

# **Phase IV Progress Report (1995)**

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# 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 ENhancement 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.

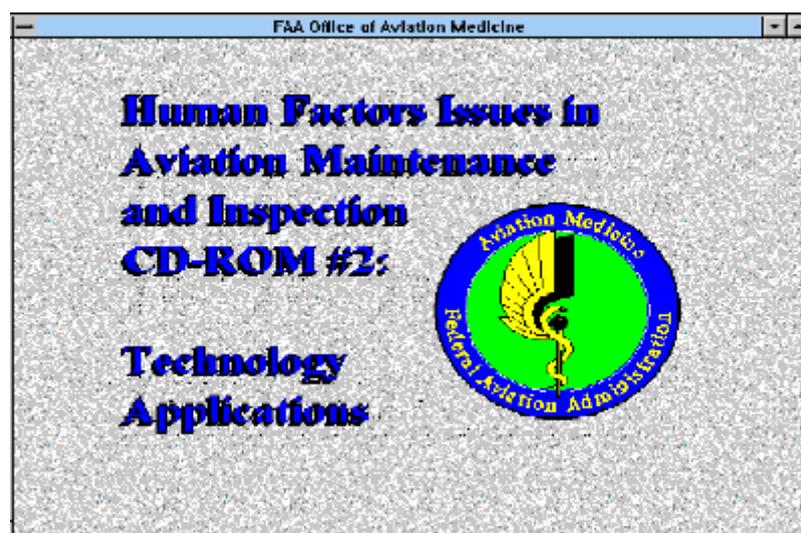
#### 1.4 INVESTIGATION OF ERGONOMIC FACTORS RELATED TO POSTURE AND FATIGUE IN THE INSPECTION ENVIRONMENT (Chapter Five)

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 NONDESTRUCTIVE 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:

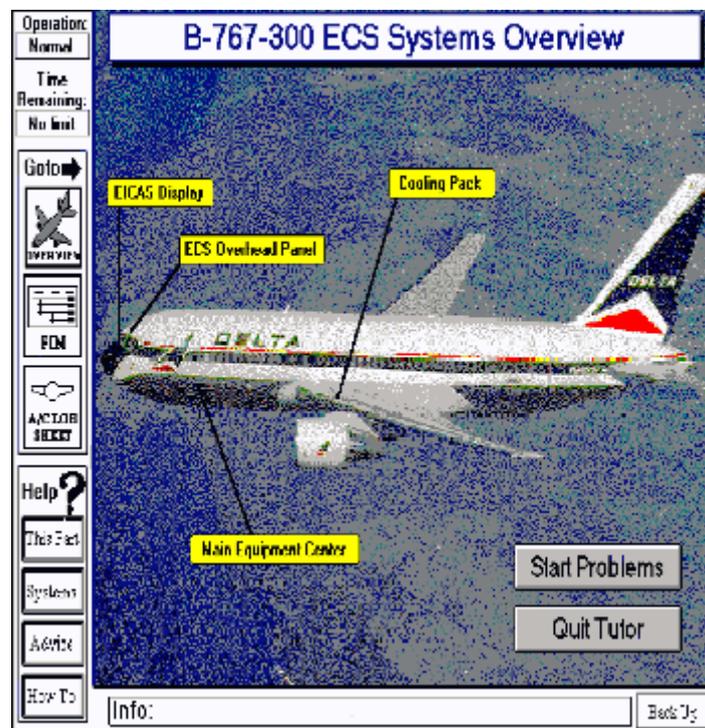
- Boredom Susceptibility
- Concentration/Attentiveness/ Distractibility
- Extroversion/Impulsivity
- Motivation/Perseverance
- Decision Making/Judgement
- Mechanical/Electronics Aptitude
- Need for Autonomy

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

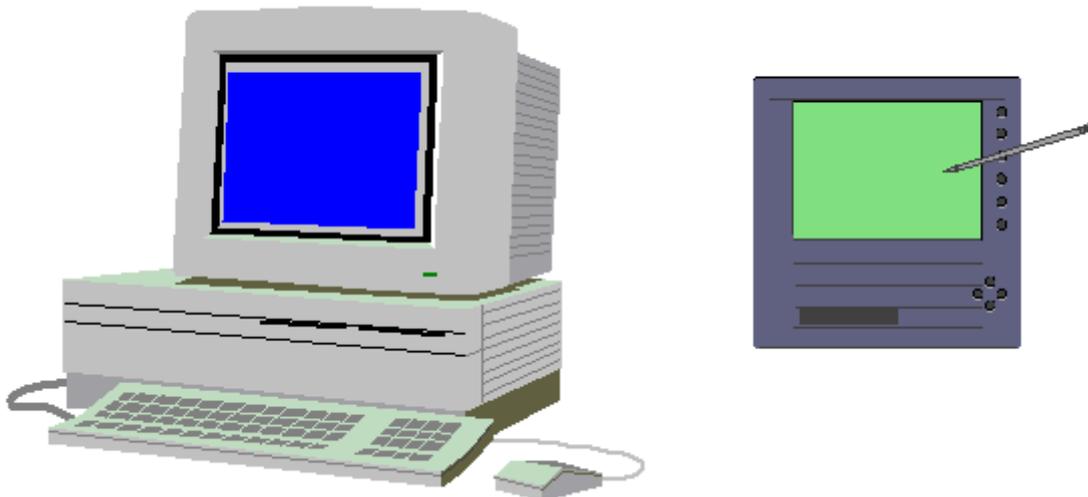
*Charles F. Layton, Ph.D.*  
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### 2.1 PENS: A PERFORMANCE ENHANCEMENT SYSTEM

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 than 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	486/25 Mhz CPU	386/25 Mhz CPU	486/25 Mhz CPU
200 Mb Hard Drive	80 Mb Hard Drive	200 Mb Hard Drive	120 Mb Hard Drive
Built-in Keyboard	Separate Keyboard	Separate Keyboard	Built-in
Pen	Pen	Pen	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 than 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 applications

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 significant 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:

#### Section I

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

Aircraft Graphic

Help

Save

Save Verify

Open

New

Exit

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

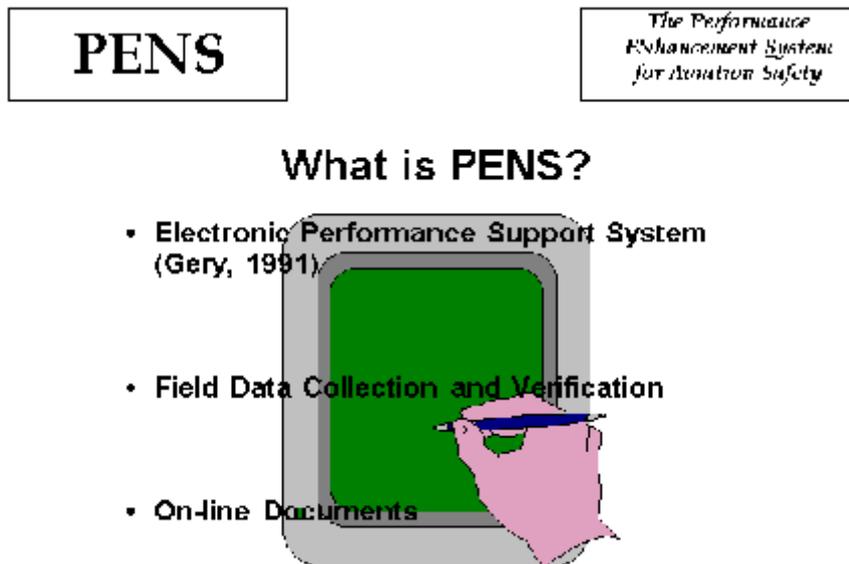
Delete

## Appendix 2-B Training Slides

### Training Slide 1



Training Slide 2



Training Slide 3

<b>PENS</b>	<b>PENS Timetable</b>		<i>The Performance ENhancement System for Aviation Safety</i>
1993	1984	1995	
<ul style="list-style-type: none"> <li>• Field Evaluation of Airworthiness Prototype</li> </ul>	<ul style="list-style-type: none"> <li>• Complete Airworthiness and Avionics PENS</li> <li>• Prototype Operations PENS</li> <li>• Field Evaluation of Operations Prototype</li> </ul>	<ul style="list-style-type: none"> <li>• Complete Operations PENS</li> <li>• Prototype General Aviation PENS</li> <li>• Field Evaluations of General Aviation Prototype</li> <li>• Complete General Aviation PENS</li> </ul>	

Training Slide 4

<b>PENS</b>	<b>Schedule Day One</b>		<i>The Performance ENhancement System for Aviation Safety</i>
	<ul style="list-style-type: none"> <li>• Demo</li> <li>• Background Information</li> <li>• Introduction to Computer</li> <li>• Windows Tutorial</li> <li>• Windows Practice</li> <li>• Pen Computer Tutorial</li> </ul>		

Training Slide 5

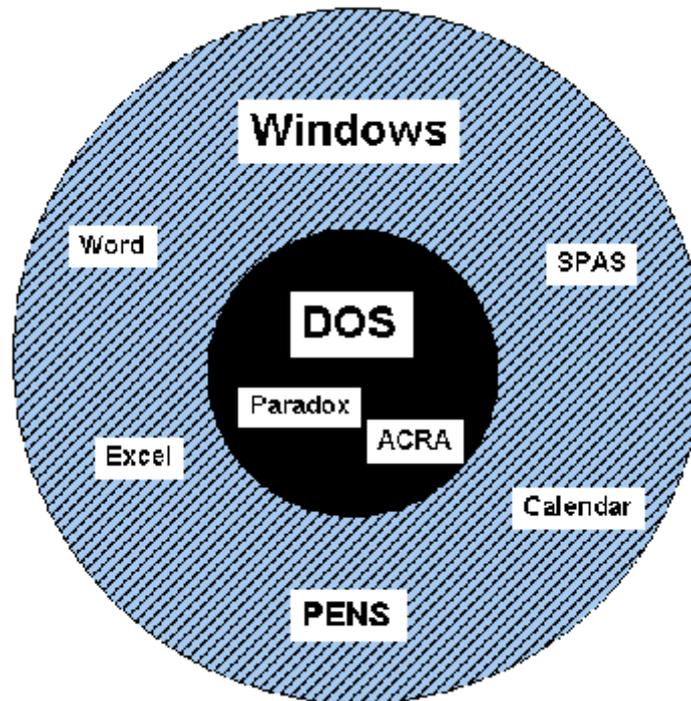
**PENS****Schedule  
Day Two***The Performance  
Enhancement System  
for Aviation Safety*

- **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.**

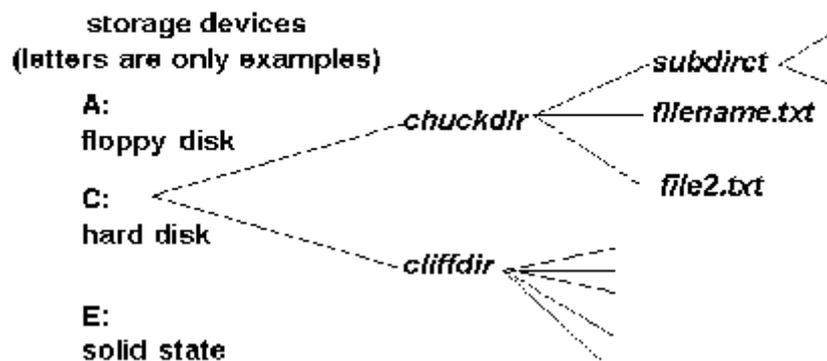
Training Slide 9

# DOS

- ◆ Stands for: *Disk Operating System*
- ◆ 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 software 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 environment.
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**

**Open Existing Form**

Form ID#	Activity	FAR	WPG	Desig	Make/Model	Callup	Status	Results
9400008	3512	65			ACRDR-100		C	A
9400009	3627	135	PRPA		MA-B19		C	A
9400010	3512	65					C	C
9400011	3512	65					C	A
9400012	3731	135		IXYA			C	A
9400013	1312	121		ABYA			C	C
9400014	3512	65					C	C
9400015	3312	135	PRPA				C	C
9400016	3920				AERMER-FBL		C	C
9400017	1511	63			T-11		C	C
9400018	3419	91			T-11		C	C
9400019	5540	65			MA-B25		C	C

Activity:    FSAS

Designator:    Temporary

Start Date:  /  /

Stop Date:  /  /

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 information is required for the activity (detailed instructions for completing the form are provided in each section).

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

Section II: Used for recording information 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 all 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

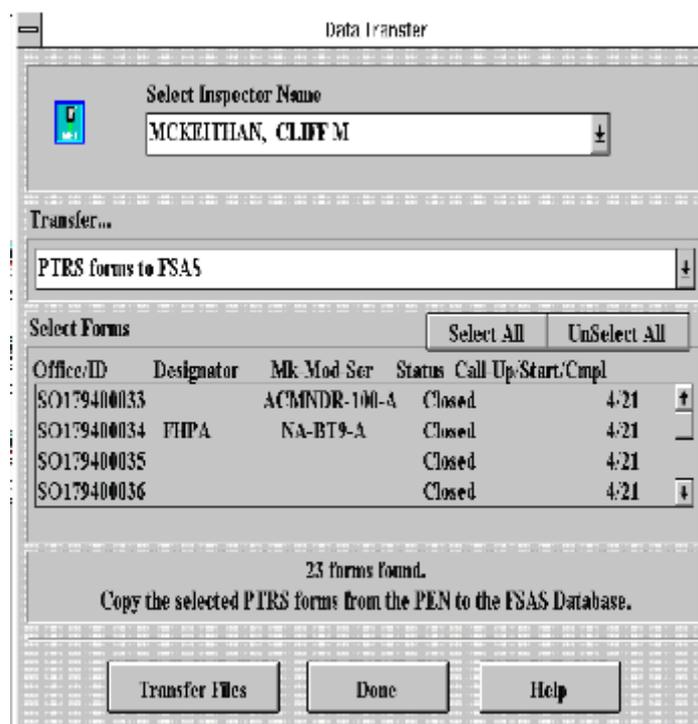
Utility Screen.

