers were coded "1" if inspection appealed to them and "2" if it did not. The number of males and females in each category are shown in **Table 7.5**.

Table 7.5 Number of males and females expressing a liking for or dislike of the inspection task

Gender	Like Inspection	Dislike Inspection

Males	10	5
Females	5	8

Although there is a suggestion of a gender difference in the data, with more males expressing a liking for inspection, a chi-square test revealed this apparent gender difference to be nonsignificant (p=.14). Liking for inspection, however, was found to be related to educational level. As noted earlier, education levels of subjects in this sample ranged from high school to graduate school. This range was dichotomized. High school graduates and those currently attending a community college or technical school were placed in one category, and those currently enrolled in a university with junior status or higher were placed in a second category. The lower educational level was coded "1", while the higher level was coded "2." Subjects in each category, along with their expressed liking (or disliking) of the inspection task, are shown in **Table 7.6**.

Table 7.6 Number in each educational category expressing a liking for or a dislike of the inspectior

Educational Category	Like Inspection	Dislike Inspection
1	12	3
2	3	10

Ten out of 13 subjects (77 percent) who expressed a dislike of the inspection task or who could not visualize themselves as inspectors were in the higher educational level category, while 80 percent of subjects in the lower educational category either liked the inspection task or could visualize themselves as inspectors. A chi-square test of the data in this table revealed the relationship between educational level and liking for inspection to be significant (p<.01).

Correlational analyses revealed that neither liking for inspection nor educational level were significantly related (p>.05) to any performance measures.

Although gender was not related to liking for inspection and, as noted earlier, was not related to any performance measures, gender was correlated significantly (r=-.58, p<.01) with scores on the Bennett Mechanical Aptitude Test. Males performed better than females on this test. Because the Bennett Test loaded substantially on Factor 4, which was significantly correlated with both missed faults and false alarms, these data suggest an indirect relationship of gender to performance.

7.3 DISCUSSION

The present study used a simulated eddy-current inspection task to address two questions, both of which are of concern to aviation maintenance and inspection:

1. Does performance on this task over a period of time simulating an 8-hour shift show any evidence of decline (fatigue)?
2. Can tests and measures be identified that will predict performance on this task?

7.3.1 Evidence of Fatigue Effects

Before considering possible fatigue effects, the experiment's procedure will be briefly reviewed. The first day for each subject was devoted to administration of the psychometric test battery and to training sessions on the NDI task. The second day simulated a work shift by having subjects perform the NDI task over four successive sessions, two in the morning and two in the afternoon. Each session was self-paced and lasted approximately 60 to 90 minutes. Fifteen-minute breaks were given between the two morning and afternoon sessions along with a 60-minute lunch break. Attempts were made to make each session as close to real life as possible by allowing subjects to take brief "stretch" breaks as often as they desired.

For purposes of data analysis, each session was arbitrarily divided into a first and second half. The results revealed a significant increase in the number of both missed faults and false alarms from the first to the second half of the sessions. Further, while missed faults did not increase over the four sessions, there was a significant increase in the number of false alarms from session 1 to session 4.

The increase in errors during sessions, where no rest periods were allowed except for brief stretch breaks, suggests a decline in performance efficiency that may have been the result of a progressive increase in tiredness and/or a decrease in attentiveness. Rating scale measures of attentiveness and tiredness both showed significant changes from the beginning to the end of the sessions, with attentiveness decreasing and tiredness increasing. However, individual differences in the magnitude of change in tiredness or attentiveness were found to be unrelated to individual levels of performance error (both missed faults and false alarms).

Changes in rating scale variables such as interest, strain, annoyance, task difficulty, and task effort were significant from beginning to end of the sessions, and, except for change in interest, were unrelated to performance error. With regard to the change in interest, subjects showing the highest levels of missed faults showed a greater decline in interest during the sessions than did subjects with the lowest numbers of missed faults.

In assessing the effects of sustained performance on error frequency, two aspects should be emphasized. First, although significant performance declines occurred during the sessions, the absolute magnitude of the increase in errors was relatively small. For missed faults, mean percent error for the first half of the sessions was 21 percent, which increased to a mean percent error of 25.5 percent during the second half. For false alarms, mean percentages of error for the first and second half of the sessions were 1.8 percent and 2.2 percent, respectively. Also, the mean percent error for false alarms during the first session was less than 1 percent which increased to 3.7 percent by the last session. Although these increases in error were statistically significant, they may not be large enough to be practically significant.

Second, the concomitant changes in such subjective measures as tiredness, attentiveness, interest, and strain, although statistically significant, also represented relatively little absolute change in feeling states from the beginning to the end of the sessions. As noted earlier, subjects typically began each session feeling moderately attentive, moderately relaxed, moderately interested, not annoyed, and having about their normal level of energy. Post-session ratings deviated little from the initial feeling states. Except for change in interest, which, as discussed above, was related to frequency of missed faults, none of the changes in feeling state was found to be related to measures of performance error. Had the sessions been longer or had they been conducted when subjects were tired initially, greater changes in both performance and feeling states might have occurred, possibly resulting in significant relationships between subjective measures and task performance.

7.3.2 Performance Predictors

A factor analysis of the various predictor variables employed yielded four factors: two correlated significantly with performance. Factor 4 showed a significant negative correlation with both missed faults and false alarms, while Factor 1 showed a significant negative correlation with the performance speed measure (mean time/rivet).

Only two tests had substantial loadings (.60 or greater) on Factor 4. These were the Bennett Mechanical Comprehension Test and WAIS Digit Span Test. As indicated earlier, mechanical ability has been frequently mentioned as possibly related to inspection proficiency. Normative data shows it to be significantly related to job performance of various groups of aircraft factory employees (Bennett, 1969). As previously noted, the Digit Span Test appears to be a measure of alertness or concentration. Several studies have shown it to be related to inspection proficiency (Gallwey, 1982; Wang and Drury, 1989). Taken together, these two tests seem to tap specific abilities relating to inspection errors the simulated NDI task measured. It is interesting to note that while missed faults and false alarms were essentially uncorrelated, both were related to Factor 4. In looking at individual Pearson correlations of each test loading on Factor 4, Digit Span correlated higher with false alarms than with missed faults. The Bennett Test showed a higher correlation with missed faults than with false alarms. This suggests that the two tests may measure different aspects of task performance. A follow-up study will examine this possibility further.

With regard to Factor 1, the tests loading substantially on this factor (e.g., EPI Extroversion, PRF Impulsivity, PRF Endurance) suggest that this factor measures a rapid/impatient/impul-sive cognitive style. It is not surprising that this factor correlated significantly with the measure of time taken to inspect the rivets (mean time/rivet). The fact that mean time/rivet did not correlate significantly with either of the two measures of inspection error would indicate that subjects did not necessarily lose inspection accuracy with increased speed of inspection.

7.3.3 Gender, Liking for Inspection, and Education Level

The previous pilot study suggested a possible gender difference in inspection accuracy. For this reason, this study examined possible male/female differences in performance. The results did not show differences between males and females in either performance accuracy or in speed of inspection. This lack of a gender effect is consistent with the findings of most previous studies of vigilance and inspection (Wiener, 1975).

Liking for (or dislike of) inspection was related to educational level, but not to any performance measures. Likewise, differences in subjects' educational levels was also unrelated to performance. These findings are consistent with those of Summers (1984) in his follow-up study of the early Air Force "Have Cracks, Will Travel" study (Lewis et al., 1978). The level of formal education (from less than high school to more than 2 years of college) was unrelated to technician performance, as was expressed liking for (or dislike of) inspection.

7.4 CONCLUSIONS

This experiment used a simulated eddy-current inspection task (a) to determine the extent of performance change, if any, over a simulated day-shift work period and (b) to investigate the relationships between various predictor variables and performance on the eddy-current task. Many of the findings, such as the lack of any relationship among inspection performance and gender, educational level, and expressed liking for inspection, were generally consistent with previous studies. Other findings, such as the relationships between a number of psychometric tests and task performance, are tentative and need to be validated with a different group of subjects. This will be accomplished in a planned follow-up study. A summary of the major findings of this study follows.

- There were statistically significant increases in both missed faults and false alarms during the 60-90 minute task sessions, but only false alarms showed any tendency to increase across sessions. Increases in the percentages of missed faults and false alarms, both within and between sessions, ranged from only 0.8 to 4.5 percent, however, and may not represent performance declines of practical significance.
- Accuracy of inspection (low numbers of missed faults and false alarms) was found to be positively related to mechanical ability, as measured by the Bennett Mechanical Comprehension Test, and concentration/attentiveness, as measured by the WAIS Digit Span Test. Tests and scales measuring such traits as extroversion, impulsivity, and lack of meticulousness (the Eysenck Extroversion Scale and the PRF Impulsivity and Cognitive Structure Scales) were significantly related to speed of inspection.
- Speed of inspection was unrelated to errors (missed faults and false alarms).
- There was a relationship between level of educational achievement and liking for inspection. Subjects with higher educational levels expressed a dislike for performing the inspection task, while those with lower educational levels tended either to like the task or not to find it unpleasant.
- Liking for inspection was unrelated to performance (missed faults, false alarms, or speed) on the NDI task.
- There were no differences between males and females in either task performance or in liking for inspection.

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CHAPTER EIGHT
RESULTS OF THE ENVIRONMENTAL CONTROL SYSTEM TUTOR EXPERIMENT AT CLAYTON STATE COLLEGE

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8.0 INTRODUCTION

The study described in this paper investigates the effect of an Intelligent Help Agent (IHA) on the effectiveness of computer-based training. The experiment was conducted February 16-17, 1993, at the Aviation Maintenance Technology Department of Clayton State College in Morrow, Georgia. Subjects used the Environmental Control System Tutor, a simulation-based trainer, either with or without an error-driven IHA. There was no significant difference in overall performance between the two groups; 80% of all subjects made two or less errors diagnosing ten system malfunctions.

8.1 ENVIRONMENTAL CONTROL SYSTEM OVERVIEW

All modern airliners use the Environmental Control System (ECS) to control the aircraft's air pressure and temperature. The ECS Tutor simulates an ECS with three control and display panels in the cockpit, electronic modules in the avionics bay, and two cooling packs in the fuselage. The ECS is a complex system. Electrical, mechanical, and airflow subsystems interact to provide cool, pressurized air to the cabin and cockpit. We chose the ECS as the training domain for the tutor because it is fairly similar across airliner types: ECS training would not be specific to one airliner. Built-In Test Equipment (BITE) makes the technician's job easier since it tests some components with the push of a button. However, BITE does not test all ECS' components. A technician must know when and how to use external test equipment to isolate malfunctions.

8.1.1 The Aviation Maintenance Technician

Aviation Maintenance Technicians (AMTs) must quickly diagnose and repair malfunctions on the aircraft they are certified to work on. AMTs must know about the systems of several types and models of aircraft. Their task is time-constrained since there is about 40 minutes between a flight's landing and takeoff. Since some repairs require more than 40 minutes, AMTs must find the faults quickly if they are to minimize delays in the flight schedules.

It is standard procedure for AMTs to use the Fault Isolation Manual (FIM), a logic tree used to diagnose malfunctions. AMTs follow the FIM's "branches" based on outcomes of their tests and inspections. The FIM specifies a "minimal path" of actions necessary to repair a failure, from a high-level description of the malfunction to the malfunctioning component. Since it is sometimes possible to diagnose malfunctions with a single test (for example, by operating the BITE), AMTs do not always use the FIM.

8.1.2 Overview of ECS Tutor

The ECS Tutor is a intelligent tutoring system (ITS) that allows AMTs to improve their diagnostic skills through simulated ECS' malfunctions of the Boeing 767. The ECS Tutor contains a deep-simulation ECS model that allows users to see the consequences their actions have on the simulated ECS. Users can change the switch settings and observe values of various system parameters. The tutor is also highly graphical, allowing direct manipulation of ECS' components, and contains realistic pictures and animation of system components and schematics. **Figure 8.1** is a sample screen from the ECS Tutor.

The tutor allows four types of actions on ECS components: operating, inspecting, testing, and replacing. In operating ECS equipment, a user, for example, can change the switch settings for the cockpit control panels. Inspecting a component includes reading display values on control equipment or looking for visible failures in pack components. Testing differs from inspection because an AMT has to perform some action; usually, it is to operate some internal or external test equipment. One example of testing occurs when an AMT tests the pack controller by operating the BITE. Replacing allows users to swap out Line Replaceable Units (LRUs) with working components.

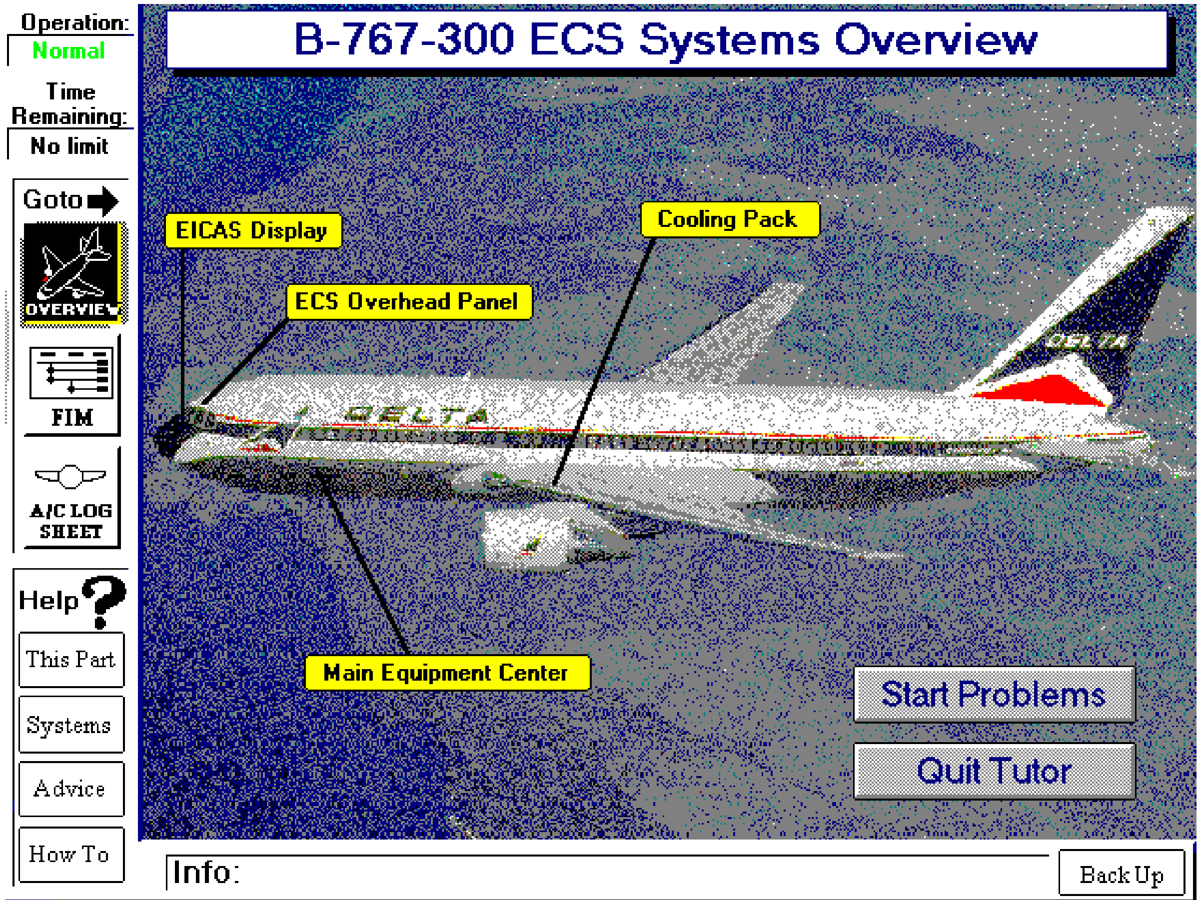

Figure 8.1 Sample screen from the ECS Tutor

8.1.3 Knowledge for Diagnosis

An AMT needs several types of knowledge to diagnose malfunctions. The ECS Tutor contains knowledge about principles, systems, components, and procedures. Principles can be either physical laws governing the behavior of systems or rules-of-thumb useful for diagnosing malfunctions. Systems are groups of connected components that interact to perform some function; a system can contain other subsystems. A component is a elementary part of a system that transforms material or energy. Finally, procedures are lists of actions performed to achieve a goal. For example, the troubleshooting steps a FIM explicate procedures for certain tasks. Knowledge types differ in their levels of abstraction. Principles, the most abstract, apply to many situations but may be difficult to apply to a specific situation. Procedures, the most concrete, are used only in specific situations.

8.1.4 Intelligent Help Agent of the ECS Tutor

The ECS Tutor offers two ways for a user to get help. First, a user can ask for help by clicking on one of the five help buttons on the bottom left side of the screen. This help is continually available while the user is troubleshooting a malfunction. Four buttons providing help correspond to the four types of knowledge used in troubleshooting, and one button explains how to operate the tutor. The five help buttons are described in **Table 8.1**.

Second, a user gets help when he or she makes mistakes. The ECS Tutor contains a qualitative model of ECS' components. The ECS Tutor's IHA can compare a user's actions with the model to determine if the user is making progress toward a solution. If the user performs an action that does not make sense, e.g., replacing a component that is working correctly, the IHA offers the user some help. The type of help offered depends on several factors, including the following:

- the type of error the user made
- the instructional strategy the tutor is using
- the number and type of mistakes the user previously made
- the threshold for offering help when users make mistakes.

Table 8.1 Types of help available in the ECS Tutor

Button	Help Type	Purpose of Help
FIM	Procedures	Standard procedures for troubleshooting malfunctions
This Part	Component	Description of the components and their subcomponents
Systems	Systems	Schematic of either the ECS' control or pack systems
Advice	Principles	Suggestion of what to do next
How To	Operation	General help with using the tutor

When a user make a mistake, the tutor offers help that the user can either ignore or view. The type of help offered will be one of the four knowledge types described above: principles, systems, components, or procedures. **Figure 8.2** offers an example of a principle. It shows a generalized electrical control circuit and describes the "backtrack" and "divide and conquer" strategies for troubleshooting electrical circuits. The user can click on a component to see how the system behaves when that component malfunctions.

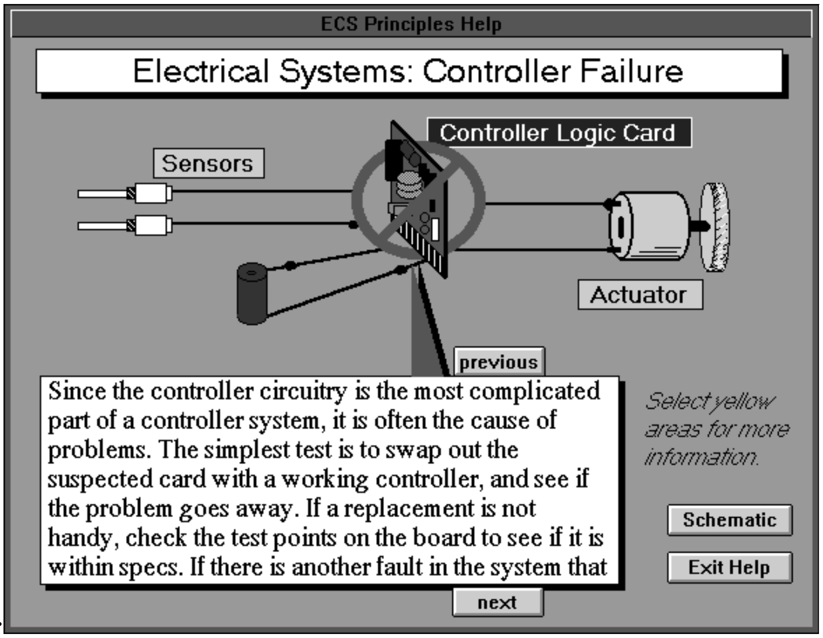

Figure 8.2 Example of a Principle

8.2 PURPOSES OF THE EXPERIMENT

One goal of our research is to evaluate the effectiveness of ITS technology as applied to AMT training. We produced the ECS Tutor, an ITS that teaches troubleshooting skills in the context of aviation maintenance. The research conducted so far has included several usability studies and a small-scale evaluation (Pearce 1993a, Pearce 1993b).

The experiment described in this paper was designed to determine the effectiveness of an IHA in a computer-based training system. Although much research has addressed designing and implementing ITSs, little has evaluated ITS' effectiveness in a classroom setting. Researchers often assume that adding intelligence to a computer-based training system will automatically improve students' performance. Our experiment was specifically designed to allow quantitative measurement of an IHA's effect.

We also wanted to determine which ITS issues are important for AMT training. Although many issues are similar to those of other instructional settings, there are also specific aviation maintenance issues. For example, the availability of BITE in newer commercial aircraft requires the technician to understand the abilities and limitations of such equipment. By observing students using the ECS Tutor in an aviation maintenance classroom setting, we examined how they use the software to learn about troubleshooting. Data from these observations were used to discern instructional, implementation, and pragmatic issues related to using the software in an aviation maintenance classroom setting.

8.3 METHOD

The experiment was designed primarily to determine the effect of including an IHA in a CBT program. We measured the performance difference between students using a tutor with an IHA and students using a tutor without an IHA. The two ECS Tutor versions were identical except for availability of an IHA. Therefore, students in both experimental groups could ask for help by clicking on one of the help buttons, but students in the "without IHA" group did not get help when they made mistakes. The subjects were not told that there were two ITS programs, and none notified the experimenters of any difference between the two versions of the tutor.

8.3.1 Subjects

The subjects consisted of 15 A&P students in the Aviation Maintenance Technology Department of Clayton State College. All subjects were enrolled in the Winter 1993 course "Cabin Atmosphere" (AVMT203) and had been at Clayton State College for at least one year. The "Cabin Atmosphere" course covers operation of the DC-9's ECS, which is less complicated (because of the limited use of electronic control) than the B-767's ECS. Before participating in the experiment, subjects had spent approximately seven hours of class time learning about the DC-9's ECS. No subject had worked on the Boeing 767's ECS, or seen the ECS Tutor before the experiment. No subject had used a FIM to troubleshoot aircraft malfunctions. The subjects' computer experience ranged from none to 3 years. As shown in **Figure 8.3**, a poll given after the tutor usage portion of the experiment indicated that while more than 80% of the subjects had used a computer before the experiment, only about 20% had previously used a CBT system.

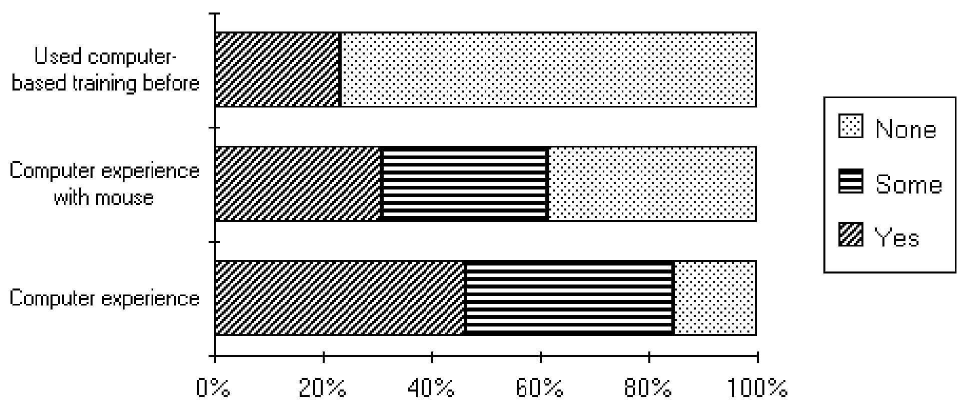

Figure 8.3 Computer Experience

8.3.2 Procedure

Subjects were randomly assigned to one of the two experimental groups. The experiment was divided into three phases: introductory lesson, tutor usage, and testing (**Figure 8.4**) conducted over two days. On the first day, all of the subjects participated in an introductory lesson covering general B-767 ECS operation; ECS modes of operation; and functions of the ECS sensors, valves, and electronics. The introduction covered material needed by the subjects to troubleshoot malfunctions, including how to use the FIM for the B-767's ECS. Since some subjects had not used a computer with a mouse before this experiment, the introduction also covered how to use the mouse and a graphical user interface. The course instructor conducted the introductory lesson, describing the ECS Tutor by projecting it on an overhead screen and then explaining the various buttons and how to use the program. All subjects went through this two-hour introductory lesson before participating in the troubleshooting portion of the experiment.