## 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 transfer 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 for 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 portion 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 occurrence 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 standard typeface

#### 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 described differently
- B. Graphic Information
- system unsupportive of graphics
  - spatial information conveyed through text, resulting in the use of complex, lengthy sentences that are d

#### 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, methods, etc.
  - directive information is not broken up into command verb, objects, and action qualifiers
  - directive information includes more than two or three related actions per step
  - 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 information
  - 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 inspection without the workcard, relying only

**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., in both text and graphics
  - 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 information on spatial location
  - 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 described differently
- B. Graphic Information
- no figure numbering, even though the workcard refers to specific figure numbers, interpretation
    - no consistent layout of figures, use of mixed layout with no demarcation
    - no consistency in view directional information, e.g., use of both UP-AFT & UP-FWD
    - non-contextual figure views, or views as the inspector sees it, just perspective part drawings
  - no information to aid in spatial location of parts
    - no back references to the workcard page/task which refers to the figure
    - improper usage of technical drawing terms, e.g., "section" and "view" are used interchangeably
    - no typographic differentiation between: figure titles, part names, crack locations, notes, etc.
    - no use of standard drawing conventions, e.g., location of sectional views
    - same graphics for both left and right wing tasks, mentally inverting the figures causes high cognitive w
    - some figures use high fidelity graphics, causing confusion and clutter
    - no consistency of scaling graphics, close-up views not differentiated from distant views

##### 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, methods, etc.
    - directive information is not broken up into command verb, objects, and action qualifiers
    - directive information includes more than two or three related actions per step

- 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 information
  - 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 inconvenience in usage
- 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 information
  - Provide a link backtrack option
  - Provide an UNDO option for navigation
    - Make linking explicit; do not leave anything to exploration or browsing
  - 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 varied us
  - Follow a pen-centric 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 format
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 everything for task
- Readability of graphics    •Separating information by frequency of use
- Ease of understanding information    •Flexibility of use
- Ease of understanding symbols/icons    •Ease of referring to attachments or manual
- Chance of missing information    •Often confused about location
- Degree of interest    •Often confused about how to return to previous location
- Degree to which rater would like to use workcard again    •Degree of fatigue after using the system
- 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	Significance of Current Paper-based		Significance of New Paper		
	9 point Rating Scale	End Points	Workcard Versus	vs. Computer Workcard	
0 8 New Computer Paper Workcard Workcard					
Readability of text	Terrible	Excellent	0.031	0.025	n.s.
Task of reading	Very difficult	Very easy	n.s.	0.025	n.s.
Ease of understanding	Very difficult	Very easy	0.025	0.01	n.s.
Amount of information	Too little	Too much	n.s.	n.s.	n.s.
Information covered everything for task	Disagree fully	Agree fully	0.025	0.005	n.s.
Tasks were well organized	Disagree fully	Agree fully	0.031	0.005	n.s.
Effort required in locating information	Very difficult	Very easy	0.005	0.005	n.s.

Consistency of organization	Terrible	Excellent	0.025	0.025	n.s.
Separating information by frequency of use	Terrible	Excellent	0.025	0.025	n.s.
Chance of missing information	Always	Never	0.025	0.005	n.s.
Flexibility of use	Terrible	Excellent	0.031	n.s.	n.s.
Ease of physical use	Very difficult	Very easy	0.025	0.01	n.s.
Ease of referring to attachments or manual	Very difficult	Very easy	0.005	0.005	n.s.
Ease of writing up an Accountability List	Very difficult	Very easy	0.01	0.025	n.s.
Ease of writing up a Non-Routine	Very difficult	Very easy	0.025	n.s.	n.s.
Degree of interest	Very boring	Very interesting	0.01	0.005	0.025
Degree to which rater would like to use W/C again	Definitely not	Definitely yes	0.01	0.01	0.025
Degree to which W/C like these should be used	Definitely not	Definitely yes	0.01	0.025	n.s.
Overall ease of usability of W/C	Terrible	Excellent	0.025	0.005	n.s.

### 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 (Drury and Loc

TASK DESCRIPTION	VISUAL EXAMPLE	NDT EXAMPLE
1. Initiate	Get workcard. Read and understand area to be covered. Calibrate.	Get workcard and eddy current equipment.
2. Access	Locate area on aircraft. Get into correct position. equipment.	Locate area on aircraft. Position self and equipment.
3. Search	Move eyes across area systematically.	Move probe over each rivet head. Stop if any indication.
4. Decision-Making	Examine indication against remembered standards.	Reprobe while closely watching eddy current trace.
5. Respond	Mark defect. Write up repair sheet or if no defect, return to search.	Mark defect. Write up repair sheet, or if no defect, return to search.
6. Repair	Drill out and replace rivet.	Drill out rivet. <a href="#">NDT</a> on rivet hold. Drill 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.

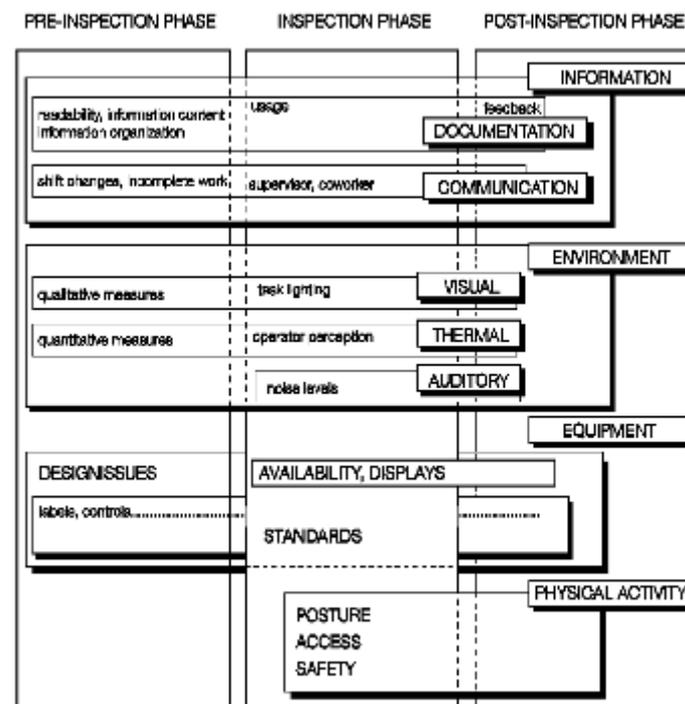
With these features in mind we designed the audit system described in the following section.

### 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 preinspection, 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  $X^2$  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.

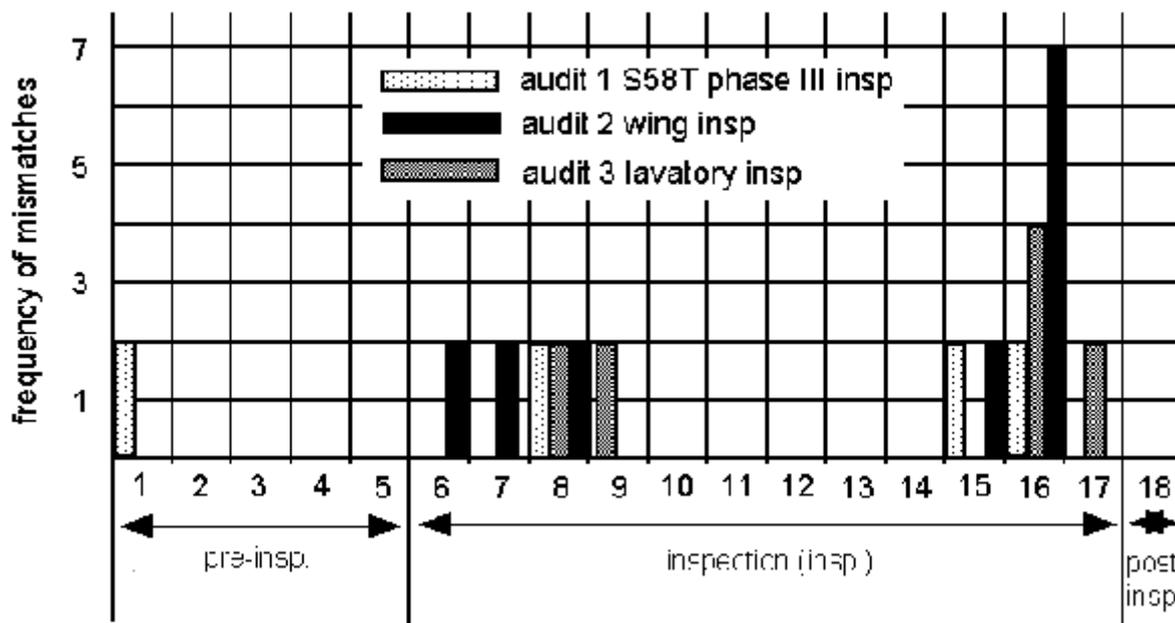
In order to better understand these disparities, checklist questions were divided into three categories, dependent upon the type of question and, hence, upon possible errors in answering the question. Thus, any question on the checklist either result in either a Reading-Off Error, an Operator Perception 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.

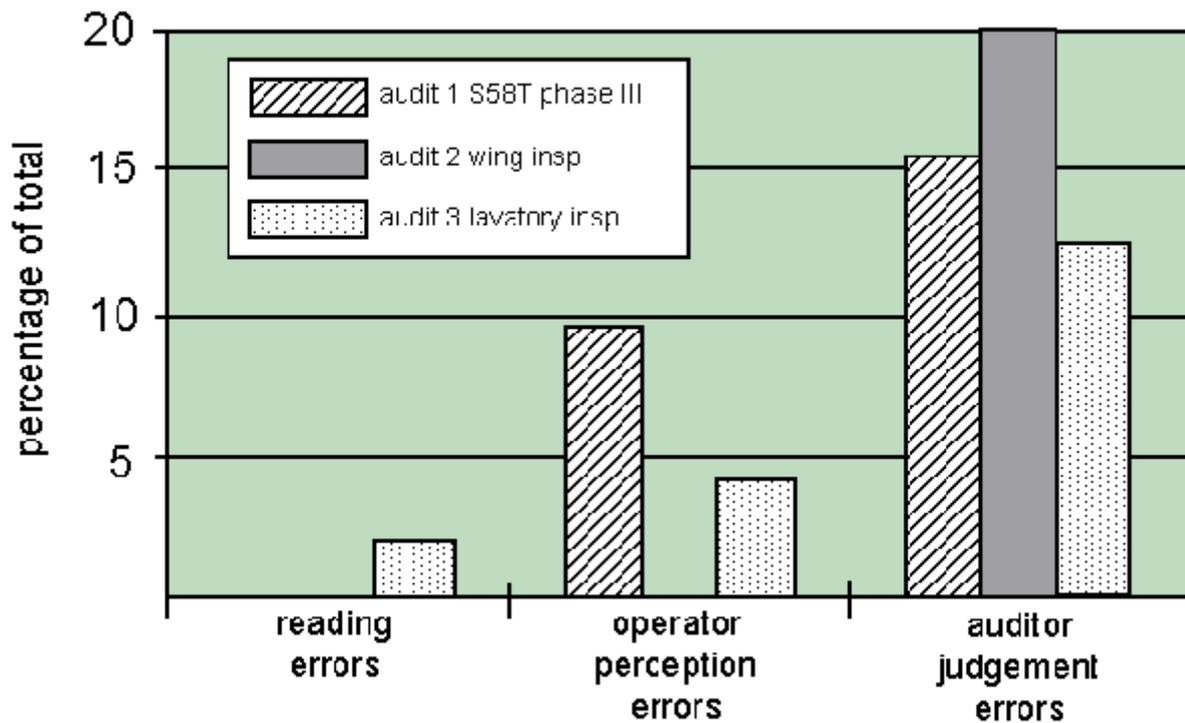
Thus, in order to reduce the mismatch between auditors, auditor judgement errors have to be reduced to the minimum. This can be achieved by the following strategy:

- 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  $X^2$  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

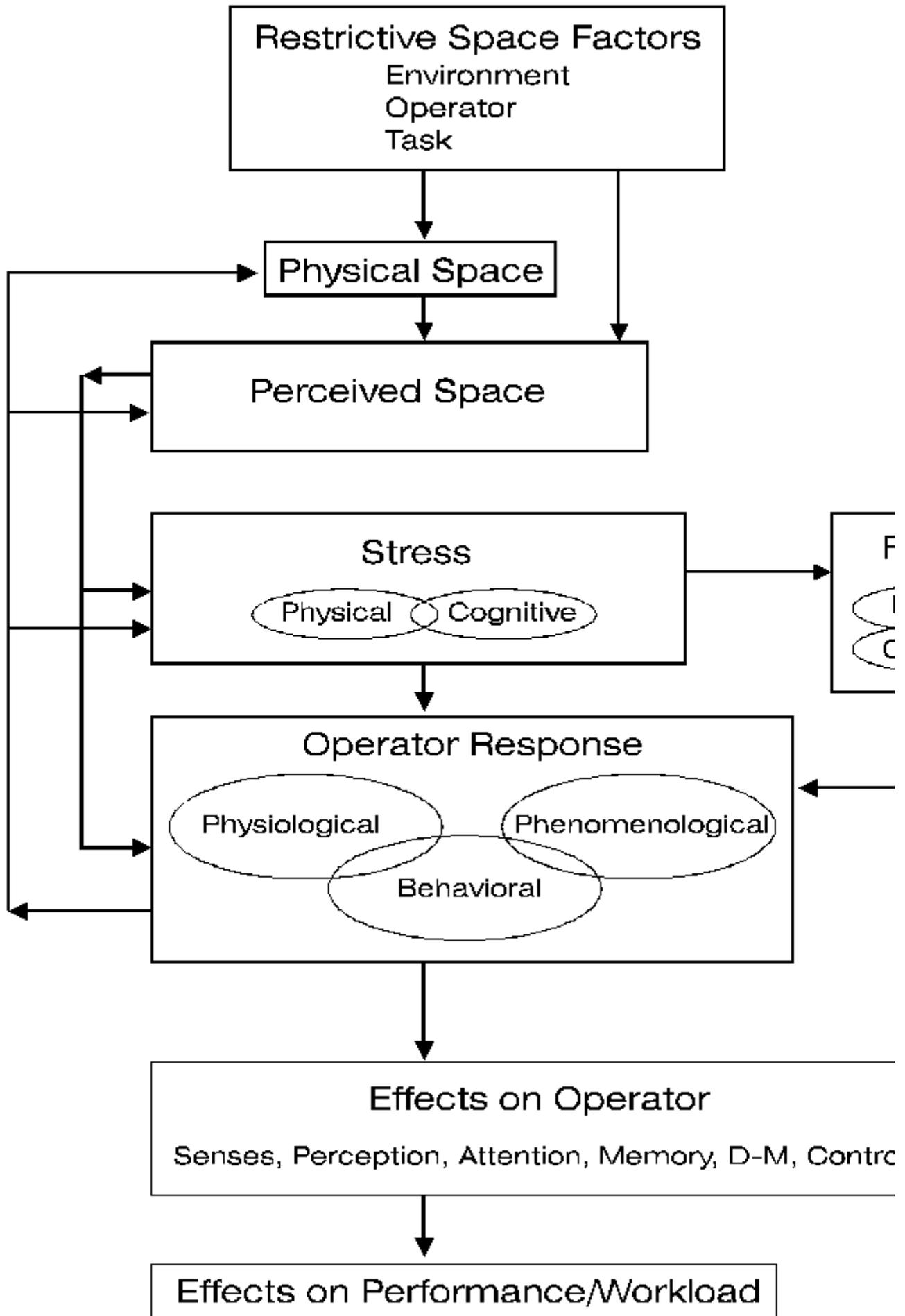
Aircraft structures are designed as a compromise among aerodynamics, strength, weight, and access. Optimum access must be conceded in order to meet other requirements, thus requiring many aircraft inspection and maintenance tasks to be performed in non-optimum conditions which may lead to fatigue.