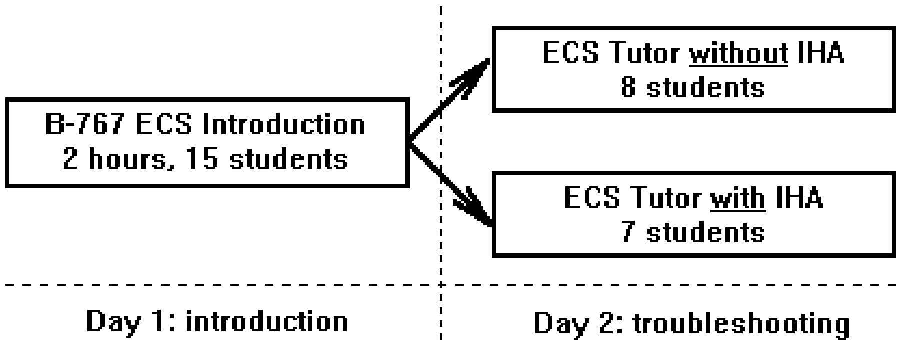

Figure 8.4 Experiment Design

On the experiment's second day, the researchers randomly split the subjects into a "with IHA" group and a "without IHA" group for the troubleshooting portion of the experiment. The subjects used the ECS Tutor on the school's training computers. Seven subjects used the ECS Tutor with the IHA operational, and the remaining eight subjects had computers with the IHA turned off. Help control was internal to the tutor, so there was no way to distinguish the two configurations, and none of the subjects said that they noticed a difference. The subjects were allowed to finish the simulated malfunctions at their own pace and were given a poll after they had finished.

8.3.3 Data

Two types of data were collected: traces of the subjects' actions and a poll the subjects completed after finishing all simulated malfunctions. Each tutor had a mechanism for tracking each action a user performed, including the following:

- Going to a program screen
- Inspecting/testing/replacing a component
- Asking for help
- Accepting or rejecting help when offered.

Along with recording each action, the tutor tracked the components that the user acted on and the time. This data allows the researchers to recreate how each subject used the tutor and to determine if subjects had any problems in using the tutor. The data from the traces for the last problem was lost on some computers, so the researchers analyzed only the data for the first 9 of 10 problems.

The researchers collected users' opinions about the ECS Tutor by using a short poll. We also administered a background poll to determine the distribution of skill levels for computer use and ECS maintenance. After subjects finished the simulation and polls, we asked them to write any impressions or observations they had concerning the tutor.

8.4 RESULTS

This section is divided into a trace analysis section covering analysis of profiles of how subjects used the tutor, a poll results section describing the poll results, and a post-experiment comments section discussing remarks subjects wrote on the poll forms.

8.4.1 Trace Analysis

A trace was kept for each malfunction problem the subjects worked on. The trace consisted of records that described the following:

- the action the user performed, e.g., an inspection of a component
- the component that was acted on, e.g., the cockpit ECS control panel
- whether this action was an error; if so, of what type, e.g., a procedural error
- the time that the action was performed.

From this data, the researchers could recreate a user's responses to the ECS Tutor. More importantly, we could infer some things about the user's mental processes. For example, if a user completed a problem in a short time relative to other users' performance, we would infer that the user has some knowledge about troubleshooting the ECS. If the trace indicated that a user referred to the FIM during the simulation, we would infer that the subject used procedures describing how to use the FIM. On the other hand, if a subject did not use the FIM all during troubleshooting, we would infer that the subject knew how to apply troubleshooting principles to the ECS configuration. The IHA performs similar inferences when it analyzes a user's actions and calculates when to give help and what type of help to give.

From the raw tutor usage data, we collected data to measure subjects' performance: the time they needed to solve a problem and the number of unnecessary part replacements. All data analyses are either are either calculations of time subjects needed to perform an action or counts of the number of times subjects performed a particular action (operate, inspect, test, or replace). Although not done in this experiment, another type of data analysis would be to look at patterns in the way subjects used the ECS Tutor. Such patterns could be measures of how quickly a user narrowed down the possibilities of component failures or how long a user continued to work on a problem after it was successfully solved.

A statistical analysis of the data did not indicate any significant difference in performance between the two experimental groups. The types of analysis performed on the data traces and the average values for the two groups are shown in **Table 8.2**.

Table 8.2 Average performance measures from the experiment

Measure	**With IHA**	**Without IHA**
Time needed to solve a problem (secs.)	377	423
Problems completed (of the first 9)	8.7	8.8
Unnecessary part replacements	2.1	2.9
Component inspections per problem	6.7	10.4
Component tests per problem	62.4	62.6
Page navigations	122	120
Times help was asked for	0.4	4.8
Times the FIM was used	37	27

As shown in the performance measures, there was little difference between the two groups. The last two measures seem to be statistically significant and require some explanation. The count of the number of times that a subject asked for help by clicking on one of the help buttons is much higher for the group without the IHA. This is because two subjects in this group each asked for help 18 times, thus skewing the average. (These two subjects were sitting next to each other but requested help mostly on different problems.) Of the other subjects in the non-IHA group, two asked for help only one time each, and the remaining four subjects did not request any help.

Figure 8.5 is a graph presenting the average group time the two groups took to complete each of the problems. Although the graph does not indicate whether the problem was solved correctly, only four problems of the total 150 were solved incorrectly. This data and other analyses show that the majority of students had little problem solving the problems. As would be expected, the first few problems took the longest, since the students were getting familiar with using the ECS Tutor. Similarly, for the measure of the number of times the FIM was used, two subjects in the non-IHA group did not use the FIM at all to solve the problems, thus pulling down the average. While the first anomaly in the data was probably due to personal cognitive styles, the second anomaly was most likely the result of a misunderstanding of the tutor's features.

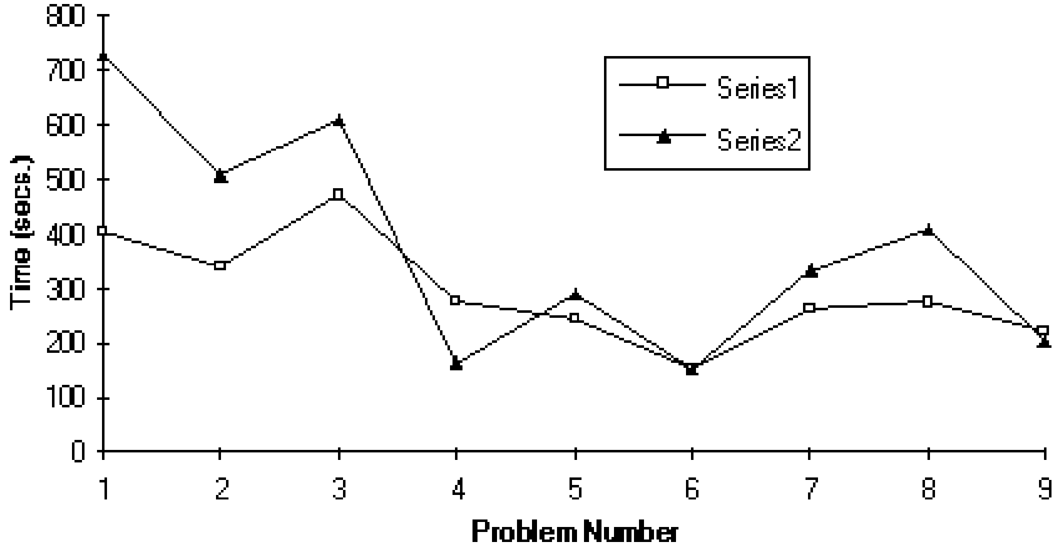

Figure 8.5 Average Group Time to Complete Each Problem

8.4.2 Poll Results

The poll contained nineteen questions about various aspects of the tutor. Questions were either general questions dealing with the tutor's usability and general behavior of the tutor or questions about several of the tutor's features of the tutor. Subjects were asked to rate their agreement with each statement, using the scale "agree strongly," "agree," "no opinion," "disagree," and "disagree strongly." The questions were equally mixed between positively and negatively phrased sentences. **Figure 8.6** shows the distribution of responses for the subjects in the individual-use group.

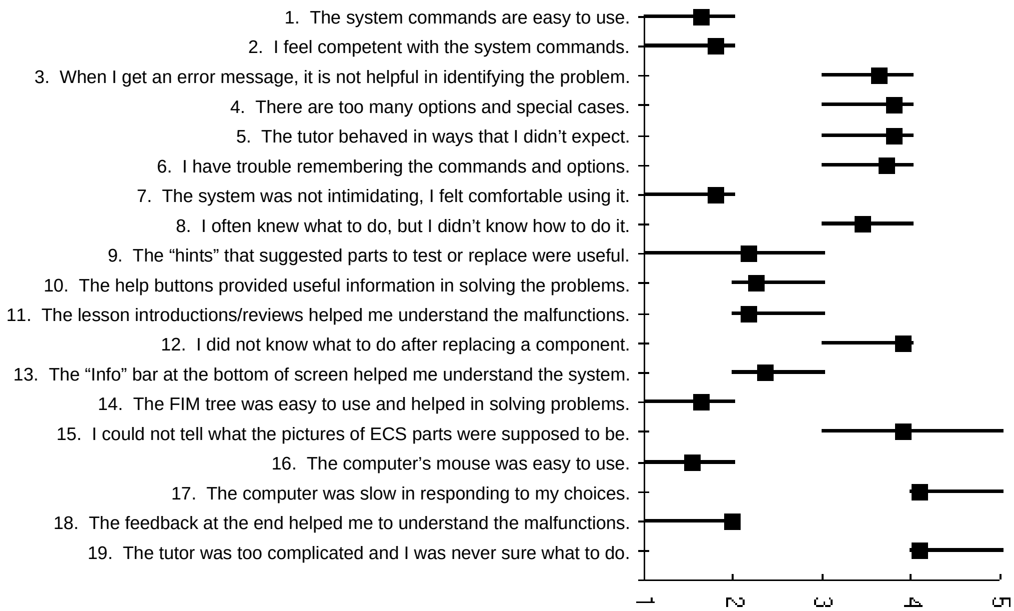

Figure 8.6 Distribution of Poll Responses

Overall, subjects' satisfaction with the tutor was high. No statistic for any of the nineteen questions indicated any weak points in the ECS Tutor. There were only two questions for which responses were not closely clustered. Question 9 asked if hints the tutor provided were useful; responses were spread between "strongly agree" and "no opinion." Question 15 concerned the resolution of the tutor's component pictures; responses were also more varied than for other questions. This issue is discussed in Sections 8.4.3.2 and 8.5.4.

These results can be compared with those from an earlier study done at Clayton State College. In the earlier study, the first fifteen questions of the poll used in this experiment were given to six subjects at Clayton State after they had solved two malfunction problems (Pearce 1993a). A comparison between the two evaluations indicates a more positive response to the current version of the ECS Tutor. This increased acceptance is most likely due to changes made in response to problems users pointed out in the early usability studies.

8.4.3 Post-Experiment Comments

The poll asked subjects to write down any comments not covered by the multiple choice questions. Only four subjects (of fifteen total) responded to this section. **Table 8.3** lists all of the subjects' written comments.

After the experiment was finished, several subjects told the instructor that their biggest problem using the ECS Tutor was to decide how much time to spend on each problem. Even though subjects knew that there were ten troubleshooting problems, the tutor gave no indication of how much time each problem should take. Some subjects rushed through the problems without spending much time to think about their actions. This comment and the written comments highlight several important issues that the researchers discovered during the evaluation.

Table 8.3 Written comments from the poll

1. Good training tool! I like it.
2. With more experience on the computer, the problems would have been easy to complete.
3. [I could not tell what the pictures of ECS parts were supposed to be] malfunctioned (damaged) HX was confused with dirty HX.
4. [I could not tell what the pictures of ECS parts were supposed to be] in the case of the heat exchanger problem.

8.4.3.1 Problems with Limited Computer Experience

Although there was only one written comment concerning confusion over how to use the ECS Tutor (number 2), the researchers observed that several subjects took more time than others to "become comfortable" with using the tutor. The subject who made the comment indicated that he had never used any type of computer before. It is understandable that it takes some time to acquire the hand/eye coordination necessary to use a mouse. The researchers did not have these problems in an earlier evaluation using computers with touchscreens.

8.4.3.2 Problems with Graphics Resolution

Subjects did not have problems understanding what was being displayed in the majority of the tutor graphics. However, as noted in comments 3 and 4, a graphic of one of the heat exchangers (HXs) caused some confusion for some subjects. The problem required the subject to determine if the HX was dirty and clogged. Since the tutor was designed to work on standard PC-compatible hardware, graphics were limited to 16 colors. This was not an issue for most of the equipment in the ECS Tutor, since the features that indicated the state of the components were well-defined. However, a clogged HX requires close inspection for dirt and other foreign objects and could not be adequately represented with the resolution used during the experiment.

8.4.3.3 Estimating Time Allocation

The ECS Tutor gives a user feedback on his or her performance on completed problems and also tells him or her how many problems are left in the current lesson. However, it does not estimate the time required to solve the remaining problems. Several students rushed through problems because they were concerned that they might run out of time. This problem of allocating time between problems is more pronounced in training than on the job. This arises in a simulated training environment, but not in actual job performance, because of "compressed time" a simulated environment presents to a user solving problems.

8.5 IMPLICATIONS AND RECOMMENDATIONS

This section covers the issues discovered during the ECS Tutor evaluation at Clayton State College and makes recommendations for future ITSs for AMT training.

8.5.1 Use of Intelligent Help

Before this experiment, the researchers expected that the ITS' intelligent help component would improve subjects' troubleshooting performance. This expectation was based on the assumption that giving a subject more information and feedback would help him or her perform a troubleshooting task. However, a statistical analysis of the data did not confirm this expectation, and the researchers found no statistically significant difference in the two groups' performance.

There are several possible explanations for this finding. Because of the small sample size involved in the experiment, individual differences were important in determining the average performance of the groups. An experiment with a larger sample size may find a significant difference in performance between the two groups.

Also, it may be that the troubleshooting task was not difficult enough for the intelligent help component to play a part in determining performance. The traces of tutor usage indicated that only four of the 150 problems (fifteen subjects with ten problems each) were not completed correctly. Of these four problems, there were two uncompleted problems in each group. No subject had more than one incomplete problem. These results may have been due to the large amount of help available to the subjects during troubleshooting. For an ITS to be effective, the problems have to be sufficiently hard for the users to make mistakes.

8.5.2 Ensuring Adequate Background Knowledge

The previous point highlights the importance of adequate background knowledge for troubleshooting performance. The students were given a thorough introduction to ECS configuration, function, and behavior and did not have to "hunt" for this information while using the tutor. If the students had not been given such an in-depth introduction, it is likely that error-driven help would have been activated more often and would have improved the performance of the subjects in the "with IHA" group.

Although most subjects did not use the intelligent help component, the three subjects who made enough mistakes to activate the IHA improved their performance as they gained experience in solving problems. There was a wide range in problem-solving times for the first few problems, but a much smaller range for the last few problems. Some of this variability is probably due to differences in computer experience, but other data indicate that at least some performance improvement was due to troubleshooting skills. For example, the number of unnecessary component replacements (the most expensive action in terms of time and money) was fairly constant as the students solved problems, even though the last few problems were more difficult than the first few. Subjects did not make increasingly more mistakes as the problems became harder; this result would indicate that they were improving their troubleshooting performance.

8.5.3 Usability of the ECS Tutor

Results of the post-experiment poll indicate that subjects had few problems using the ECS Tutor. No problems previously pointed out were raised during this experiment because feedback from previous usability studies led to improvements in the tutor's interface. For example, in the first Clayton State usability study, several subjects were confused by the "radio button" control on one of the screens used to select between the tutor's two modes of operation. Radio buttons are commonly used in software with graphical user interface. However, subjects who have not used such computers frequently do not understand what the radio buttons do until they have been explained. Rather than have the instructor explain radio buttons, it was easier to replace them with graphical toggle switches that the target audience easily recognizes and understands.

A user of a CBT program should be concentrating on the task, not on the actions required to operate the interface. It is important that the interface be as "transparent" as possible. When a user has to struggle to learn how to use a CBT program, it is unlikely that he or she will be able to solve the target problem or, more importantly, to remember what he or she did during the training session. Because we integrated the results of usability studies and user feedback, we minimized the problems subjects had in using the ECS Tutor.

8.5.4 Graphical Resolution

In designing the ECS Tutor, there was a tradeoff between providing high-quality graphics and producing a program that could function on a large number of computers. Because the number of computers in the aviation industry that support high-resolution graphics is small, it would make little sense to require that the tutor work only on high-end computers. The ECS Tutor was designed to work in the standard VGA mode common on most business computers. Standard VGA mode only supports 16 colors and is fine for displaying drawings and line art, but not good for displaying recognizable photographs.

For the most part, subjects had little problem recognizing or understanding the systems and components presented in ECS tutor pictures. Because the tutor concentrated on high-level cognitive skills (troubleshooting) instead of low-level psychomotor skills (recognition, coordination), few of the tasks required high-resolution graphics. However, in the case of the heat exchanger (HX), subjects had recognize that the HX in the picture was damaged. The user must be able to see fine irregularities in the component's structure, and it is difficult to show such damage with a small number of display colors.

There are several ways to address the problem of limited computer display resolution. Since recognition is not a major training goal of ECS Tutor, it is possible to add a text label saying that there is damage to the component being shown. This solution applies wherever damage recognition is not a problem with real components, as in the case of physical damage to a part. However, for cases where recognition is an important part of the task being taught, it is necessary to use higher-resolution graphics of the components with high-resolution computer monitors or, when fine detail is required, through a computer-controlled videodisk.

8.5.5 Providing Adequate Feedback

Because the purpose of a training system is to improve performance in terms of time, accuracy, cost savings, etc., for a particular task, it should be able to tell a user how well he or she is performing, and how well he or she is expected to perform. This feedback is needed so that the student can

- regulate performance
- make decisions about the need for further practice.

The ECS Tutor's IHA exists in part to support the second purpose; it tells a user when he or she makes diagnostic reasoning errors. The tutor provides feedback for performance regulation by telling users how many problems remain in each lesson and also approximately how much time their actions would take were they actually repairing an ECS. However, ECS Tutor does not estimate how much time a user should spend on each problem. Some subjects commented that they rushed through the problems and made mistakes they would not have made had they stopped to think about their actions.

Subjects' post-experiment comments point to the importance of providing users with adequate feedback. A training system should give adequate feedback to users and should also provide an estimate of how much time to spend on remaining problems. The consequences of not providing adequate feedback include users who do not learn that they do not understand something about a system and users who operate the training system improperly and do not learn what was intended. On the other hand, it is important that users not be given too much information while they are using an ITS because of problems of learning transfer from simple training tasks to complex real world tasks.

Improved feedback in the ECS Tutor would be helpful to future users. This could be done by providing an conservative estimate of how much time each problem should take (based on the user's computer experience) and providing a clock counting the actual time. The feedback screen should be designed so that the user does not confuse the real time with the simulated time. Since the user is learning how to troubleshoot, feedback should stress accuracy over speed until the user has learned enough to diagnose faults quickly. Several users also suggested that an "estimated cost" evaluation be added to the performance measures so that the student can learn about the costs of poor troubleshooting, e.g., replacing working parts.

8.6 CONCLUSION

One goal of this experiment was to measure the effectiveness of the ECS Tutor's Intelligent Help Agent (IHA). Our evaluation of the data did not find any statistically significant difference in performance between users with or without the IHA. The most likely explanation for this result is the small number of mistakes subjects made during the experiment. Because the IHA is error-driven, it was not activated enough to have a significant effect on subjects' performance. If the diagnostic task had been made more difficult (for example, by removing the FIM from the tutor), then the IHA would probably have had a more significant impact on subjects' performance.

The results of the experiment, data from the poll, and researchers' observations of the subjects point to significant issues for applying ITS to aviation maintenance training. The most significant outcome of this study is that the use of an IHA in a computer training system should be planned in the context of the rest of the training system. For example, subjects may not use an IHA if the task is too simple or if there are job aids decreasing the number of mistakes. Another finding is that subjects need adequate background knowledge both for the training task and the training software before they begin using the training software.

Results of the polls given during the experiment indicate that the ECS Tutor has evolved into a user-friendly training system. Through repeated usability studies with AMTs, we have been able to identify problems in the user interface and to make improvements. We also discovered that designers should consider the tradeoff between computer display resolution and system cost. Choices should be made in the context of the training the ITS is intended to provide; the required display resolution depends on how much picture detail is needed for adequate training. Finally, our last finding was that adequate, but not excessive, feedback maximizes the quality of training an ITS provides. Feedback should include how much time the student should spend on each problem and how well the student has solved the problems in terms of mistakes, simulated time, and cost.

8.7 References

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CHAPTER NINE
RELIABILITY IN AIRCRAFT INSPECTION: UK AND USA PERSPECTIVES

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9.0 ABSTRACT

In response to recent concerns about the reliability of aircraft inspection and maintenance procedures, the CAA and the FAA have been investigating human factors issues. Two investigators who had separately studied human factors in civil aircraft inspection undertook to study each others' jurisdictions to compare techniques and problems in the USA and UK. Aircraft inspection sites were visited jointly and separately in both countries, with an analysis made of the overall inspection/maintenance system and of larger floor operations.

The overall conclusion was that similarities were more common than differences due to the technical specification of the tasks, the regulatory similarities and the skill and motivation of inspectors. Differences between companies outweighed jurisdictional differences in many areas, suggesting that a common policy can be followed to improve such areas as visual inspection lighting, physical access to inspected areas, and the informational environment.

Larger differences were observed in the areas of work organisation and nondestructive testing (NDT), with sharing of experiences in both areas being possible for improved inspection reliability.

In the UK, the inspectors and maintenance technicians were closely integrated in the formal organisation, with inspectors often acting as supervisors for a maintenance team which performed the repair. In the USA, a more formal division existed between inspection and maintenance, with coordination usually through the supervisory levels. While both approaches are viable, both need better support for integration and communications. Training is needed in supervisory skills, as well as management structures and documentation which allow all concerned to obtain the information necessary to successful task completion.

In **NDT** operations there was a difference in emphasis between the two countries, with the USA more concerned with rule-based performance and the UK with knowledge-based. In addition, inspectors in the USA were less likely to be NDT specialists, performing both NDT and visual inspection, although changes are now occurring in this. Although both jurisdictions require both operating modes at different times, this fact is not well recognised. Hence, the training and documentary support for both levels is lacking, as is a clear indication of switching rules between the two.

With the increasing internationalisation of the aircraft maintenance industry, accelerated by well-publicised events with aging aircraft, differences may be expected to disappear over time. However, this should be a controlled process leading to utilisation of the best features of different jurisdictions if the full potential of inspectors within the system is to continue to be realised.

9.1 OBJECTIVES

The first objective of this study was to combine into a single concise document material collected jointly and separately by the investigators so as to highlight the similarities and differences in aircraft inspection between the UK and the USA.

The second objective was to draw any conclusions which would allow the transfer of techniques or information relating to human factors in aircraft inspection between the two systems to the benefit of airworthiness.

9.2 BACKGROUND

The application of Human Factors techniques to aircraft inspection is relatively recent on both sides of the Atlantic. A major 1981 UK study (Lock and Strutt, 1985) was not complemented by equivalent work in the USA until after the interest in continuing airworthiness spurred by the Aloha incident in 1988. Because of the commonality of interest in improving inspection reliability in the two jurisdictions, the FAA and the CAA signed a Memorandum of Cooperation in April 1990 to cover joint work in this field. This would build on the then-current human factors work in both countries, as well as various studies of structural mechanics and flight loads.

Since that date, M. W. B. Lock and C. G. Drury have been co-operating specifically on cross comparisons of USA and UK practice as part of their contract work with the FAA and CAA respectively. The aim was to take two scientists who had studied aircraft inspection from a practical viewpoint, but from different academic backgrounds, and have them jointly observe a number of inspection operations in both countries in addition to their other contractual observations. The disciplines of the two participants were complementary in that Dr. Lock is an applied physicist with a particular expertise in Non Destructive Testing (NDT) while Dr. Drury is a Human Factors (HF) engineer with a particular expertise in industrial inspection.

This report is intended to be complementary to the reports issued by the two participants separately as part of their contract work. These other reports are listed in Section 9.6. In particular, the site visit - based work described here is also referred to in the following reports:

1. **Human Factors in Aviation Maintenance: Phase One Progress Report.** FAA Office of Aviation Medicine, September 1991

2. **Inspection Reliability for Transport Aircraft Structures: A Three-Part Study: Part 1 Initial Investigations.** CAA Paper 90003, April 1990

3. **Inspection Reliability for Transport Aircraft Structures: A Three-Part Study: Part 2 The Current Situation.** CAA Draft Paper, May 1991

9.3 METHODOLOGY

A number of visits were undertaken by each participant in each country, either separately or together. There was no attempt at comprehensive sampling; rather the knowledge of each participant was used to select sites which would be illustrative of various features. For example, in the UK visits were made to specialist third-party **NDT** companies which serviced civil aviation as they represent a major source of NDT expertise utilised by some airlines.