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.



## 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, 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	$W \dots 0$	$S \dots 0$
1	Proportional to space	$W_{\text{task + compensation(s)}}$	$D_{\text{task + compensation(s)}} > \text{HOC}$
2	Acceptable	$W_{\text{task + compensation(s)}}$	$D_{\text{task + compensation(s)}} > \text{HOC}$
3	Acceptable	$W_{\text{task}}$	$D_{\text{task}} < \text{HOC}$

## 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

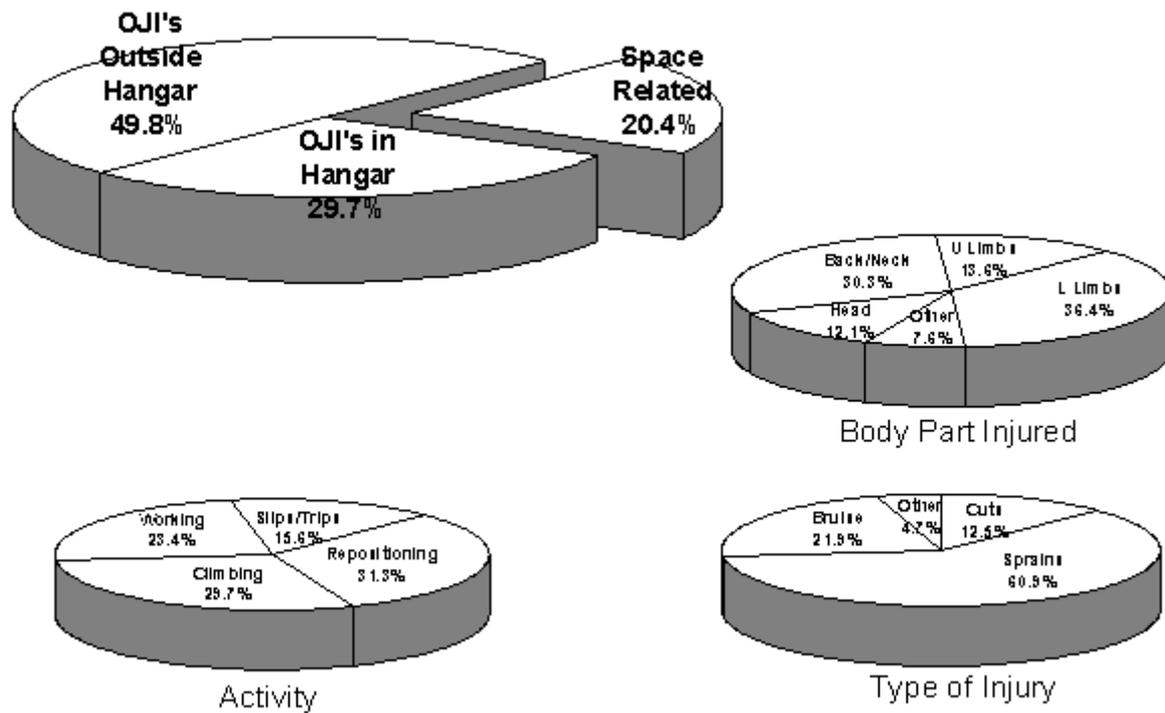


Figure 5.2 OJI Report Summary

### 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 exacerbating 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, Kansu, 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 Limbs	Lower Limbs	2S	1S	2B	1B	K	W	S	L	C
<b>Trunk</b>	<b>Limbs</b>										
Straight	2 Below										
	1 Above										
	2 Above										
Bent	2 Below	 kk	 kk	 kk	kk	kkkk			kk	kk	
	1 Above	 kk	 kk	 kk	kk	kkkk	kk		kk	kk	
	2 Above	kk kk	 kk	kk	kk						
Twisted	2 Below			kk							
	1 Above			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

% of Work- Action  
 Task ing Time Categories

STABILIZERS

1.Legs Straight, Trunk Straight, 2 Arms Below Shoulders 9.3% AC1  
 2.Kneeling or Crouched, Trunk 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 Shoulder 19.0% AC1-AC3  
 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

## By Task

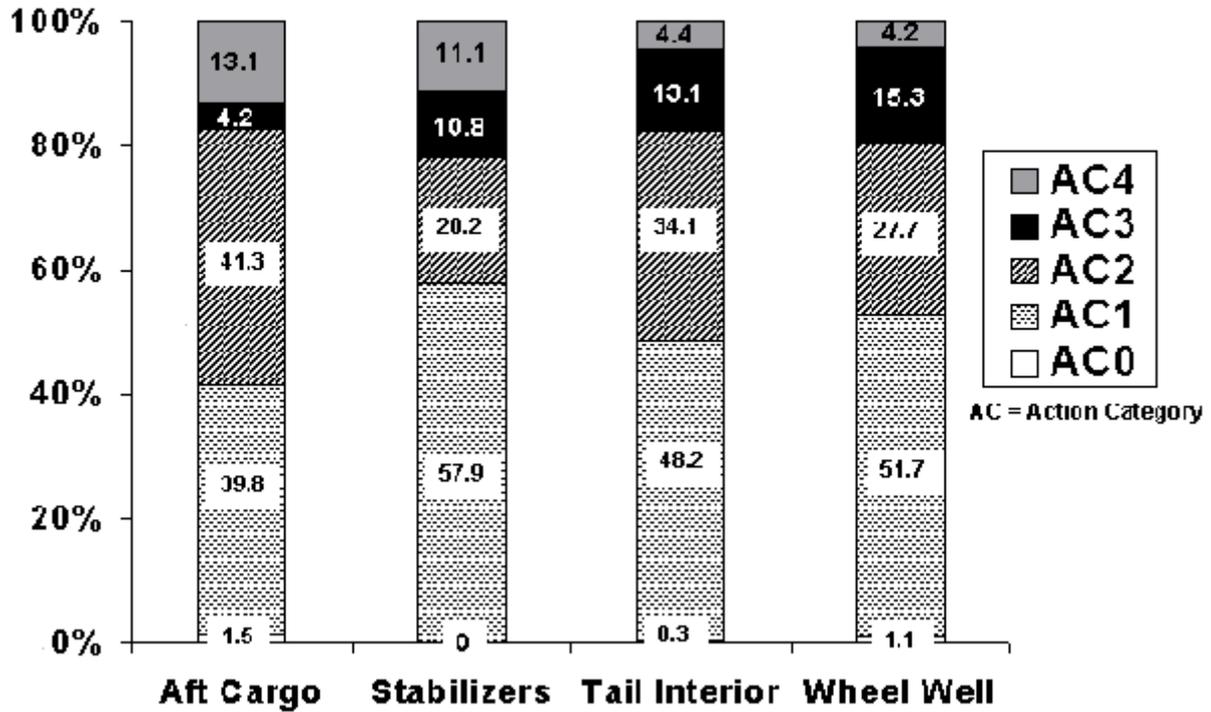


Figure 5.3 Posture Analysis

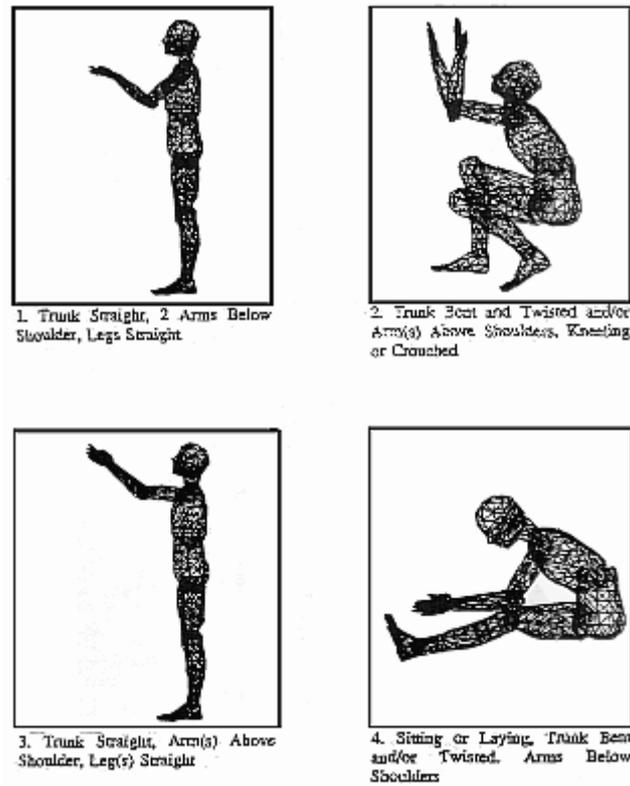


Figure 5.4 Stabilizer Postures

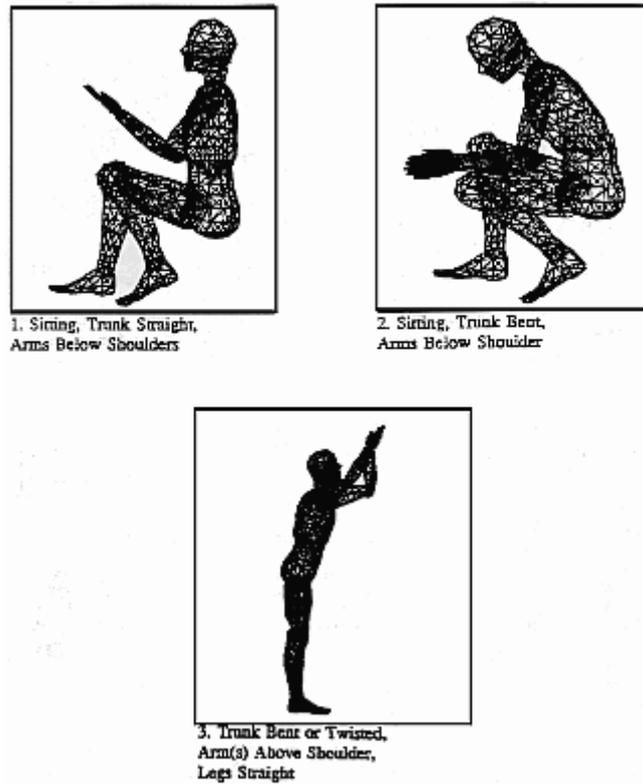


Figure 5.5 Tail Interior Postures

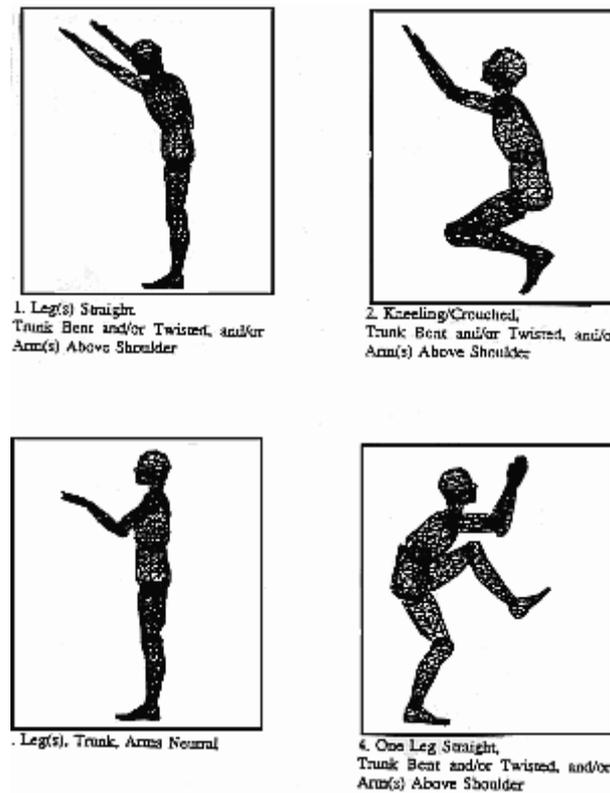
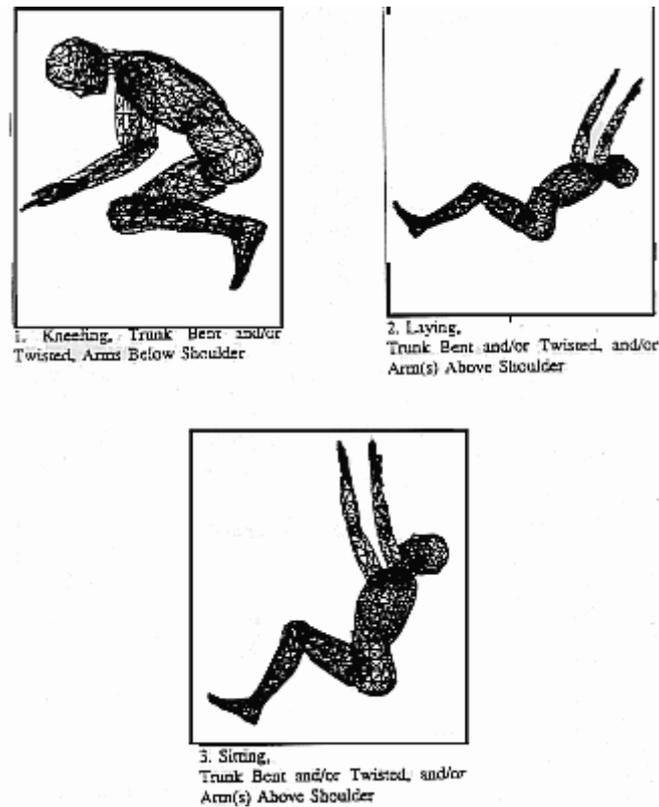


Figure 5.6 Wheelwell/Main Landing Gear



**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 ( $t = 3.17$ ,  $p < 0.0005$ ). 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).

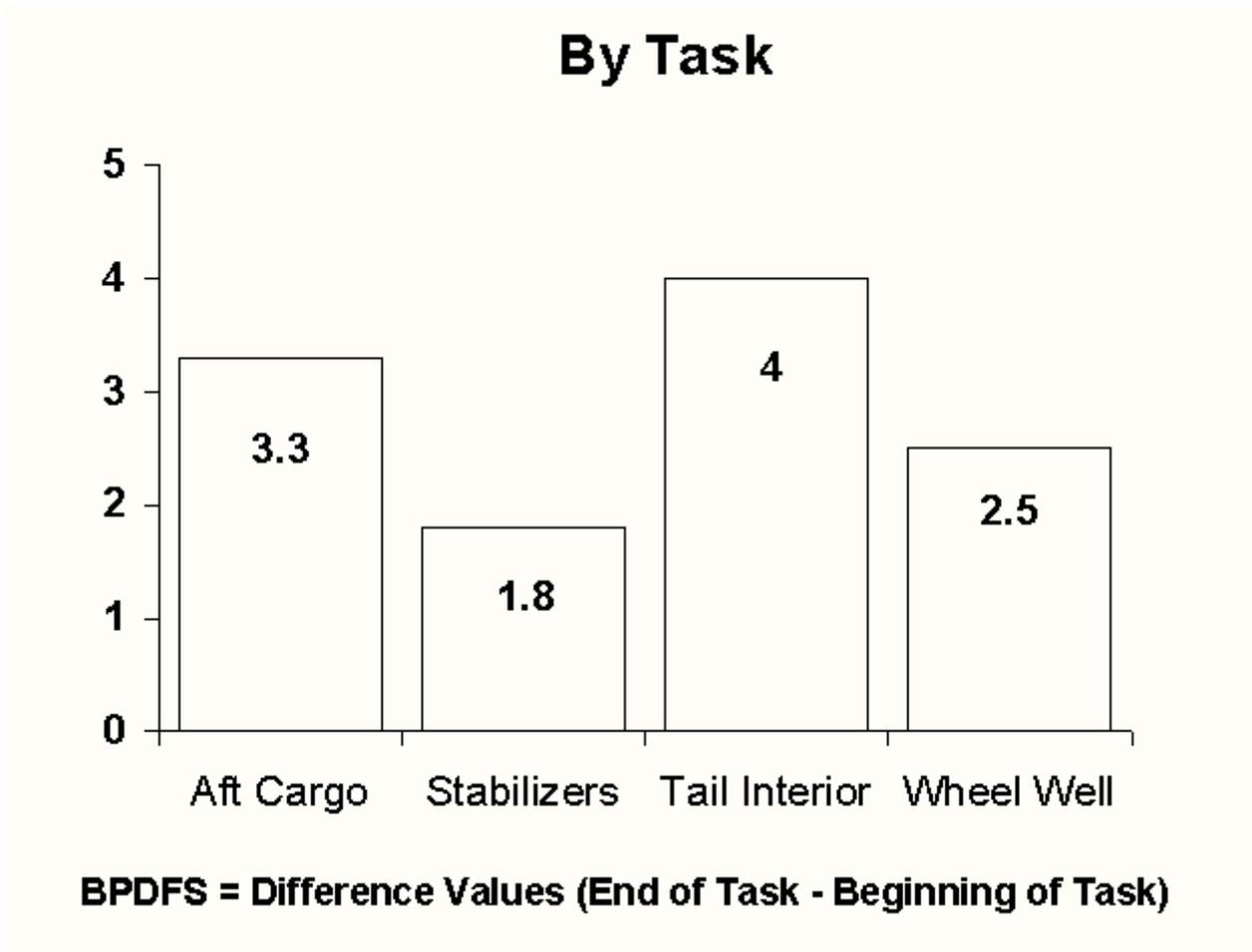


Figure 5.8 Body Part Discomfort Over Time

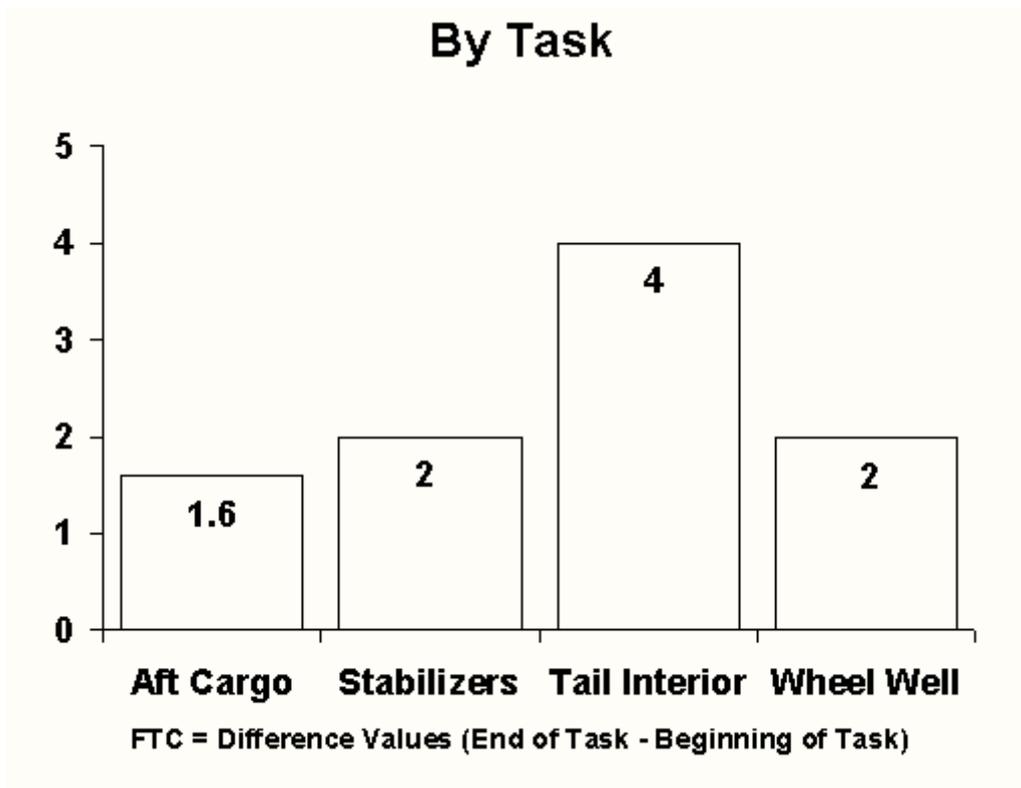
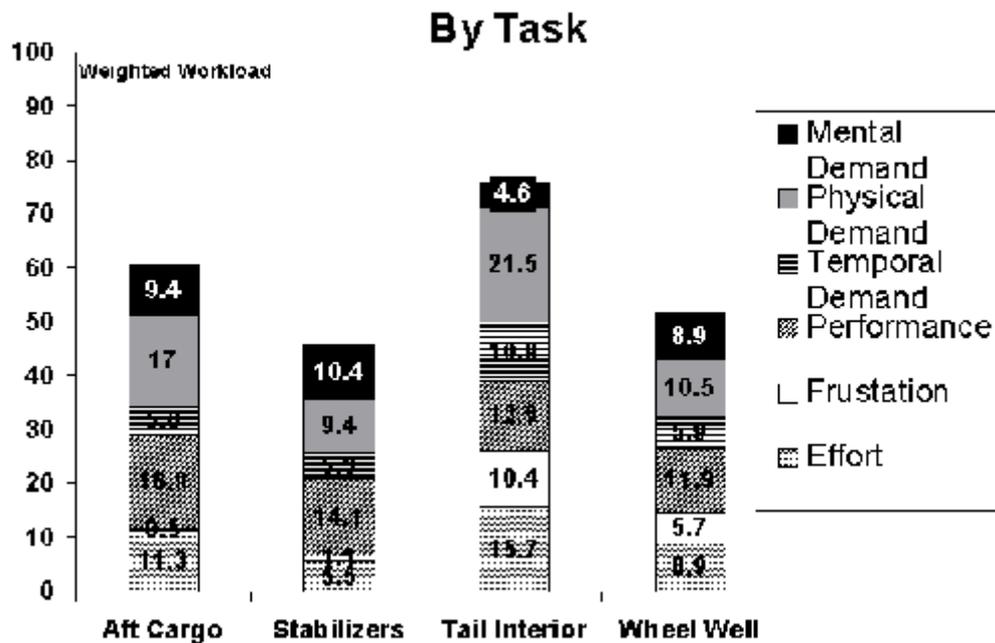


Figure 5.9 Fatigue Over Time



**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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and  
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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<sup>1</sup> to read, print, and manipulate the various media that make up the library.

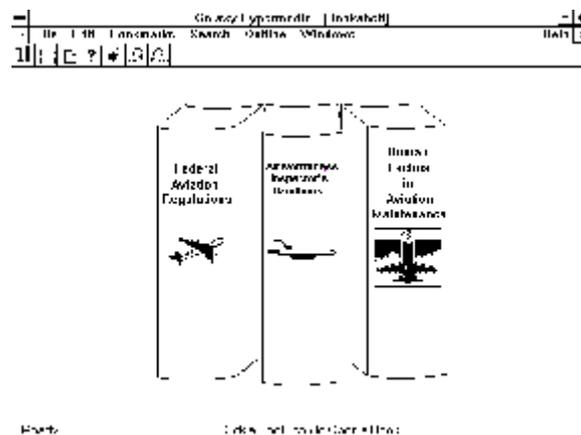
## 6.1.1 Navigation

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

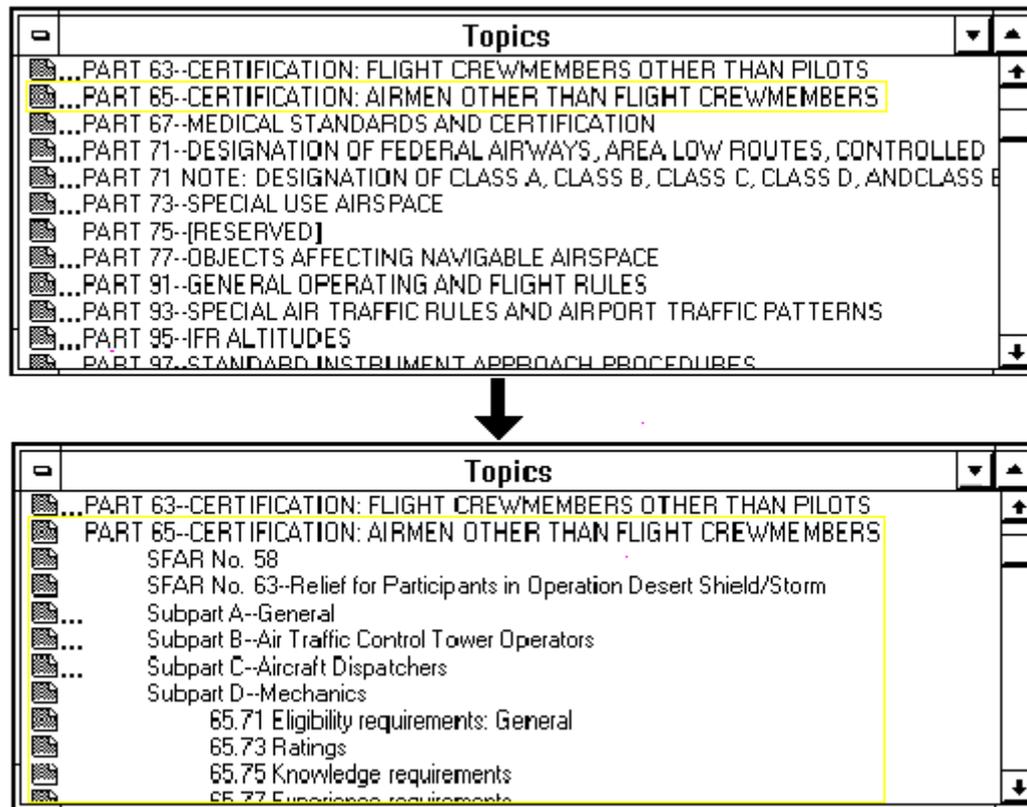


**Figure 6.1 The HIS Bookshelf**

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<sup>2</sup> 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**