At each site, the visit was divided into two sections, although these often overlapped in coverage:

Systems Overview: First the management of the maintenance of the site was probed in management interviews. The structure of the maintenance and inspection organisation(s) was elicited during discussions with managers, shift supervisors, foremen, and often with staff who were outside the line management structure. These could include training personnel, archive keepers, work card preparers, planners, and so on depending upon the initial discussions with management. The aim was to be able to write a short description of how the system **should** operate, and the management philosophy behind this system structure and functioning.

Hangar-Floor Operations: Detailed observations of the practice of inspection, and its organisational constraints, were made by following an inspector for all or part of a shift. As the inspector progressed through a job, questions were asked concerning the inspection itself and ancillary operations, such as spares availability from stores, or time availability for training. Thus a reasonably complete task description and analysis could be written on the inspection task itself, while obtaining information on the wider context of the inspector's job. This technique also allowed the collection of anecdotal recollections of previous jobs, and other events from the past. While these had an obviously lower evidence value than direct observation of task performance, they did provide a valuable adjunct to the data collection process.

Sites visited included major air carriers, regional or second-level airlines, repair stations and **NDT** companies. In addition visits were made to **FAA** and **CAA** personnel and to a Royal Air Force base where maintenance and inspection procedures are written.

9.4 RESULTS AND DISCUSSION

In this section points of difference between the two systems will be described for a number of areas judged by the authors to represent potentially transferable ideas. No attempt is made to compare the legal framework in the two countries, as this information is rather well known to the two regulatory bodies, and to most airline managements, often from direct international experience. Rather, the experiences and evaluations of the participants will be stressed to determine how the systems worked in practice.

When an area is presented, the points of similarity are discussed first, including any observations on the relative variability between and within countries. Next, the different features of each country's practice are presented. These sections establish the factual basis for evaluation and discussion of the importance of differences, needs for improvement in both countries, and any transferable features which could improve airworthiness. Conclusions from all of the areas are brought together in the final section.

9.4.1 Maintenance/Inspection Responsibilities

Both countries: Maintenance and inspection tasks are separated in a similar manner in both US and UK, both within the maintenance schedule and on the task cards at hangar floor level. Task cards are individually assigned to either maintenance technicians or licensed inspectors. Defects arising from the inspection, also termed non-routine repair (NRR), squawks or snags, are the subject of further cards which are raised by the inspector and, after rectification, signed off, or stamped off, by an inspector.

UK variations: The management structure of maintenance and inspection is usually closely intermeshed. In the past it was sometimes the case that the engineering manager and the quality control chief were the same person and, although this is not the case in large transport aircraft it can still be the case in smaller commuter airlines. Work arising from an inspection can be allocated to maintenance technicians by the inspector who is often also a supervisor, or by a senior person who has responsibility for both inspection and maintenance. The inspector is frequently consulted during the defect rectification, in some cases is the actual supervisor of that work, and will usually be the person to accept the repair.

US variations: The management structure of maintenance and inspection is separated up to a level well beyond the hangar floor. A wide variation of management authority was found whereby either of maintenance and inspection, or even planning, could dominate (Taylor, 1990).

In a few companies visited there was provision for some coordination between the two, by an engineer whose job was to ensure some cross talk. This person could also serve the function of shift change co-ordinator.

Work arising from an inspection is often allocated by a maintenance supervisor so that the inspector who raised the defect has no responsibility for defect rectification and may not be the inspector who does the buy-back inspection. Some airlines have an inspector specifically assigned to perform only buy-back inspections.

Evaluation: The separating of the management structure in the USA is dictated largely by the existing Federal Aviation Requirements. The notion of the need for checks and balances as an error reduction mechanism is deeply felt. At the hangar floor level the general view is that repair and maintenance would suffer if the maintenance technician knew that certain inspectors were 'buying back' the work, as some are thought to be less stringent than others.

The general view in the UK was that the system of having the same inspector responsible throughout for any particular defect and its rectification was preferable as the repair could be monitored at appropriate stages ensuring that the job had been performed correctly.

In the event of an inspection resulting in a significant repair being necessary, the supervisors of both maintenance and inspection confer with the inspector while, for a small item, the inspector alone assumes responsibility. There must be a point at which the inspector has to decide which of these two courses is correct, although supervisors on their own initiate a review of NNR cards with inspectors. The decision might depend variously on safety, cost, time etc. but the crossover point does not seem to have been well defined and was seen to vary considerably between companies.

9.4.2 The Supervisor/Inspection Dichotomy

Both Countries: The supervision of the aircraft maintenance technician (AMT) or mechanic is of primary importance. There is always the need for monitoring their output whether for quality or quantity. The responsibility for this supervision varies both from operator to operator and from country to country.

UK Variations: There is a tendency for the supervision to come largely from the inspectorate side in UK. Indeed, in many companies each inspector will be wholly responsible for a small team of mechanics and the jobs to which they are allocated. In any case it is common for the mechanic to be in close contact with an inspector during a job, especially if it is a defect arising from inspection.

US Variations: Due to the way that accountabilities are allocated, the American system divorces the inspection and maintenance responsibilities at hangar level although some coordination is still maintained. The system involves inspectors locating defects and raising the appropriate paperwork as in the UK, but then the responsibility for the job becomes that of the maintenance organisation and it is only after the repair is complete that the inspectorate are asked to re-inspect the area and 'buy-back' the completed job.

Evaluation: While the reasons for, and technical consequences of, the separation of responsibilities were covered in 1 (above), there are still issues of management and communications which need addressing. First it should be noted that the standards of repair deemed acceptable by the inspectors did not appear to differ between the two countries. An aircraft was judged safe when it not only met the written standards but also when, as many expressed it "the plane is safe enough for my family to fly in".

There are two sides to the question of whether the inspector should act as supervisor or have a team of mechanics. One has to weigh the advantages of having close communication between the inspector and mechanic against the continual interruption of the inspector's train of thought caused by requests to check current situation of a repair or for further work. Some companies use a leading hand (an long-experience mechanic) as an intermediary and in a large company, where there is sufficient work, this seems a good alternative.

It is rare for an inspector/supervisor to have any personnel-management training beyond a couple of days. The tasks to be communicated are frequently complex: the difficulty of scheduling and supervising several different simultaneous maintenance activities and the communication skills required to secure proper repairs should not be underestimated.

Not all tasks are straightforward or even repeats of those previously performed so that it will probably be quicker and more accurate for the mechanic to be informed directly by the inspector/supervisor than by documentation and a third party. However, freedom from the supervisory role enables the inspector to assume the role of final arbiter at buy-back.

If the potential difficulty with the UK system is in ensuring an ability to lead as well as inspect, the potential difficulty in the US system is with communication.

There is a need to communicate both within a single shift and across shifts between the following groups:

Inspectors

Maintenance technicians

Inspection management

Maintenance management

Quality control

Planning

Some of this communication is written, for example, in job cards and NRRs, and some is verbal. The quality of written NNRs had considerable variability between inspectors, between companies and between countries. In the US, this assumes more importance as not only the maintainer has to understand the NRR to carry out the (often complex) repair, but so must the buy-back inspector to ensure that the original fault has indeed been eliminated. Little formal training in written or verbal communication was seen. While formal coordinators were seen at some companies, and other companies were small enough that direct communication was inevitable, there is still a need for formal training of inspectors and maintenance technicians.

Inter-shift communications varied widely by company. Some had an informal talk between equivalent supervisors at shift change, some had a written checklist, while one company had a formal half-hour combined written report and tour of the on-going jobs by both supervisors. At the individual inspector and mechanic level, shift change ranged from merely receiving the supervisors' instructions to formal start-of-shift meetings. With many maintenance operations, and even some inspection jobs, covering multiple shifts, systems are needed to ensure that the complex communications required do indeed take place. It is vitally important that the incoming shift have complete information on the status of each repair/inspection. A failure of such information flow was recently cited as being causal in a recent accident in the USA.

9.4.3 Non Destructive Testing

Both Countries: The 1980's saw a large increase in the application of **NDT** to aircraft inspection practises and this rise has been continued. The situation is largely manufacturer-driven so that a similar situation exists in all maintenance/inspection shops.

In many applications, the bulk and weight of the **NDT** electronics box is such as to make location of it within easy visual range, difficult. More use of secondary visual or aural devices is required. Such devices are small repeater screens, LEDs on probes, and earphone systems (especially where the tone changes with the size of the ultrasonic or eddy current parameter).

UK Variations: Training is currently based on the PCN (Personnel Certification in **NDT)** scheme monitored by the British Institute of NDT and the industries it serves.

In the aircraft industry, training corresponds, in the main to PCN level 2, with the necessary endorsements, which allows the inspector to perform **NDT** tasks and to define new methods which are used subject to manufacturer's approval. Training to this level can be done in-house or through a registered and certified establishment specific to aircraft NDT. This is followed by a period of about 6 months on-the-job instruction.

A further grade, level 1, is also common which qualifies the technician to make go/nogo decisions. This is mostly used for simple MPI or Dye Penetrant examinations in the workshops.

Some effort is being made to ensure that the signatories for the operator under BCAR A8-6 are level 3, a supervisory grade.

US Variations: Here the reliance is on task-specific instruction, being a combination of teaching the techniques and general on-the-job training although some organisations do require ASNT level II certification. In essence, the training schedules and content are similar to the UK but without the outside qualifying body. This has resulted in widely differing depth and duration of the training. An especial example is that of impedance plane eddy current methods where training periods from a few hours to several days were reported to the authors by inspectors. In addition, airlines in the USA have typically had **NDT** as part of regular inspection duties, rather than having a specialist NDT department or section. This situation is now changing to some extent, with many operators establishing new NDT sections and others reverting back in some instances. There are regulatory moves towards creating uniform and separate NDT qualifications.

Evaluation: There are fundamental differences between visual and **NDT** inspection techniques. Foremost is the extra time spent setting up and calibrating the equipment, and the actual inspection can take considerably longer. Then there is the problem of validation of the techniques (i.e. do they find the defects as designed and with what reliability) as well as with confirming the actual defect found by NDT, which may take considerable maintenance time to uncover for visual confirmation. Also, NDT is used at times to confirm the extent of a visually-discovered crack.

Between the UK and USA are two major differences in philosophy, which can affect the practice of **NDT**. First, the UK assumes a what could be classified (Rassmussen, 1984) as a knowledge-based inspector, i.e. one who has a considerable depth of knowledge in the subject and who is expected to use such knowledge relatively frequently to solve problems from first principles. The USA inspector is more frequently expected to rely on **rule-based** reasoning, using well-learned and (reasonably) well- documented IF-THEN rules to complete the inspection. The distinction is one of emphasis rather than bifurcation, with the UK inspector having reasonable rules and the USA inspector having reasonable knowledge, but the difference does exist. Inspectors have to switch between these two levels of abstraction at appropriate times. Thus, both forms must be adequately supported by the system, for example by training, clear documentation, and explicit switching rules between the two. Both operating philosophies can be expected to produce reliable results under ideal conditions, but each has its characteristic errors. Knowledge-based reasoning is difficult to reproduce in different inspectors, and in the same inspector at different times, whereas rule-based reasoning can lead to inappropriate decisions if the situation does not exactly match the rules. One observation was made of an inspector mis-calibrating an eddy current device by setting the frequency in Mhz rather than in Khz, an error extremely unlikely for a knowledge-based inspector. Rule-based reasoning in complex systems is often characterised as "brittle", while knowledge-based reasoning allows more discretion, which can lead to errors when the reasoning, or the perception of the situation, is false.

Second in the differences of consequence is the distinction between specialist **NDT** inspectors and generalists, who perform NDT activities along with visual inspection when needed. The generalist has a broader knowledge of the particular aircraft and its recent history such as indications of wear or unexpected service conditions. Such an inspector is also able, and expected, to use well-practised visual inspection skills to observe areas around the site of the NDT inspection for other, non-NDT, indications. The specialist, on the other hand, can be expected to be recently practised in the NDT technique required at that instant, and also to have a broader and deeper knowledge of NDT methods as well as specific techniques. Such an inspector will have less of a problem of skill maintenance under long periods of disuse, and thus be less prone to the errors associated with lack of recent practice. A number of occasions were observed where a generalist inspector had to seek help from others who had performed the particular NDT inspection recently, as the instructions on the work card or in the manuals were ambiguous.