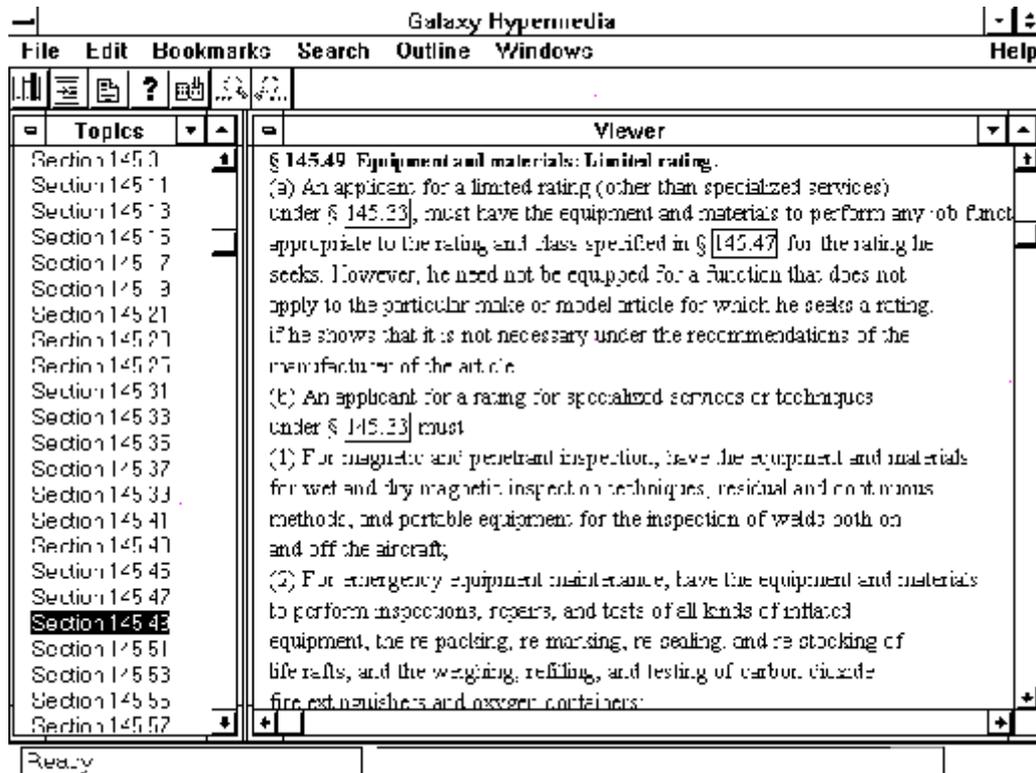


Figure 6.3 The Outline and Document Viewers

#### 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.

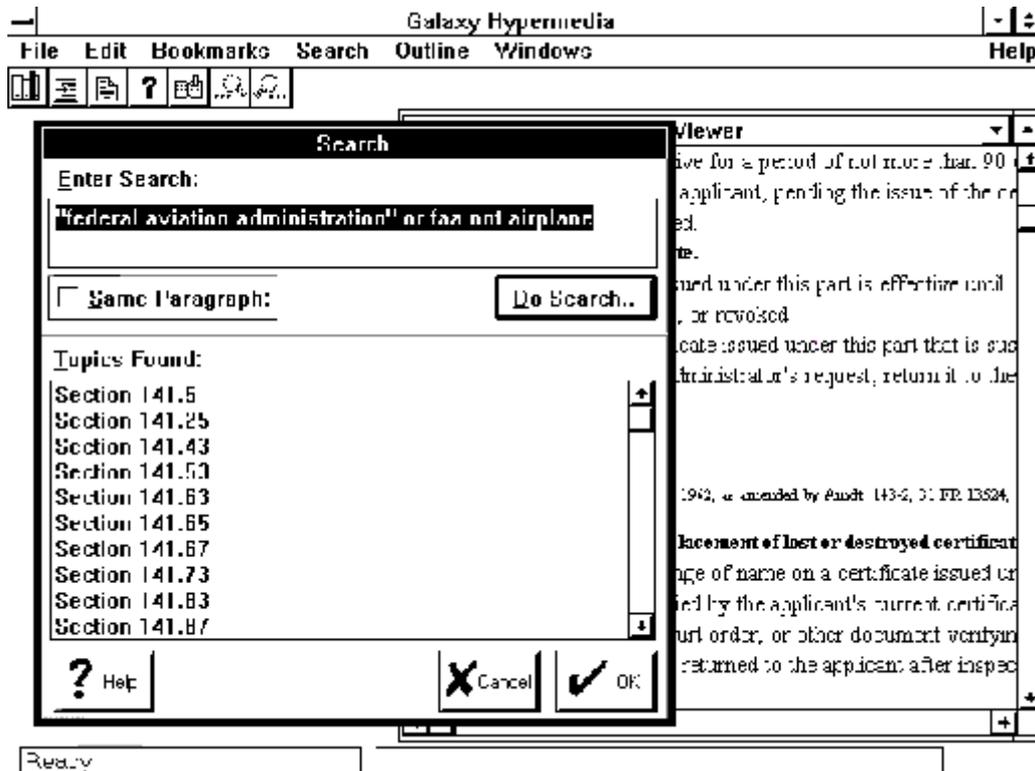


Figure 6.4 Search Query Dialogue Box

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*.

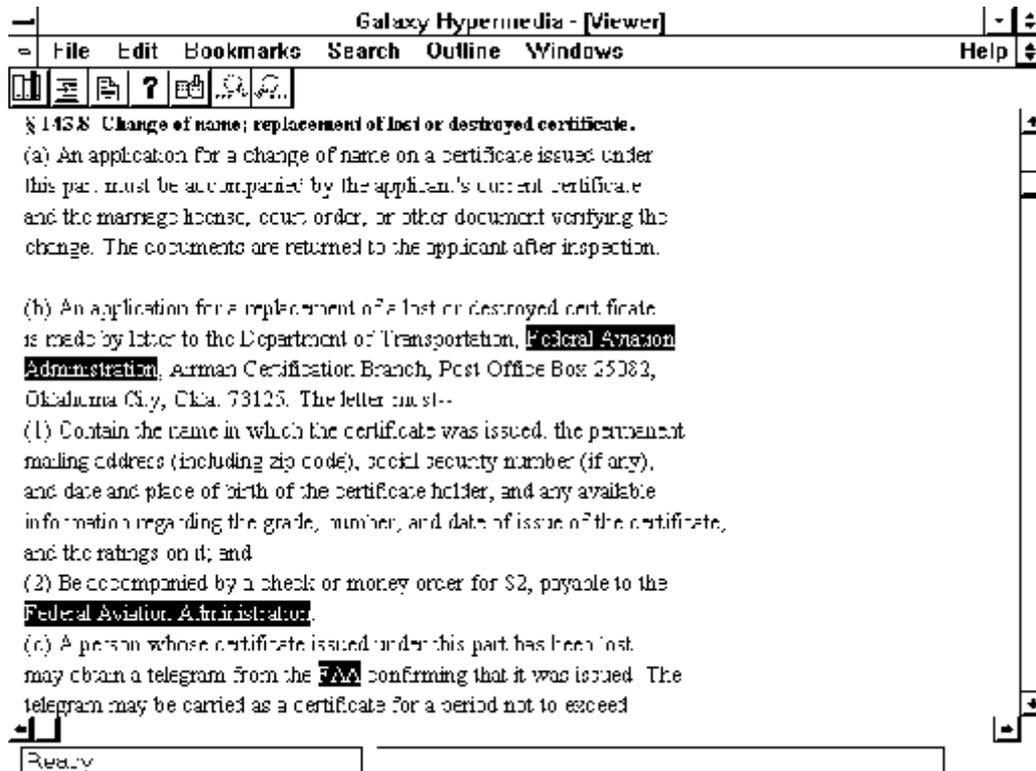


Figure 6.5 Search Hits

#### 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

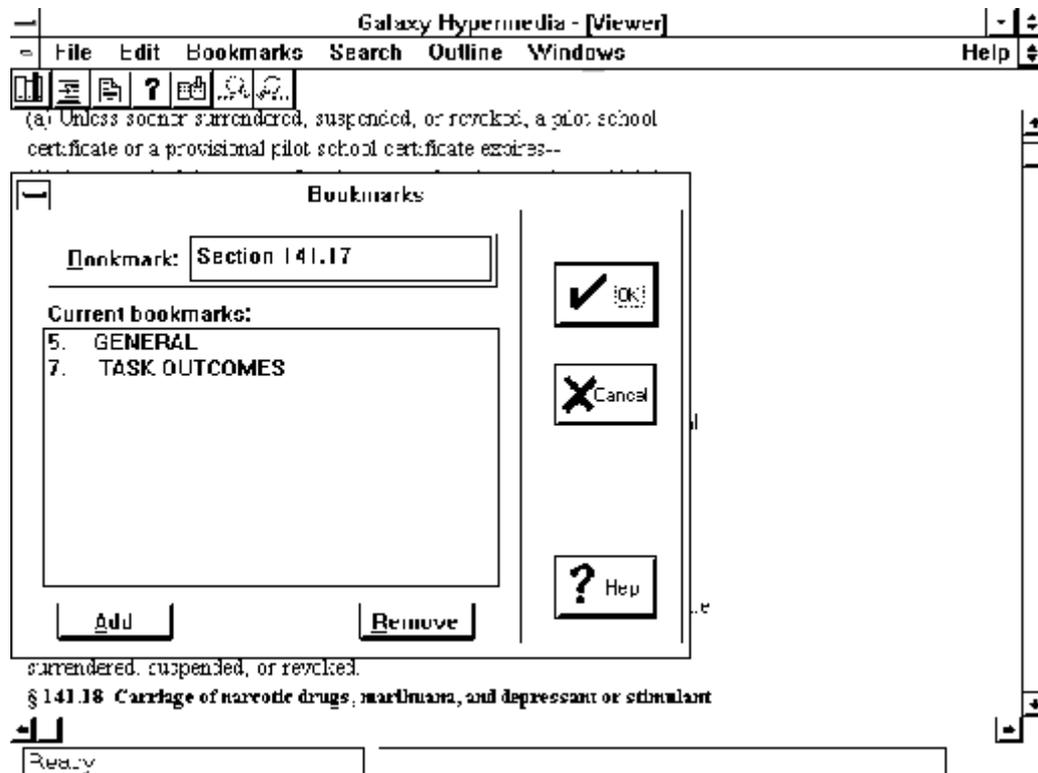
The Document Viewer, shown in [Figures 6.3](#) and [6.5](#), allows a reader to scroll through and read a hypermedia document, as well as to investigate search hits. Text formatting such as boldface, italics, underlining, and multiple font sizes and typefaces, enables the on-line document closely to 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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### 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 magnitude 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

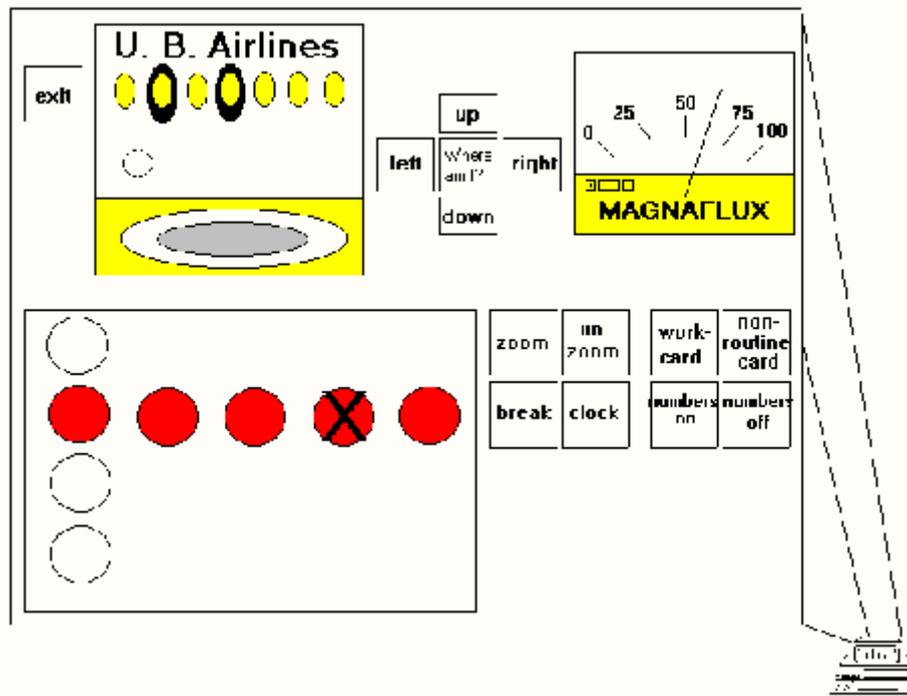
A total of 28 subjects, 15 males and 13 females, participated in the study. All were right-handed, had normal near visual acuity (as determined from an Orthorater screening test), reported normal hearing, and were between 18 to 29 years of age. All had graduated from high school, with most being full- 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/Distractibility
- 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 similar 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 an 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, incidentally, 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

Session	Period		Session
	1	2	
	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

Session	Period		Session
	1	2	
	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/attentiveness. 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

<b>Gender</b>	<b>Like Inspection</b>	<b>Dislike Inspection</b>
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 inspection task

<b>Educational Category</b>	<b>Like Inspection</b>	<b>Dislike Inspection</b>
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/impulsive 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.

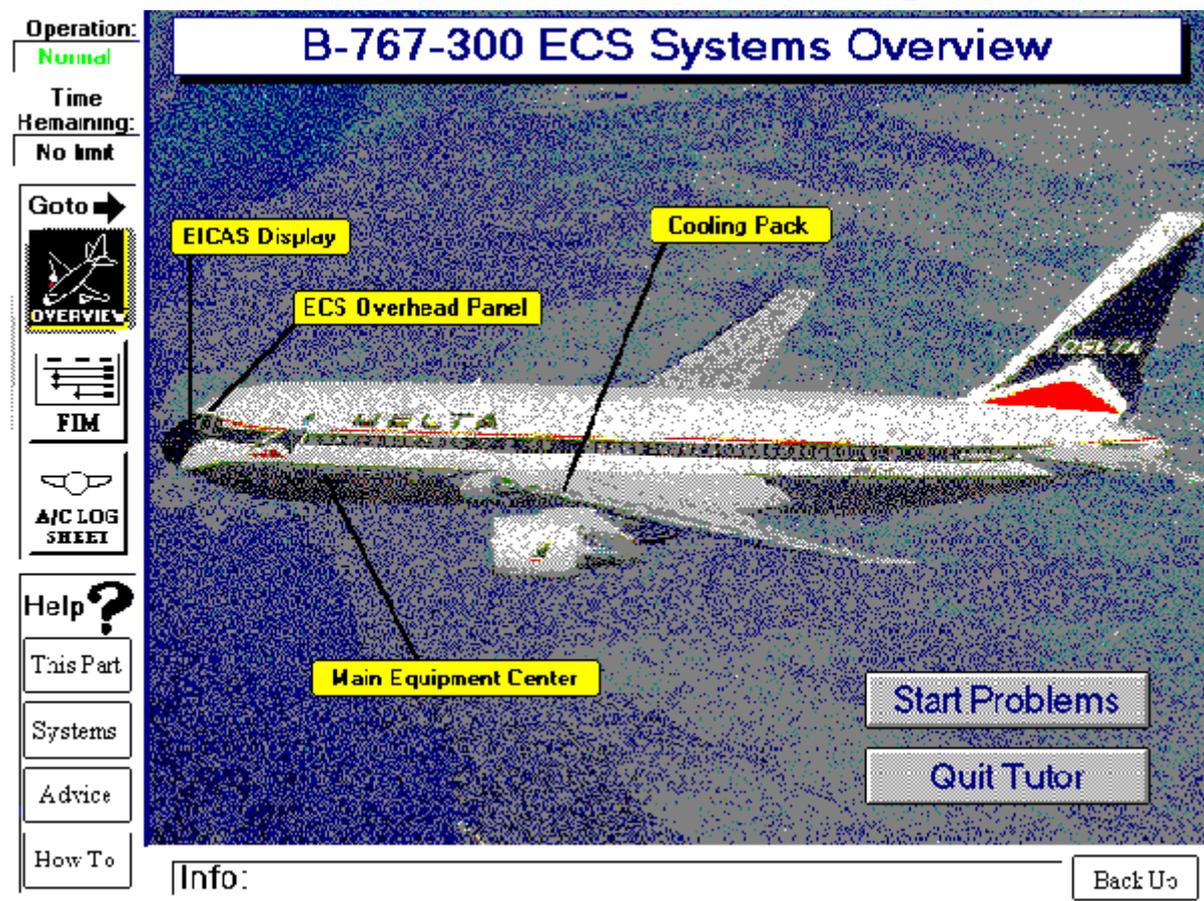
It is standard procedure for AMTs to use the Fault Isolation Manual (FIM), a logic tree used to diagnose malfunctions. AMTs follow the FIM's "branches" based on outcomes of their tests and inspections. The FIM specifies a "minimal path" of actions necessary to repair a failure, from a high-level description 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 an 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.

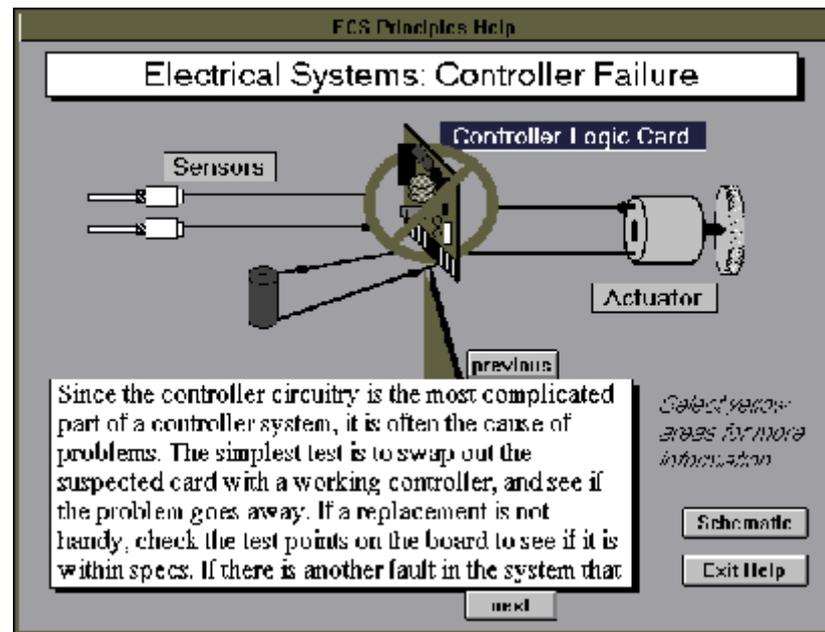


Figure 8.2 Example of a Principle

## 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.

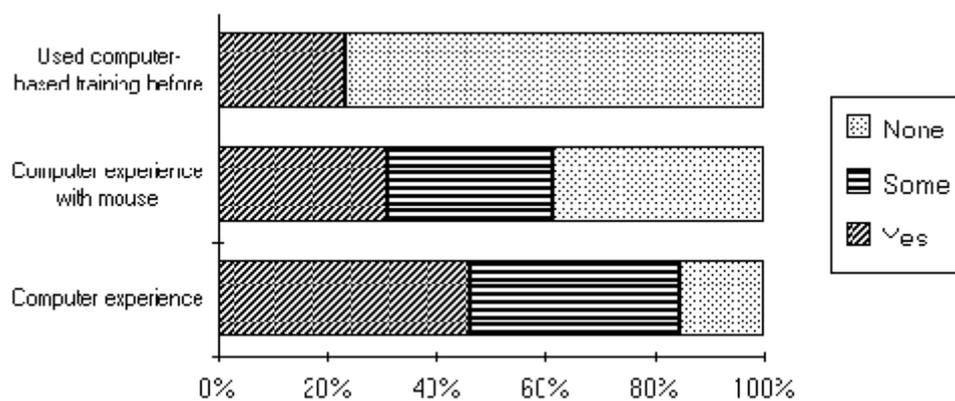
## 8.3 METHOD

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

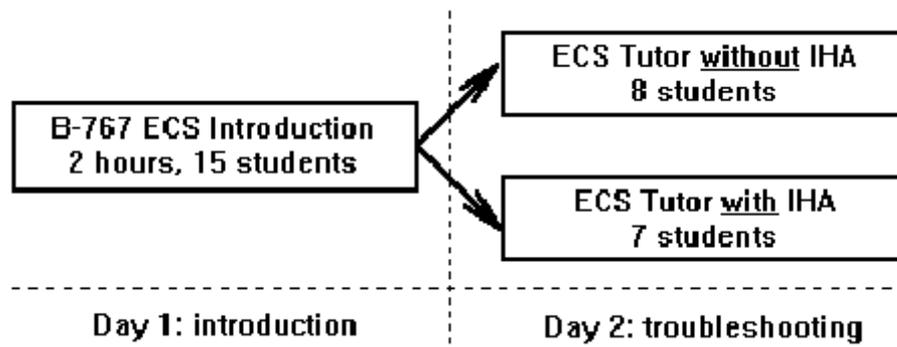
The subjects consisted of 15 A&P students in the Aviation Maintenance Technology Department of Clayton State College. All subjects were enrolled in the Winter 1993 course "Cabin Atmosphere" (AVMT203) and had been at Clayton State College for at least one year. The "Cabin Atmosphere" course covers operation 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.

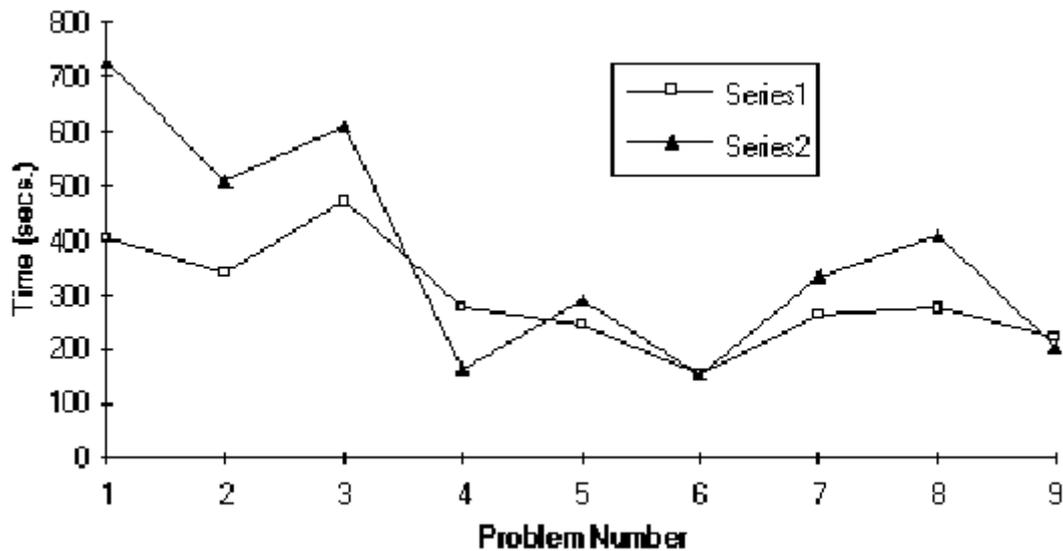
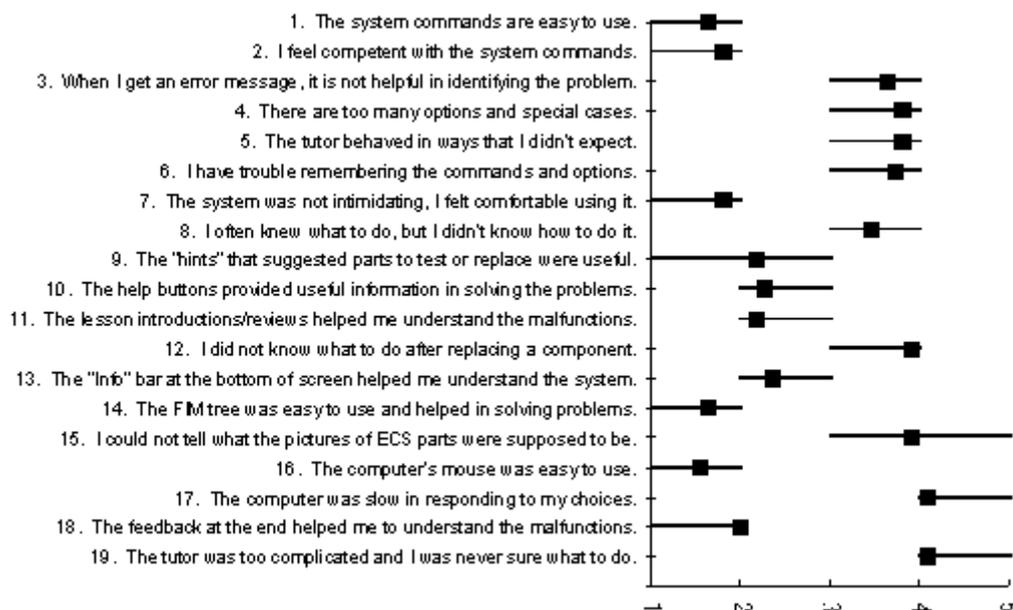


Figure 8.5 Average Group Time to Complete Each Problem

### 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

Pearce, M., "Advanced Technology Training for Aviation Maintenance: An Evaluation," Human Factors in Aviation Maintenance - Phase Two Progress Report, Federal Aviation Administration, DOT/FAA/AM-93/5, 1993, pp. 9-17.

Pearce, M., "Results of the Environmental Control System Tutor Experiment," Human Factors in Aviation Maintenance - Phase Three, Volume 1 Progress Report, Federal Aviation Administration, DOT/FAA/AM-93/15, August 1993, pp. 5-23.

# 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 organization 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 organization, 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 recognized. 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 internationalization of the aircraft maintenance industry, accelerated by publicized events with aging aircraft, differences may be expected to disappear over time. However, this should be a controlled process leading to utilization of the best features of different jurisdictions if the full potential of inspectors within the system is to continue to be realized.

### 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 utilized 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 organizations 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 organizational 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 organization 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 NRRs 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/no go 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 organizations 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 (Rasmussen, 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 characterized 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 penalize 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 organizations, shift work is allocated generally across the organization, 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 organization of working time is so heavily influenced by social needs, the system used should be as simple as possible for predictability. Obviously, spreading night work over a larger population, rather than having some groups bid out of it, will minimize 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 organizational 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 revitalized 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 centers 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 utilize 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 capitalize 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 organizational 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 favor 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 organization 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 behavior, although to different extents. This should be realized and support in training, hardware, and documentation provided in both countries to enable inspectors to move easily and recognizably 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.

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#### *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.

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### 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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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:*

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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*.

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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:*

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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:*

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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:*

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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:*

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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:*

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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:*

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Greenstein, J.S., and Arnaut, L.Y. (1988). Input devices. In *Handbook of Human-Computer Interaction*. North-Holland, New York, NY, pp. 495-519.

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# **Phase V Progress Report (1995)**

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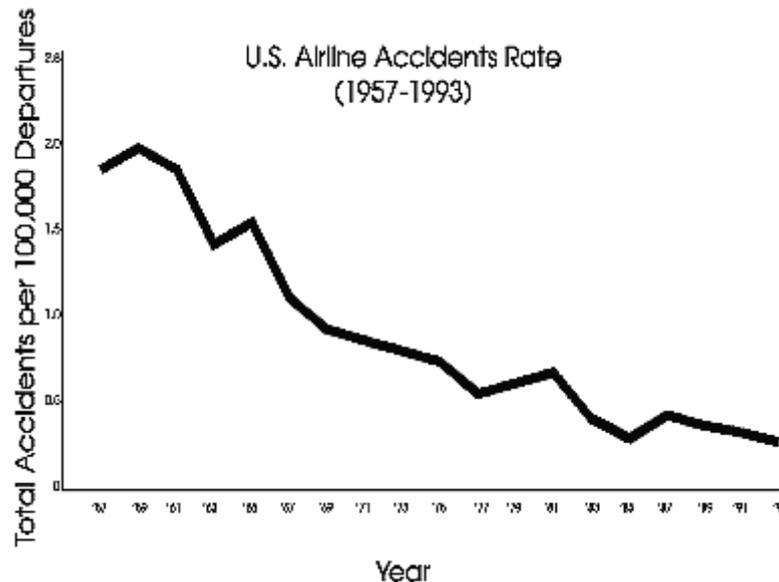
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# Chapter 1

## Phase V Overview

William Johnson, Vice President  
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### 1.0 Introduction



**Figure 1.1 U.S. Airline Accident Rate per 100,000 Departures (1957-1993)**

NTSB, *U.S. Air Carriers Operating Under 14 CFR 121, All Scheduled Service (Airlines)*, 1994

Aviation safety is most commonly measured by accident rate vs. 100,00 departures. Trends, depicted in [Figure 1.1](#), show that aviation safety benefits from continuous improvement, meaning that this earth's safest transportation is becoming even safer. Hardware is the primary reason that aviation safety is improving. Modern power plants and aircraft systems have increasing reliability. Aircraft, air traffic control, and airport navigation, landing, and communications digital systems have also contributed to the safety factor. Some suggest that the extent to which hardware can increase safety has reached an asymptote; it is not likely to make much more improvement. However, attention to the human as operator and maintainer of the aviation safety system, has the highest potential for additional safety enhancement. In fact, human error is the #1 cause of aviation incidents and accidents (NTSB). Since 1989 the FAA Office of Aviation Medicine has conducted research related to human factors in aviation maintenance. The research program is the world's largest such study of human performance in maintenance. Involving universities, government laboratories and private industry, the research addresses many aspects of human performance in maintenance. The research ranges from basic scientific experimentation to applied studies in airline work environments. The applied studies represent the largest part of the program.