9.4.4 Bonding

Both Countries: In both countries there is a projected lack of trained inspection staff: indeed of all maintenance staff, (Shepherd, 1991). It is inevitable that there will be some movement of staff from one operator to another; this happens in all industries and is quite acceptable. However on occasions, when a new repair station is set up or an operator expands quickly, there have been as many as 100 maintenance staff 'poached' in a short time.

In an effort to stop this, many companies have implemented policies of bonding in one form or another. This usually takes the form of requiring personnel who are taking a training course to sign a declaration to the effect that they will not leave the company for a period of time, or that if they do they will repay a proportion of the training costs. The repayment is usually scaled from the full cost immediately following qualification and reducing, on a sliding scale, to zero after 1-3 years.

UK Variations: Only one company visited had a current bonding policy and that only asked for proportional repayments for lodging and travel etc. when they were on a course at another site. No training costs were included even though these could be as high as £40k. In only one case had this policy been implemented in recent memory and that involved the sum of under £2k.

Many other companies had such a policy and the main reason that they had abandoned it was that legal advice suggested it to be untenable and 'binding in honour only'.

USA Variations: In the USA, bonding is the rule rather than the exception at the engineering sites visited. In one company, staff were even bonded for a first-aid course.

Evaluation: In any industry a pool of skilled personnel is necessary. The time for inspectors to reach fruition is longer than for most skilled technicians and they therefore have a rarity value.

It is reasonable that employers should want to protect their investment in time and money. However, it is also reasonable that any person should be able to sell themselves freely in the market place.

Due to legal uncertainties, especially in the UK, it may no longer be realistic to bond employees but the industry needs a stable work-force. One solution offered to some industries in the UK was the government-sponsored training boards. Here, there was some sharing of training costs by an industry-wide levy which was redistributed to companies who provided training themselves.

It would act as a deterrent for mass poaching if the operators had a common agreement; perhaps not to have a general levy but to repay training costs if personnel changed employment. This could be done on a reducing scale, as in the bonding agreements.

It would do several things:

1. It would compensate the previous employer to some extent, and not penalise employers who run extensive training programs.
2. It would act as a deterrent to large poaching operations.
3. It would not prevent staff movement completely but would act as a brake on the recently qualified who are, as far as the operator is concerned, an important investment.
4. Abuse of the mutual repayment system might be thought to be a potential problem but withdrawal of cooperation when the abuser has an aircraft on the ground in need of parts could allay that.

Several managers with hangar responsibility have responded to this suggestion positively and said that they certainly consider paying compensation to get the right employee.

Job advertisements in the aeronautical press frequently mention bonding as one of the condition of employment. In view of the legal situation this should be discontinued.

The most appropriate source of actions on the above suggestions would be the representative groups such as IATA and ATA, rather than the regulatory bodies.

9.4.5 Working Times

Both Countries: Because of airline flight schedules being confined largely to daytime operations, it follows that much regular inspection and maintenance activity involves night work. Inspection in particular must precede maintenance in heavy checks, so that there is considerable pressure on the inspection department to complete the incoming inspection in a timely manner. This is usually achieved by a mixture of shift work and overtime.

UK Variations: In many maintenance organisations, shift work is allocated generally across the organisation, with rotating shifts and moderate use of overtime and weekend work, although inspectors still voice complaints about shift lengths and allocations.

US Variations: In many airline maintenance operations, shift work is allocated on the basis of seniority. Thus the bulk of the socially-unpopular night work is given to junior inspectors. Relatively high amounts of overtime are worked whenever an aircraft arrives for maintenance. At some sites an additional problem was caused by the maintenance site being located in an area whose housing costs are too high for maintenance and inspection employees, leading to long commutes, usually by private automobile due to the lack of public transport at shift change times.

Evaluation: Inspection work can involve constant alertness in the face of little stimulation, with some use of complex decision making. Both of these activities show degraded performance under conditions of sleep loss or disrupted schedules. To mitigate these effects despite a continuing requirement for night operations requires the detailed application of human factors knowledge relating to shift work (e.g., Schwarzenau et al, 1986). Shift workers rarely invert their body rhythms, so that a frequently-rotating system is to be preferred to one with long blocks of time on each shift. Because organisation of working time is so heavily influenced by social needs, the system used should be a simple as possible for predictability. Obviously, spreading night work over a larger population, rather than having some groups bid out of it, will minimise the overall effects of shift work, and prevent the concentration of experience onto the day shift. As with considerations of overtime, there are historical reasons for the current systems, so that any change will not be easy in organisational terms.

The situation is exacerbated by the lack of unanimity amongst workers: some preferring 12 hour shifts; others, night work etc. A solution involving rotating shifts or, at least, volunteering for the generally less popular shifts and some form of flexi-time might be attempted although the problems at shift-change could be too complex.

Overtime for inspectors is, in general, not a good idea from a strictly technical, human factors viewpoint. Data from laboratory studies shows decreased detection abilities with prolonged work, although degradation of decision performance in job operations is more difficult to document. When combined with long commutes involving active driving, there are also implications for worker safety at the end of an overtime period as well as for job performance.

9.4.6 Demand and Supply of Mechanics/Inspectors

Both Countries: The typical progression to inspector is from mechanic, so that the supply of inspectors is largely dependent upon the survivorship function of mechanics. With the increased demands for inspection, caused in part by aging aircraft (or continuing airworthiness) considerations, both supply of new inspectors and loss of existing inspectors are critical issues for the present and the future. Recent studies in the USA and Canada (Shepherd, 1991) have documented that a crisis may soon be reached.

UK Variations: Here the tradition has been to apprentice a school-leaver to a company to learn the job of mechanic, with CAA examinations and company examinations both being given at regular intervals throughout the apprenticeship. When mechanics are certified, after a certain time, and more training, they can be recertified as inspectors. Not all who are qualified are given inspection jobs, depending upon current employment opportunities within that company. Other ways of entry are via the services (RAF, Army, Navy), which accounts for a large proportion in some fields (e.g., up to half of **NDT** inspectors), and occasionally from the shop mechanics. Leaving is often to other airline companies (see Bonding above), but does occur to other industries at times. Pay is considered to be poor, but rarely poor enough to cause a move. The typical grumble is that the job status is not perceived highly outside the aircraft industry.

US Variations: Most mechanics attend an A&P School after leaving high school, to be trained at their own expense for approximately two years. The output from these schools has a high wastage (perhaps up to 50%) to other industries, such as automobile mechanic or dental equipment technician. There is some recruiting from the services, but the numbers are too small to provide a large fraction of inductees. At the same time, retirements are increasing due to previous cycles of hiring and freezing. Over the next ten years there is predicted to be a severe shortfall between the demand for mechanics and the supply, even with relatively optimistic assumptions about recruiting, retention, and productivity.

Evaluation: Apprenticeship schemes are starting in the USA after a considerable lapse, and are being revitalised in the UK after considerable recent neglect. Such schemes hold promise for increased supply, as trainees are paid during training, and have a strong company identity after certification. However, they represent a considerable cost outlay for the company; an outlay which may not always be repaid (see Bonding above). Joint ventures between companies, high schools and junior colleges have been tried with some success both in USA and Europe as a way to expose more people to careers in aviation. Similar schemes between companies and A&P schools are now under way, with results which appear to be encouraging. Low pay and poor working conditions must also be addressed. Pay rates in the starting jobs are particularly low. This is even more of a factor at the second-level companies, who are often considered as 'holding areas' for staff by the major carriers, leading again to a high rate of leaving in the industry.

Working conditions such as shift work, dirt, confined spaces, and lack of amenities can be changed only by action on many of the human factors points made in this and previous reports. Such conditions are not acceptable in the current market place, and indeed would not be tolerated by most of the office staff in many of the companies visited. If the mechanics who will become the inspectors are to be recruited and retained in sufficient numbers to ensure continued safety, the conditions will have to improve.

When inspectors rather than mechanics are considered, there are additional problems. If a mechanic chooses to become an inspector he will move from the top of the seniority levels in one group to the bottom in another. This often entails a reversion to an unpopular shift, and more isolation from the management function (who are often concentrated on the day shifts), before seniority in the new occupation is established. The inspectors studied for this report had all, by definition, survived these problems. Maintaining adequate future supplies requires similar studies of those who chose not to continue to inspector level.

The route into civilian inspection, especially for **NDT**, from a military background is unnecessarily difficult. A joint committee on training would benefit both parties: morale would be boosted for those in a service environment and the civilian sector could have a ready supply of personnel who would only need training in the company system.

9.4.7 Visual inspection and eye tests

Both Countries: Conditions for visual inspection varied greatly from operator to operator with a similar variation of the good, the bad and the ugly in each country.

The provision of lighting varied widely with respect to both hangar fixtures and portable sources.

Provision for ensuring that an inspector could actually see differed widely.

UK Variations: No mandatory eyesight test is required for visual inspectors except as part of the medical examination when entering the company. The situation varied from greatly from regular two-yearly tests to none at all. There seems a great reluctance for operators to finance this programme. **NDT** specialist inspectors are better served with mandatory examination being part of the annual requirement.

US Variations: All inspectors have regular eye tests (??as part of the FAA requirement??). Particular vision standards are defined, e.g., 20/25 Snellen (near) and 20/30 (distance). Colour vision is handled as part of the physical requirements.

Operators generally finance these tests either in their own medical centres or out-of-house.

Evaluation: Lighting within the hangar together with supplementary sources on docking and independent stands is usually sufficient to allow inspection of the outer surfaces of the aircraft. However these lights are frequently bright point sources which also reflect off the bare r painted metal surfaces of the aircraft. If an inspector glances at these, a mild form of arc eye may result from the direct or reflected glare. This degrades the acuity of vision and can take several minutes to revert to normal. Inspection quality during this time is greatly reduced. A greater number of less bright sources such as daylight fluorescents is recommended.

It must be a universal requirement for an inspector to be able to see. Without regular testing, the inspector may easily drift into inadequate vision. Gradual receding of the in-focus plane is all part of the aging process. An elementary test in the UK, (Lock & Strutt, 1985) showed there to be little or no correlation between the distance at which typescript could be read and whether an inspector had had a recent eye test or whether he wore glasses.

There is a reluctance on the part of the operator to declare an inspector unfit to continue inspection duties on the grounds of failing eyesight whereas they would not hesitate if the inspector was otherwise medically unfit.

9.4.8 Reporting imminent indications

Both Countries: (This is not an area where there are transatlantic differences but, if taken up it might have implications in both the UK and the USA.) During much inspection work there are occasions when some indication of a possible defect is seen. For visual inspection this is not easy to exemplify, but may take the form of incipient corrosion or slight rubbing. In **NDT** such an indication is much easier to define. Most techniques have a calibration step which sets a standard for defect reporting. In ultrasonics, for instance, this may be the height of the oscilloscope signal or simply a measured skin thickness. There is usually a substantial difference in these reportable indications and the perfect component or material appearance, in the visual case, or the background electronic noise for ultrasonics or eddy currents etc.

Evaluation: It would not take a great deal of effort for the inspector to make an official note of such a sub-reportable indication so that it could be appended to the task card on the next inspection check.

With the solid establishment of computer-enhanced task card preparation, this should present few problems. Corrosion initiation points might be detected early and the system would also provide a useful source of fracture mechanics data if, on a subsequent inspection, a crack were found.

Operators could utilise this information on all their aircraft and, if it proved useful in early identification of future trouble, it might be even be made a fleet-wide index. For any form of human inspection, feedforward information such as previously-reported sub-threshold defects, can substantially improve defect detection performance (Prabhu and Drury, 1991).

9.4.9 Work Cards, Information and Automation

Both Countries: The Work Card (also called Job Card or Task Card) is the primary command document for any inspection task. It is also the primary record of work performed, being signed and dated by the inspector and used as a reference for all Non Routine Repair (NRR) cards raised during its execution. As such, it must be well designed from the inspectors perspective if it is to be used without error. In both countries, many types of card were seen, with differing degrees of user-friendliness, and with differing levels of automation. Also the integration of the work card with other tools used by the inspector varied widely. Further information on the shortcomings of many work card systems can be found in Drury, Gramopadhye, and Prabhu, 1991 (see Appendix I). Hence specific instances are selected from our observations to show how improvements may be possible, rather than contrasting systems between countries.

UK Variations: One airline visited had a computer assisted method of job control and defect reporting which was of general interest. Work Cards had bar codes attached, as did inspectors badges. Thus to register that a job has started, the inspector swipes the bar code reader across the Work Card and across his badge. Then after inspection is completed, all defects arising are entered with a swipe of the work card, a swipe of the badge, and swipes of each of a set of defect bar codes located beside the reader. These defect bar codes have names and illustrations of the possible defects attached to them, and lead directly to computer generated NRRs.