The human factors in aviation maintenance research program uses airline and industry maintenance facilities as the primary laboratories. FAA inspectors working on airline air worthiness have also helped to define, develop, and evaluate products of the human factors research.

In the six years of the research, the Office of Aviation Medicine has conducted and published proceedings of nine workshops on Human Factors in Maintenance and Inspection. The research team has published over 200 technical papers. Three [CD-ROMs](#) have been published and distributed to

over 3,000 recipients.

This report documents the primary research and development efforts conducted in the fifth year of the research program. As in previous years, the report represents a broad spectrum of human performance research and development, each shall be described briefly in the remainder of this introductory chapter.

## 1.1 Job Aiding for Aviation Safety Inspectors (Chapter 2)

The Performance Enhancement System (PENS) is an ongoing research and development effort to empower FAA Aviation Safety Inspectors (ASIs) with mobile computing software and hardware. The chapter describes two mobile computing applications, one for government (PENS) and the other for industry (CASE).

PENS provides ASIs with a mobile computer to collect and analyze data in the field. The system, described in the chapter, also permits ASIs electronic access to critical data like the Federal Aviation Regulations and the FAA Inspectors Handbooks. The chapter also describes an extensive field test of PENS and ongoing evaluations of emerging mobile computing hardware and software technology.

The airlines share a system to audit providers of goods and services. The system is named Coordinating Agency for Supplier Evaluation (CASE). The CASE system is comprised of paper forms and a hard copy instruction guide book to complete the forms. The CASE mobile computing software has integrated all information into a complete digital system. The chapter 2 appendix describes the CASE software.

## 1.2 Computer-based Training for Regulatory Documents (Chapter 3)

The System for Training Aviation Regulations (STAR) combines multimedia training software and the FAA Human Factors Information System (HIS) to provide a mix of training and digital documentation. The training system is being designed to present cases, or scenarios, to learn about the Federal Aviation Regulations and other regulatory documents for maintenance. The chapter describes how STAR instructional design and training system analysis were conducted. Descriptions of STAR functionality are also included.

## 1.3 Digital Documentation Systems (Chapter 4)

The research program has a rich history applied to digital documentation systems. The Human Factors Information System (HIS) is a hypertext multimedia software system that was developed for [FAA CD-ROMs](#) 1-3. This special purpose system was designed to meet specific FAA hypertext requirements and to minimize costs associated with mass production and distribution of certain FAA databases. This chapter describes the design and evolution of HIS. It also shows interface examples of how HIS is applied to the CD-ROMs and to the digital *Human Factors Guide*.

## 1.4 On-Ramp to Information Superhighway (Chapter 5)

The Office of Aviation Medicine has distributed research results via three CD-ROMs, as previously described. This media has worked well as the number of installed CD-ROM computers has increased in government and throughout the aviation industry. The research related to the "FAA Information Skyway" is developing the hardware/software infrastructure to, eventually, distribute research results via the Internet.

The chapter describes a user assessment of the on-line information needs of the aviation maintenance

community. The chapter describes the kinds of services that are needed and likely to be provided by an "Information Skyway." The initial World-Wide Web has been established and is operational. The chapter describes the services/reports that are currently available. It also describes future directions.

### **1.5 Development of an Airline Human Factors Program (Chapter 6)**

This project was done in cooperation with Northwest Airlines, at the DC-9 base in Atlanta. The goal was to establish a human factors task force to review a variety of human performance issues associated with the inspection department.

The chapter describes how the task force was formed and the composition of worker and management participants. Also described are a variety of opportunities for improvement in decision making and communication in the maintenance process.

### **1.6 An Audit System for Maintenance Human Factors (Chapter 7)**

The purpose of this task was to provide a valid, reliable, and usable tool for evaluating human factors in maintenance tasks. A software tool was designed and developed as a product of this research. As reported in the chapter the majority of the work went towards the ergonomics audit information with the software development task being secondary. The chapter includes hard copies of most of the forms contained in the software program. The final version of the ergonomics software package shall be included with the digital publication of the *Human Factors Guide*.

### **1.7 Checklist Reliability (Chapter 8)**

Maintenance workcards are the technician's equivalent of the pilot's checklist. The workcard is meant to ensure that maintenance is performed in the correct order and that no step is omitted. The chapter reports on a study of how the design of workcards affects their use and the subsequent potential for error.

The chapter describes a task analysis of workcard usage conducted in an airline maintenance environment. The research analyzed maintenance data from the Aviation Safety Reporting System to determine if workcard usage or non-usage contributed to safety infractions. Also reviewed is application literature on human error with respect to checklists. The chapter ends with a description of the creation and evaluation of a workcard for shift turnover.

### **1.8 Cooperative Work with Aging Aircraft Inspection Validation Center (Chapter 9)**

The Office of Aviation Medicine has engaged in cooperative research with the FAA Technical Center via the Aging Aircraft Inspection Validation Center (AANC). The research supports the Visual Inspection Research Program at Sandia National Laboratories in Albuquerque, NM. The chapter describes the process of visual inspection and describes an evaluation measuring visual inspection performance.

### **1.9 Individual Differences in Inspection Performance (Chapter 10)**

Numerous research studies have shown a wide range of individual performance differences among inspection personnel. This basic scientific study measures relationships between NDI task performance and psychometric measures of mechanical ability and attention-concentration. The

chapter describes a battery of mechanical aptitude tests, a simulated NDI task, and the ability of the tests to predict performance. The exciting answer to these predictive questions can be found in the chapter!

## 1.10 Study of Teamwork in Maintenance (Chapter 11)

Most maintenance activities are conducted by teams of aviation maintenance technicians (AMTs). Therefore, team planning, coordination, and communication are critical to safe and efficient completion of all maintenance tasks. This chapter reports on a study of teamwork in maintenance and outlines a training program focusing on teamwork. The chapter reports the results of an evaluation of a teamwork training program conducted in a FAR 147 school. The chapter ends with a technical specification for a computer-based training system for team training.

## 1.11 Advanced Certification Initiatives (Chapter 12)

FAR 65 addresses the certification of aviation personnel other than flight crew members. Over the past few years the FAA, in cooperation with an Aviation Rulemaking Advisory Committee (ARAC), has been revising Part 65 to address competencies and requirements for Aviation Maintenance Technicians. This chapter reports on the ARAC activities and impending rule changes. This chapter also considers methods to create an "advanced certification" system that could be administered by private industry instead of FAA.

## 1.12 Human Factors Workshop-Appendices

The Office of Aviation Medicine has conducted nine workshops on Human Factors in Maintenance and Inspection. The proceedings from eight of these workshops are published in hard copy and on the FAA CD-ROMs. The ninth conference was held in November, 1994, and focused on review of the *Human Factors Guide for Aviation Maintenance*. Few speakers at the ninth meeting spoke on topics other than specific chapters of the *Guide*. Therefore, a dedicated 9th Meeting Proceedings shall not be published.

The appendices of this report contain papers from the 9th meeting that are not directly related to the *Human Factors Guide*. The first speaker was Dr. Jon L. Jordan, Federal Air Surgeon. Dr. Jordan's paper reviewed the five year progress of the research program. He highlights major program products and looks to the future of the research program.

Dr. Patrick Walter is the Director of the Aging Aircraft Inspection Validation Center at Sandia National Laboratory. His paper describes the research program at Sandia. The appendix also contains a paper from Mr. Eddie Rogan, Human Factors Engineer - British Airways. Mr. Rogan describes the human factors research at British Airways with specific reference to the Managing Engineering Safety Health (MESH) system. MESH is a method for reporting, analyzing, and mitigating human error in maintenance.

Also included in the appendices is a list of attendees who participated in the Agenda 9th Workshop.

## REFERENCES

NTSB, Broad Cause/Factor Assignments, 14 CFR 121 Operations, 1992

## Chapter 2

# Job Aiding: Performance Enhancement System

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### 2.0 Introduction

One of the tasks in the Human Factors in Aviation Maintenance and Inspection Research Program involves investigating advanced technologies and how these technologies might be applied to aviation maintenance tasks. We have been investigating pen computing technology and have developed a prototype application, called the Performance Enhancement System (PENS), for the [FAA](#) Flight Standards Service. We have also been working on a transition of our experiences from this project to industry. The bulk of this chapter describes the Flight Standards work, while [Chapter 2 - Appendix](#) addresses the work we have done with an industry partner.

We had several milestones with [PENS](#) in the last year. The first field study was completed in April 1994, and the results of that study were published last fall. Fall 1994 also saw the initiation of [FAA](#) training of Aviation Safety Inspectors on PENS concepts. Version 2 of the system software was completed in preparation for a second field study in Winter 1994/1995. Finally, a number of computers have been evaluated in-house, and several units have been selected for in the study to evaluate.

### 2.1 Background

The Performance Enhancement System represents a series of investigation and implementation phases supporting the goal of matching the needs and responsibilities of Flight Standards Service (AFS) Aviation Safety Inspectors (ASIs) with automation capabilities. This project is a direct result of the AFS Training and Automation Committee's Information Systems Strategy, which recommended that all future automation systems be developed in conjunction with the work force so that systems are designed to meet workers' needs and desires. The Training and Automation Committee has been instrumental in supporting [PENS](#) and in providing project oversight.

Field data collection is one characteristic of [ASI](#) activities. The data are collected on paper forms, and data entry clerks transcribe these forms into computer databases. These data are then recorded in a national database and are used to monitor the aviation industry's safety. Another characteristic of field inspectors' activities is that they must authoritatively answer questions as they arise. This requires ASIs to carry voluminous, cumbersome field copies of regulations and guidance.

Four primary concerns provided the impetus for development of [PENS](#). First, data entry clerks are a significant annual expense for [AFS](#). If it were easy for inspectors to enter data into the computer databases themselves, AFS would save the money it now spends on data entry. Second, there is a significant time delay of up to two weeks in form transcription. By decreasing that time delay, AFS could be more effective at monitoring and ensuring compliance in the aviation industry. Third, many data transcription errors occur in the current process, so many that the Government Accounting Office has repeatedly criticized the [FAA](#) for the poor quality of its data. Fourth, paper regulations and guidance materials are not used effectively because they are bulky and difficult to maintain. The combination of all these factors points toward automation as a potential solution. Field automation, at a minimum, would allow [ASIs](#): 1) to store data directly in the proper database format; 2) to verify the validity of data at the time of an inspection; 3) to eliminate the time delay associated with transcription; and 4) to use on-line guidance materials quickly, easily, and with minimal maintenance of the documents. Other benefits would accrue as more tools were added to field computers.

The project began as an investigation, sponsored by the Office of Aviation Medicine (AAM), into the utility of pen computers for aviation industry inspectors and maintenance technicians. This phase of the project continued from approximately January until August 1992. During this time, [FAA](#) Administrator Thomas Richards learned about pen computers and thought that they might be a good tool for Aviation Safety Inspectors. To this end, he requested briefings from the Flight Standards Service. The Flight Standards Service learned of the [AAM](#) research and requested information in August 1992. After a series of briefings to FAA personnel, including Clyde Jones, [AFS](#) Director Thomas Accardi, and Associate Administrator for Regulation and Certification Anthony Broderick, we briefed Administrator Richards in November 1992, and Acting Administrator Joseph Del Balzo in January 1993.

Between January and August 1993, [PENS](#) received a lot of publicity within Flight Standards Services, both in AFS Headquarters and in the field. The project continued with a low level of funding from the Office of Aviation Medicine. From August 1992 through August 1993, a series of task analyses and prototypes were carried out to determine the basic content of a field computer tool. The Fort Lauderdale Flight Standards District Office (FSDO) was fundamental to the success of these initial analyses and prototypes.

Funding for a national field human factors study of [PENS](#) concepts was provided in August and October of 1993. Because of all of the publicity the project had received over the previous year, [AFS](#) Headquarters felt considerable pressure to start the field study quickly once funding was available. After some very rapid prototyping and testing with Atlanta [FSDO](#) inspectors, the national field study began on November 15, 1993, continuing until March 1, 1994.

## 2.2 Summary of Field Study Results

The following is a summary of Performance Enhancement System concepts that were evaluated, the nature of the field study, the important results, and considerations for full implementation. The full results and discussion can be found in *The Performance Enhancement System Field Evaluation Report*.

### 2.2.1 Inspector Characteristics

Four airworthiness (maintenance) aviation safety inspectors at each of nine sites, a total of 36 inspectors, participated in the study. The inspectors averaged 49 years in age, had been inspectors for five and a half years (most airworthiness inspectors are former aircraft mechanics), and had five and a half years of computer experience. Sixty-five percent of the inspectors use the current data entry system, and sixty percent own computers.

Note that inspectors' computer experience correlates with their experience as [ASIs](#). The current computer systems installed at the field evaluation sites run a very limited set of [DOS](#) applications, not Microsoft Windows applications. [PENS](#) runs in Microsoft Windows for Pen Computing.

Training was given according to time, rather than to criterion. Inspectors were trained for two days. The first day consisted of an explanation of file storage conventions, [DOS](#), Windows, and handwriting recognition, including training the computer to recognize the inspectors' handwriting. The second day consisted of training on [PENS](#) software.

We spent much more time covering basics in Windows than we thought would be necessary. Even though each office had Windows installed on its workstations, inspectors were generally inexperienced Windows users. The most likely explanation for their inexperience was that few inspectors had any need to run Windows software. The extra Windows training did not significantly affect the amount of training devoted to [PENS](#); there was time left at the end of the second training day.

## 2.2.2 Materials

Three different models of pen computers and one standard notebook computer were fielded at each office. Thus, 36 computers were put into the field. Computers were selected based on their particular combination of features and their differentiating characteristics. That is, the computers were selected because they had certain features in common, but each also had a particular feature that made it unique. These computers allowed inspectors to evaluate the tradeoffs between weight, versatility, and speed. The computers' features are summarized in [Table 2.1](#). The features listed in [Table 2.2](#) are common to all four computers.

## 2.2.3 Results--Computer Platforms

The inspectors were asked to rate a number of usability characteristics of each computer. The characteristics included weight, ease of use, screen characteristics, environments in which the computer was used, and the like. With regard to particular characteristics of pen computers, the only significant result was that the GRiD Convertible was judged more comfortable than the [NEC VersaPad](#). This result is consistent with inspectors' comments that its case made the VersaPad difficult and cumbersome; the Convertible was much more compact and easy to use.