US Variations: In two sites, the work card was integrated into a carrying case which also held the NRR forms, aircraft station diagrams, pens, and even mirrors. At one site the work cards were full size, approximately A4, while at the other they were smaller, approximately A5, with the carrying cases scaled appropriately.

Evaluation: Work cards will become more automated. Portable computers with multi-level task information have been proposed already (Reference 1). The advantages of automation are consistency, access to aircraft-specific information, and a less error-prone human interface. But automation must be undertaken correctly, or errors and frustrations will result. For example, work cards which were generated by early computer systems (still in use) have low quality dot-matrix printing, even in all capitals in places, leading to low legibility. Moves towards "good" automation need to be encouraged. Thus the use of named examples of defects on the bar code cards has the effect of reinforcing correct naming of defects. NRRs are then raised with the appropriate and correct names on them, reducing the possibilities of mis-interpretation by mechanics and buy-back inspectors. One can foresee the use of a portable computer containing the work card, with the ability to read bar codes from the aircraft structure to ensure correct location of areas for inspection, and built in defect menus keyed to the defect types possible in that inspection. Hypermedia formats can be applied to the presentation of knowledge and rules at multiple levels.

An integrated solution to the clutter of carrying the work card, other paperwork, and small tools is urgently required in many sites. Inspectors access the inspection area along ladders and scaffolds with their hands full of equipment, adding to the hazard of the task. One inspector entering a wing tank was observed as he removed items from his pockets, belt and hands to be able to fit through the access cover. There was a considerable pile of equipment resting on the wing after the removal was completed. New solutions need to be devised, of which the quoted examples are best considered as early prototypes.

9.4.10 Access

Both Countries: The modes of access for inspection of aircraft have been greatly improved in the past 10 years. This may be due to the fact that wide-bodied jets cannot be inspected standing on an oil drum or the top of a step ladder and that custom built docking is more efficient. Fortunately, this attitude has spread to smaller aircraft in a few companies although not down to the older aging aircraft such as the 707s and BAC 111s where the extra heavy engineering occasioned by the SSID programmes etc. render good docking most advantageous.

UK and US Variations: There are no essentially British or American variations although the closer and more frequent contact with the government inspectorate (HSE) in the UK than with the OSHA in the USA results in a safer environment with greater adherence to details such as toe-boarding and plank ends in scaffolds, and toxicity levels in composite repair work.

Evaluation: There is still a need for improved access. All establishments visited had examples of steps which were poorly designed or ed. Steps, mobile staircases and ladders vary enormously in quality and safety. Most have wide bases to avoid tipping and many have hand rails but there are still too many that tip easily, that are rickety with loose joints and that have wheels which do not lock. One otherwise sturdy staircase had only one wheel that was lockable and so moved around gradually during inspection; others could not be adjusted for foot height and rocked continually during inspection. The worst case involved steps that were ten feet tall with a top barely large enough for two feet so that the inspection of the fwd service door, an intricate enough task involving much torso movement to enable a close scrutiny of a complicated structure, necessitated one foot on the steps and the other on the aircraft.

On top of the wing, there is still an unwillingness to fence the perimeter yet the curve and camber of the wing make it a genuine danger where each succeeding step becomes the more hazardous.

Particular problems, such as production break inspection, can give rise to excellent access solutions: the arced bridges used being perfect for that particular job. However, they were extremely awkward when used subsequently for a horizontal lap joint.

The height of the platform is of some importance. The ideal eye position for visual inspection and **NDT** probe manipulation are not the same nor is that required for engineering work. There is also the need for a place to conveniently locate the NDT equipment itself. More adjustability in heights is required, preferably power driven from on board. It is very time wasting for the worker to demount to adjust the jack-up leading to the temptation to forego adjustment and work at a non-optimal height. Tailplane vertical surfaces are a particular case where this is required e.g., for manipulation and alignment of an Xray set outboard of the rudder. The popularity of the cherry-picker is due largely to the independence and variability of height and position even though it is frequently far from being a stable platform.

The most frequent problem, however, was simply of an insufficient supply of access equipment with inspectors and mechanics continually borrowing each others access stands. This wastes, time and effort, suggests to an inspector the company's lack of concern for the importance of the job, and may be the cause of an incomplete inspection due to either forgetfulness or exasperation.

Despite the plethora of access aids, the inspector will still find himself in spaces where access is difficult due to the overall aircraft design. Hatches can be too small to enter comfortably, internal spaces too small to allow for the focusing distance of the eye: if one is already holding a torch (flashlight) and a stick mirror then an additional magnifying lens becomes almost an impossibility.

Finally, the general clutter beneath and around most aircraft needs eliminating. This is generally a mix of portable work benches which can easily be moved or avoided and services such as air or electricity supplies which cannot. These trailing services are especially hazardous when they originate away from the aircraft bay e.g., the hangar walls and so hinder the movement of wheeled equipment, e.g., staircases. In some hangars, the services come from a central line below the aircraft belly and this is to be recommended as it alleviates much of the more hazardous clutter; service lines tending to remain within the footprint of the aircraft.

9.5 CONCLUSIONS

In this study, as in the previous studies of Appendix I, it was apparent that all concerned with civil aircraft inspection took their jobs most seriously, and had very high standards. Nevertheless, there are still areas for system improvement which can fully capitalise upon this highly motivated workforce.

Most of the system differences were found between individual companies rather than between the two countries. In any case, technical differences were few, as these are dictated by written regulations in each jurisdiction and circumscribed by the manufacturers' requirements for inspection tasks.

The main points raised in each of the results sections follow, arranged in the order of occurrence and not that of importance.

9.5.1 Maintenance/Inspection Responsibilities

The organisational position of inspectors could vary between the separation of inspectors from maintainers in the USA to the inspector serving as a maintenance supervisor in some UK companies. There are arguments in favour of each system with close integration of maintenance and inspection, especially through long tasks with multiple buy-back stages, weighted against perceived impartiality of a separate inspectorate.

9.5.2 The Supervisor/Inspection Dichotomy

Whether inspectors have supervisory responsibility or not, they require better support in the areas of communications (written, verbal), the organisation to support these communications, and, where appropriate, some interpersonal skills development. Training and systems modifications are needed to fully support these activities.

9.5.3 Non-Destructive Testing

In the **NDT** area, there was a difference in the depth of training and degree of specialization between the USA and the UK, with the UK inspectors required to have deeper knowledge and more specialization. Both countries require inspectors to use rule-based and knowledge-based behaviour, although to different extents. This should be realised and support in training, hardware, and documentation provided in both countries to enable inspectors to move easily and recognisably between the two modes.

With the advent of increased **NDT** use and much more complex systems, the current moves towards NDT specialists with at ASNT level II or PCN level 2 should be encouraged.

Equipment should be made more portable with greater use of repeater units in the same visual envelope as the probe elements in ultrasonic and eddy current techniques.

9.5.4 Bonding

In the UK, it is generally accepted that 'bonding' personnel to pay back all or part of their training costs on leaving a company is untenable in law. The practice is endemic in the USA and is universally disliked by the inspectorate force. The cost in terms of dissatisfaction probably exceeds the monetary considerations.

A replacement system, involving mutual cooperation and compensation by participating aircraft engineering companies could solve the major problems of poaching and uneven distribution of training costs. IATA or ATA or a similar body would be the best source of such an agreement.

9.5.5 Working Times

There is a great difference in the length and rotation of shifts in both countries. In the USA there is a greater tendency for the older inspectors to be given preference in a choice of shifts. The effect of this in companies where no shift-rotation occurs is often to condemn the younger, less experienced inspectors to nightwork with the concomitant difficulties of travel and social problems. This is especially significant for the married inspector with a family who, due to the high housing costs around many airport locations, has furthest to travel.

9.5.6 Demand and Supply of Mechanics/Inspectors

An upturn in demand caused both by expansion and retirement of the original generation of aircraft maintenance personnel has resulted in a resurgence of apprenticeship schemes in both countries. In the USA, the onus of training to AMT standard is on the worker whereas the UK route has been predominantly based on day-release to training centre or technical college.

Attraction of the high-grade personnel required could be improved by improvements in low starting pay, poor working conditions and a cessation of bonding.

An improved interface is recommended between military and civilian aircraft maintenance employment.

9.5.7 Visual Inspection and Eye Tests

There are no mandatory requirements in the UK or in the USA for annual checks of visual inspectors' eyesight to specified standards. USA operators tend to have an in-house requirement and this is frequently financed by the company. UK operators rarely have tests other than on initial entry into a company.

There is such a requirement for UK **NDT** personnel: there should be for all inspectors.

Hangar lighting is frequently insufficient, especially secondary, portable lighting. Fluorescent sources are to be preferred to bright, point-source bulbs which can cause unnecessary glare either directly or on reflection.

9.5.8 Reporting Imminent Indications

Where NRRs arise from a reportable level, there could exist a secondary reporting system for sub-reportable, but still visible, indications. This might be incorporated within the task card or some other computer system to act both as a highlight for future inspection, and a source of data for fracture mechanics analysis.

9.5.9 Work Cards, Information and Automation

Increased use could be made of computer-technologies in the near future to provide the inspector with enhanced on-line information of the task in hand. This might be implemented as a small portable computer indirectly accessing a company mainframe. The information could consist of a multiple choice level of presentation of the task description to suit the inspector's experience, the past history of that particular aircraft or of the relevant fleet statistics.

9.5.10 Access

There are no great regional differences in access provision. The problem area is for the older aging aircraft which is unlikely to have custom-built staging or docking and yet will be liable to extended structural inspection. Indeed, even the access stairs etc. available are frequently in very poor condition through age and neglect.

Services are centrally located under the fuselage more frequently in the USA, eliminating much of the problem of trailing wires, cables and hoses which can be a source of hazard in the movement of wheeled access platforms.

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CHAPTER TEN
GUIDELINES FOR DESIGNING AND IMPLEMENTING COMPUTER-BASED TRAINING FOR AVIATION MAINTENANCE

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10.0 ABSTRACT

This report is an bibliographic overview of selected issues in designing computer-based training (CBT) systems. It covers instructional design, information presentation formats, screen design and layout, and hardware issues. This report in the form of a bibliography for each of the relevant CBT design issues.

10.1 INTRODUCTION

Broadly defined, a computer-based training (CBT) system is a combination of computers and special software for training and education. Within this broad definition, there are many different approaches, systems, and technologies. Their common goal is to transfer skills and knowledge from an expert to the student via a computer system in such a way that the knowledge will develop and/or improve performance on a set of tasks. What differentiates a CBT system from traditional teaching methods is that CBT can be interactive, dynamic, and individualized. CBT does not require one-on-one interaction with an instructor. The computer program can be designed to simulate a piece of equipment, to react to user actions, and to provide appropriate feedback.

10.2 CBT SYSTEM DESIGN ISSUES

There are many decisions to make in designing and implementing a CBT system. The selection of approaches and technologies should be based on the organization's instructional needs and budget. This section describes factors that must be considered when creating CBT programs.

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10.2.1 Instructional Approach

Depending on the type of information and knowledge being taught to the student, there are usually several appropriate instructional approaches. For example, to teach the rules of the road, a standard present-and-test approach is appropriate. Actual driving (or a simulation) is appropriate for teaching the physical and coordination skills necessary for safe driving. Note that a CBT program may combine several of these elements.

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10.2.1.1 Linear/Tutorial Training

The linear training method of CBT presents the material in much the same way as a book. Users can "step" forward and backward through the material, and possibly jump to other topics and subjects. Linear training differs from a book in that the program can use multiple types of presentation methods, including graphics, audio, and video.

Bibliography:

Alessi, Stephen M., and Trollip, Stanley R. (1985). *Computer-based instruction: Methods and development*. Prentice Hall, Inc: Englewood Cliffs, NJ.

Black, J., Bechtold, J., Mitrani, M., & Carroll, J. (1989). On-line tutorials: What kind of inference leads to the most effective learning? *ACM CHI 89 Proceedings*.

Charney, D. H., and Reder, L. M. (1986). Designing interactive tutorials for computer users. *Human-Computer Interaction 2*(4), pp. 297-317.

10.2.1.2 Simulation-based Training

A simulation-based CBT system simulates some type of task through dynamic interaction. The software provides a realistic imitation of the necessary equipment and activities and behaves like the "real" world. For example, the CBT may require the student to troubleshoot a piece of equipment by inspecting, testing, and replacing its components.

Bibliography:

Harri-Augstein, S., and Thomas, L. F. (1984). Simulators which invite users into learning conversations. *Proceedings of IFIP INTERACT'84: Human-Computer Interaction*, pp. 785-793.

Hollan, J. D., Hutchins, E. L., and Weitzman, L. (1984) STEAMER: An interactive inspectable simulation-based training system. *AI Magazine*, *2*.

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Wiederholt, B.J., Norton, J.E., Johnson, W.B., Browning, E.J. (1992). *MITT writer and MITT writer advanced development: developing authoring and training systems for complex technical domains* (AL-TR-1991-0122). Brooks AFB, Texas: Air Force Systems Command.

10.2.1.3 Intelligent Tutoring

An intelligent tutoring system (ITS) mimics the instructional strategies of an instructor or domain expert. An ITS can give advice, provide feedback, and explain mistakes. By automating some of the assistance that instructors usually have to repeat several times, ITS can provide consistent training to a large number of students.

Bibliography:

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Norton, J.E., Wiederholt, B.J., and Johnson, B.J. (1991). Microcomputer intelligence for technical training (MITT): The evolution of an intelligent tutoring system. In *Proceedings of Conference on Intelligent Computer-Aided Training*.

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

10.2.1.4 Psychomotor Training

Psychomotor training is used to teach physical skills. The task being taught should require some sort of perceptual (usually visual or auditory) or complex motor skills. For example, a CBT system might be used to teach a technician how to operate NDI equipment. The limitations of current computer interfaces may require that special equipment be used to provide a realistic simulation of the actual environment.

Bibliography:

Gaines, B. R. (1972). The learning of perceptual-motor skills by man and machines and its relationship to training. *Instructional Science*, *1*, pp. 263-312.

Lintern, G. Augmentation feedback for perceptual-motor instruction. Paper presented at meeting of the American Psychological Association, Montreal.

10.2.2 Information Presentation Formats

The training and instructional analysis provides a functional description of what information the CBT must provide to users. Presentation media affects a CBT's cost so the media should be selected based on instructional criteria, rather than any aesthetic judgements or preferences.

10.2.2.1 Text

Text is the most common CBT presentation format, since all computers support text. Text can be used to identify and describe processes, objects, and procedures. Designer should:

- Limit word use, be clear
- Use large fonts and readable colors

Bibliography:

Bieger, G.R. and Glock, M.D. (1986). Comprehending spatial and contextual information in picture-text instructions. *The Journal of Experimental Education*, *54*, 181-8

McTyre, J.H., and Frommer, W.D. (1985). Effect of character/background color combination on CRT character legibility. *Proceedings of the Human Factors Society, 31st Annual Meeting,* 779-781.

10.2.2.2 Graphics

When a CBT program needs to show what a piece of equipment looks like, or how a system is organized, a graphic is the best presentation method. Graphics can be pictures or line drawings of equipment or schematics showing connectivity and functionality of components. Designers of CBT systems should:

- Make as simple as possible and do not show unnecessary objects
- Consider display resolution of computers

Bibliography:

Hovy, E. and Arens, Y. (1990). When is a picture worth a thousand words? - Allocation of modalities in multimedia communication. *AAAI Symposium on Interfaces at Stanford*.

Meyer, G.W., Rushmeier, H.E., Cohen, M.F., Greenberg, D.P., Torrance, K.E. (1986). An experimental evaluation of computer graphics imagery. *Association of Computing Machinery Transactions on Graphics*, *5*(1), pp. 30-50

Verplank,W.L. (1988). Graphics, challenges in designing object-oriented user interface. In *Handbook of Human Computer Interaction*. North Holland: Elsevier Science Publisher B.V., New York, NY.

10.2.2.3 Animation

An animation can be used to explain a process or to demonstrate the steps of a procedure. Examples include animations of flows in electrical and hydraulic systems and animations of the installation procedure for an avionics component. Designers should:

- Makes the program more engaging
- Do not make longer than necessary

Bibliography:

Palmiter, S., Elkerton, J. and Bagget, P. (1991). Animated demonstrations vs. written instructions for learning procedural tasks: A preliminary investigation. *International Journal of Man-Machine Studies, 34,* 687-701.

Park, O. and Gittelman, S.S. (1992). Selective use of animation and feedback in computer-based instruction. *Educational Technology Research and Development, 40(4),* 20-38.

Rieber, L.P. (1990). Animation in Computer-based instruction. *Educational Technology Research and Design, 38(1),* 77-86.

10.2.2.4 Audio

Audio, including narration, equipment sounds, and musical accompaniment, is used to add realism, increase entertainment factor, or communicate long text passages. Designers should:

- Not overuse; have a reason for using it
- Allow user to control volume, turn off

Bibliography:

Bly, S. (1982). Presenting Information in sound. In *Proceedings of Human Factors in Computer Systems*, 371-375.

Sorkin, R.D. (1987). Design of Auditory and tactile displays. In G. Salvendy (Ed.) *Handbook of Human Factors*. New York: John Wiley & Sons, 549-576.

10.2.2.5 Video

Like animation, video can be used to describe a process or to show a procedure. Video differs from animation in that it is a more accurate representation of the "real world" and usually has an accompanying soundtrack. Since video is more realistic than animation, it is usually better for describing procedures such as test or installation steps that a technician will perform on the job. Computer system designers should:

- Give user control over playback
- Match purpose with video quality

Bibliography:

Fritz, M. (1993, January). Is interactive videodisc dead yet? *CBT Directions*, pp. 24-32.

Pearce, M. (in press). How much is enough? Choosing a computer-based video technology. In *Proceedings of the Second Annual Conference on Multimedia in Education and Industry*.

Silber, J. (1992, May/June) FlightSafety and the DVI medium. *Instructional Delivery Systems,* pp. 9-13.

Singh, R. (1986). Interactive video in education and training. In K. S. Gill, (ed.) *Artificial Intelligence for Society*. Chichester etc.: Wiley, pp. 229-234.

Swartz, M., Wallace, D., and Tkacz, S. (1992). The Influence of frame rate and resolution on human performance. In *Proceedings of the Human Factors Society 36th Annual Meeting*, pp. 1440-1444.

10.2.3 Screen Design and Layout

This section describes the issues involved in designing and laying out information on the computer display.

Bibliography:

Engel, S.E. and Granda, R.E (1975). Guidelines for man/display interfaces (Technical Report TR 00.2720). Poughkeepsie, NY: IBM

Helander, M. G. (1987). Design of visual displays. In G. Salvendy (Ed.) *Handbook of Human Factors.* New York: John Wiley & Sons, pp. 507-548.

Sewell, D.R., Rouse, W.B., and Johnson, W.B. (1989). Initial evaluation of principles for graphical displays in maintenance problem solving (Tech REpt. No. ST-TR-8817-001). Atlanta, GA: Search Technology.

Smith, S.L. and Mosier, J.N. (1986). Guidelines for designing user interface software (Technical Report ESD-TR-86-278). Hanscom Airforce Base, MA: USAF Electronic Systems Division.

Tullis, T.S. (1988). Screen design. In *Handbook of Human Computer Interaction*. North Holland: Elsevier Science Publisher B.V., New York, NY, 377-407.

10.2.3.1 Screen Organization

Screen organization is important to the for the users to be able to quickly understand any computer screen. There is no one "optimal" design for any particular tasks, although there are many features that can decrease the quality of a screen. Designers should strive for consistency within each program and between other programs.

Bibliography:

Galitz, W. O. (1985). *Handbook of screen format design*. Q. E. D. Information Sciences, Wellesley, MA.

Helander, M. G. (1987). Design of visual displays. In G. Salvendy (Ed.) *Handbook of Human Factors*. New York: John Wiley & Sons, pp. 507-548.

Tullis, T.S., and Helander, M. (1988). Screen design. *Handbook of Human-Computer Interaction*. North-Holland, New York, NY, pp. 377-411.

10.2.3.2 Color

Color is extremely useful for dividing a display into separate regions. Also, color differences will be useful in a visual search task for particular items, provided the user knows about the differences in advance. A minimum number of colors should be used, because a large number of colors for coding will increase the search time. Motivational effects of coloring display are complex, no firm recommendations can be made. However, it is noticed that viewers do express a preference for color even when it does not objectively improve their performance.

Bibliography:

Christ, R. E. (1975). Review and Analysis of color coding research for visual displays. *Human Factors, 17(6)*, 542-570.

Davidoff, J. (1987). The role of color in visual displays. In D.J. Osborne (Ed.), *International Reviews of Ergonomics, 1*, 21-42.

Murch, M. M. (1984). Physiological principles for the effective use of color. *IEEE CG & A*, November, 49-54.

Thorrel, L.G. and Smith, W.J., (1990). *Using Computer Color Effectively*. New Jersey: Prentice Hall.

10.2.3.3 Typography

Typographic design has the goal of making text readable and understandable. When displaying text on a computer, there is a tradeoff between limited screen space and legibility of the fonts. Designers should consider the target users, computers, and environment when designing a text display.

Bibliography:

Marcus, A., "Typographic Design for Interfaces of Information Systems, *Proceedings of Human Factors in Computer Systems*, 1982, pp. 26-30.

Van Nes, F. L., (1986). Space, colour and typography on visual display terminals. *Behaviour and Information Technology*, *5*(2), pp. 99-118.

10.2.3.4 Evaluation and usability

Evaluations are necessary to determine if any changes are needed to fulfill the goals of the CBT system, and to provide data for future CBT systems. In the first case, the evaluation examines the instructional features of the CBT system and how the students use the system. In the second case, the goal is to use what was learned during the design and implementation of one CBT system to assist in the creation of other CBT systems.

Bibliography:

Jeffries, R., Miller, J. R., Wharton, C., and Uyeda, K. M. (1991). User interface evaluation in the real world: A Comparison of four techniques: Practical design methods. In *Proceedings of ACM CHI'91 Conference on Human Factors in Computing Systems*, pp. 119-124.

Kearsley, G. (1982). *Costs, benefits, and productivity in training systems*. Reading, MA: Addison-Wesley Publishing Company, Inc.

Maddox, M.E., & Johnson, W.B. (1986). Can you see it? Can you understand it, does it work? An evaluation plan for computer-based instruction. *Proceedings of the International Topical Meeting on Advances in Human Factors in Nuclear Power Systems* (pp. 380-389). LaGrange, IL: American Nuclear Society.

Sewell, D.R. and Johnson, W.B. (1990). The effects of rapid prototyping on user behavior in systems design. *Journal of the Washington Academy of Sciences*, *80*(2), 71-89.

10.3 HARDWARE ISSUES

This section describes some of the issues involved in choosing hardware to support CBT hardware. The selection of hardware should be driven by the type, amount, and quality of media necessary for instruction.

10.3.1 Computer Display Quality

The computer monitor and the video adapter card work together to display the text, graphics, and video that the PC generates. There are several dimensions along which the adapter/monitor combination can vary, including resolution of the video adapter, size of the monitor, and the number of colors. The appropriate combination depends on the type of data the CBT displays. For programs that display only text, the lower resolutions are appropriate. If a program displays graphics, video, and animation, then higher-end equipment is necessary.

Bibliography:

Harpster, J. L., and Freivalds, A. (1984). VDT screen resolution and operator performance. In *Proceedings of IFIP INTERACT'84: Human-Computer Interaction*, pp. 91-95.

Snyder, H. L. (1988). Image quality. In M. Helander, *Handbook of Human-Computer Interaction*. New York: North-Holland, pp. 437-474.

10.3.2 Input Devices

An input device is a computer peripheral that allows users to enter data into the PC. The most widely known input device is the keyboard which allows users to enter text. However, most training approaches and tasks do not require users to enter large amounts of text. Keyboards are not widely used in the newer CBT systems since it is easier to interact with the computer through a "selection" device such as a mouse, touchscreen, or light pen.

Bibliography:

Card, S.K., English, W.K., and Burr, B.J. (1978). Evaluation of mouse, rate-controlled isometric joystick, strap-keys, and text keys for text selection on a CRT. *Ergonomics, 21*, 601-613

Greenstein, J.S., and Arnaut, L.Y. (1988). Input devices. In *Handbook of Human-Computer Interaction*. North-Holland, New York, NY, pp. 495-519.

Greenstein, J.S., and Arnaut, L.Y. (1987). Human factors aspects of manual computer input devices. In G. Salvendy (Ed.) *Handbook of Human Factors*. John Wiley & Sons, New York, pp. 507-548.