**Table 2.1** Characteristics of the Four Computers Used in Field Study

GRiD Convertible	<a href="#">NEC VersaPad</a>	TelePad SL	Toshiba Satellite T1900
486/25 MHz CPU	486/25 MHz CPU	386/25 MHz CPU	486/25 MHz CPU
200 Mb Hard Drive	80 Mb Hard Drive	200 Mb Hard Drive	120 Mb Hard Drive
Built-in Keyboard	Separate Keyboard	Separate Keyboard	Built-in Keyboard
Pen Stylus	Pen Stylus	Pen Stylus	Trackball

When ratings for pen computers are compared with the notebook computer (Toshiba Satellite T1900), both the GRiD Convertible and the TelePad SL were judged to be faster. Inspectors generally disliked the VersaPad, and that may have biased the inspectors' evaluations. We originally thought that the VersaPad was a good computer to use to examine tradeoffs between computer characteristics because it had a smaller hard disk and was also much lighter.

Finally, inspectors addressed the tradeoff between weight and capability. Many inspectors complained that the VersaPad did not have enough hard disk capacity because it was too small to contain on-line versions of both the [FARs](#) and the Airworthiness Inspectors' Handbook.

**Table 2.2** Common Features of the Four Computers

8 Mb RAM  
 Backlit LCD Monochrome display  
 PCMCIA Data Storage Card  
 DOS 6.0  
 Windows  
 Microsoft Word 2.0 (except the [NEC VersaPad](#))  
 PENS Prototype Software

Perhaps the most telling data on the computers were collected in response to the question, "Would you use this computer in the field as part of your job?" Inspectors generally preferred the GRiD Convertible and the TelePad SL over the [NEC](#) VersaPad and the Toshiba Satellite. However, none of these computers are currently in production: the GRiD Convertible and the [NEC](#) VersaPad have been removed from the market; the TelePad SL is due to be replaced this Fall with the TelePad 3; and the Toshiba Satellite T1900 has been replaced with another model.

Because the notebook computer was comparatively heavy and cumbersome, it was extremely difficult for inspectors to use it while they performed an inspection. While they could easily operate a pen computer with two hands, the notebook computer really needed to lie on a flat surface. Inspectors indicated that they definitely would not be able to use a standard notebook computer as part of their daily routine, although a pen computer was feasible.

Inspectors were unanimous in requesting smaller, lighter computers. They were particularly interested in devices that would fit in their coat pockets such as personal digital assistants, e.g., Apple Newton, Tandy/Casio Zoomer, etc. However, such devices currently do not have either the storage or the processing resources to run applications necessary for [ASIs](#). Inspectors were also intrigued by the possibility of using speech recognition for data collection, as this would keep their hands free.

#### 2.2.4 Additional Issues

Interviews with inspectors revealed that, although immediate recording of field data may not always be required, immediate access to previous data or regulatory materials is required. For inspectors, a computer is more useful as an information management and retrieval tool than as a data collection vehicle for inspection activities.

Inspectors raised a number of additional concerns during the study. Many inspectors were concerned about liability for the equipment should it be stolen, dropped, or left on an airplane. Some inspectors were concerned with perceptions of people they were inspecting, i.e., they were worried that they appeared inept or incompetent when using a computer. Other inspectors were concerned that a computer lent an air of permanence to notes they made, and, as a result, operators would be less cooperative, even though notes on paper have the same degree of permanence. While there are practical solutions to all these issues, the issues themselves go well beyond the questions of which computer is better or if a field computer can be used for one-time data capture.

With regard to environmental considerations, inspectors noted that the computers stopped working when the temperature approached freezing. Cold temperatures also make it more difficult to use a computer because of the inspector's need to wear gloves, bulky coats, etc. Finally, as one might expect, inspectors were reluctant to use computers in snow or rain for fear of damaging the machines.

### 2.3 Training

The Regulatory Standards and Compliance Division, AMA-200, has begun training new [ASIs](#) on the concepts embodied in the Performance Enhancement System. Although the system is not ready for full implementation, inspectors should be initiated into future system capabilities as they receive their first training. In this way, inspectors will see the system as a tool in their compliance arsenal and as an integral part of their jobs.

Version 2 of the software was only recently completed, so the training group has provided only a brief system introduction during the training courses. However, the training group has indicated that they will gladly incorporate more training as soon as the system is ready for full implementation.

## 2.4 Version 2 of the Performance Enhancement System Software

Version 2 of the Performance Enhancement System software has been completed and is ready for the next field study. This software incorporates changes and improvements over the last version in four major areas:

1. the code was converted from C/C++ to Microsoft Visual Basic to allow significant improvements in the software's design and maintainability
2. the software has greatly expanded its functionality to address all three [ASI](#) specialties: Operations, Airworthiness, and Avionics
3. the Program Tracking and Reporting Subsystem (PTRS) data collected have been subjected to the same validation procedures used on data entered through the Flight Standards Automation System (FSAS)
4. the three leading FAA digital regulatory guidance document systems will be compared in the field study.

The following sections address each of these areas.

### 2.4.1 Software Conversion to Visual Basic

One of the biggest changes in Version 2 is that it has been converted from C/C++ to Visual Basic, which is rapidly becoming the standard development environment for Microsoft Windows software. This switch has improved the "look and feel" of the software, has made development easier, has increased maintainability, has improved our ability to add functionality, and has improved database capabilities.

The enhancements in Version 2 improve usability and user acceptance. As shown in Figures [2.1](#) and [2.2](#), the scroll bar has been removed from the [PTRS](#) form and has been replaced with tabs. This change makes navigation between sections of the form easier and more direct. Forms generally have more visual depth, appearing three dimensional. This new appearance facilitates functional grouping and makes buttons distinct from fields. Version 2 gives users the impression that it is a professional product, rather than a research and development tool.

**Figure 2.1 Performance Enhancement System *Version 1***

Figure 2.2 Performance Enhancement System *Version 2*

Because many development tasks are handled by Visual Basic, rather than by a programmer, software development has become much easier. Since the programmer does not have to worry about low level Windows routines necessary to make buttons work, he or she can focus on greater design issues of layout, error prevention, database support, and the like. Furthermore, Visual Basic improves Version 2's maintainability because it is now much easier to follow the software's flow of control and structure. Since Visual Basic uses the Basic programming language (which is frequently the first computer language one learns) the odds that the [FAA](#) will be able to maintain the software are greatly improved-especially when Visual Basic is compared with an esoteric language like C or C++.

Visual Basic supports myriad control features allowing one to add features supporting specific requirements of an application. These controls are called VBXs, and many are supplied by Microsoft with Visual Basic. Thousands more are available from third parties. Had the project been continued in C/C++, these types of controls would have been developed in-house, requiring significant time and effort. In Version 1 of [PENS](#), virtually any desired control outside the very limited set supported by the C/C++ compiler would have to have been developed from scratch.

Finally, Visual Basic includes database support for a variety of databases, including Microsoft Access and Paradox 3.5. This support allows us easily to migrate the software to support future databases as AFS systems evolve. The current [AFS](#) standard database format is Paradox 3.5, but it appears that in the near future Microsoft Access and SQL formats will be used. Visual Basic has built-in support for each of these formats.

## 2.4.2 Expanded Software Capabilities

Version 1 of [PENS](#) consisted of three primary modules: the data collection and on-line policy module; the data transfer module; and the supervisory review module. Each module and its improved version is discussed in turn.

The data collection and on-line policy module consisted of the [PTRS](#) form for data collection, the Federal Aviation Regulations (FARs), and the Airworthiness Inspector's Handbook ([FAA Order 8300.10](#)). Version 2 of this module has been split into its constituent parts. The data collection portion has been expanded to include the ten forms most commonly used *in the field* (not in the office), including the PTRS form. These ten forms address the operations and avionics specialties, in addition to airworthiness.

New data management capabilities have been designed into Version 2. Work has been divided into three general categories: work yet to be begun resides in the "In Box"; work started, but incomplete, resides in "Work in Progress"; the "Out Box" contains completed activities before they are transferred to the office databases. A fourth data repository, the "Archive," maintains a backup set of all data that have ever resided on the portable computer. With this structure, inspectors quickly determine what activities are currently open, what activities are completed, and what activities remain to be accomplished. This capability is illustrated in [Figure 2.3](#).

The screenshot shows a software window titled "Open Activity". At the top, there are four buttons labeled "In Box", "Work in Progress", "Out Box", and "Archive". Below these is a table titled "Current Activities - Work In Progress". The table has the following data:

Record	Inspector	Office	Activity #	FAD	Designator	Status	P/T	Call-up Date	Start Date	NPG
9500010	JAC	FS27	1711	61		P		12/09/94		
9500011	JAC	FS27	1712	135	DALA	O		12/21/94	12/21/94	

Below the table is a "Description:" field containing the text "On-Site Incident Investigation". Underneath is a search section titled "Search for Specific Records...". It includes input fields for "Activity #:", "Record ID:", and "Start Date:". There are also fields for "Designator:" and "NPG:" with radio buttons for "Required" and "Not Required". A "Search" button is present. At the bottom of the search section, there is a note: "Specify an Activity Number or leave blank to find any Activity Number." Below the search section are three buttons: "Open", "Move to WIP", and "Cancel".

**Figure 2.3 Work Program Management**

Extensive error prevention mechanisms have been built into these forms. The philosophy of the [PENS](#) design process is to guide users so that they enter correct data, not to correct errors after-the-fact. Wherever possible, databases have been incorporated to allow the user to select from a set of possible entries, rather than to generate his or her own entries. Data that can be inferred from previous entries are automatically entered into the forms. For example, values for the Callup, Start, and Completion Dates are constrained by the inspection's status. As shown in [Figure 2.3](#), the "Start Date" field is grayed because the Status is "P" for planned. Once the Status is "O" for open, the "Start Date" field is immediately available. Finally, data that are redundant across forms are automatically shared so that an inspector need record those data only once.

The on-line help system has been expanded to include Version 2's new functional capabilities. Help now addresses how to use the software, rather than how to complete a given activity. However, steps to complete an activity will be included in Version 3 of the software because Job Task Analyses are to be incorporated. Two additional help features have also been incorporated in Version 2: Bubble Help and Micro Help. Bubble Help is familiar to most Microsoft software product users; it is the text description appearing when the pointer rests on an icon. Bubble Help ensures that toolbar functionality is clear. Bubble Help is illustrated in [Figure 2.4](#). Micro Help is a text description of the

function currently in use appearing at the bottom of the screen. For example, when a user clicks on the "Make-Model-Series" field in the PTRS form, Micro Help indicates that the code may be selected from a list. Micro Help is shown in [Figure 2.5](#).

The on-line FARs and Handbooks in Version 1 were very difficult to maintain and keep current. Because some commercial vendors specialize in such documents, it was deemed appropriate that inspectors compare the most promising of commercial alternatives. The in-house versions of these documents are not incorporated in Version 2. This topic is discussed in more detail below.

The data transfer module has been divided into two separate utilities in Version 2. One of these utilities transfers [FSAS](#) data to the field computer; the other transfers data from the field computer to FSAS. The former utility will be used rarely, for example when a field computer is initially loaded with the inspector's work program. The inspector will use the latter utility whenever he or she returns from the field and is ready to transfer field data to the office file server.

Figure 2.4 Bubble Help Example

Figure 2.5 Micro Help Example

The supervisory review module has been dropped from Version 2 because inspectors rarely used it in the first field evaluation.

### 2.4.3 PTRS

Data Validation, the Regulatory Support Division, AFS-600, and the Operational Systems Branch, AFS-620, in particular, have been instrumental in allowing us to test the [PTRS](#) data collection software. The Operational Systems Branch initiated a procedure that allows us to send PTRS data collected with our software through the same upload procedure utilized in [FSDOs](#), including data validation. This allows us to ensure that all data are consistent with the current [FSAS](#) data entry system. With Version 1, we had difficulties with some hidden database fields our software did not fill and we were unaware of these difficulties until we started field-testing the software. Version 2's data validation capability allows us to work out such kinks *before* we get the software into the field.

### 2.4.4 Digital Regulatory Guidance Documents

As noted above, one of the critical needs inspectors cited in the first field study is an ability to research policy and regulatory guidance while they are in the field. Version 1 of the software supported a prototype of this capability. At the time, it was necessary for us to develop this prototype in-house because the products were not available commercially. However, three commercial providers now have released extensive Windows-based systems: Aviation Compliance Services (ACS) released the FAR Library; Aircraft Technical Publishers (ATP) released the United States National Aviation Regulatory Library; and Summit Aviation released the Computerized Aviation Publications Library. Each system contains the Federal Aviation Regulations, some Advisory Circulars, some [FAA](#) Orders, and additional publications. Each package is unique, and each publisher releases updates on its own schedule.

The [ACS](#) and Summit systems have a simple document viewer with simple searching techniques. The [ATP](#) system is a powerful research tool, containing significant cross referencing of documents and aircraft information. There are significant cost differences among the products. Our current plan is to compare all three products in a small field study and then to let inspectors determine which

product best meets their needs. ACS and ATP have agreed to supply their product at cost; negotiations with Summit are underway.

## 2.5 On-going Computer Evaluations

We are continuing to evaluate portable computers to stay abreast of the latest developments in portable computing technology. Portable computers are becoming smaller and lighter, with more processing power, and a longer battery life. New developments in pen computer technology have allowed manufacturers to reduce their size and weight while simultaneously increasing their capabilities and battery life. These units have improved so much recently that they deserve a fresh look from inspectors, particularly from airworthiness inspectors.

Subnotebook computers offer a compromise between the capabilities of full notebook computers and their weight. Subnotebooks typically have somewhat smaller hard disk drives of around 120 MB (although this is increasing) and use external floppy drives; they are much smaller than notebook computers and weigh approximately half as much. A subnotebook computer will fit in a large overcoat pocket, which approaches inspectors' requests for a unit that would fit in a pocket.

While subnotebook computers may fit a majority of inspectors' needs, inspectors may also wish to do research on policy guidance in the field. In the last year several notebook computers with internal CD ROM drives have been introduced. These CD ROM notebooks have full multimedia capabilities, as well. These machines come in two configurations. One design has a CD ROM drive underneath its keyboard; the other uses a separate CD ROM docking station attached beneath a standard notebook computer. The first design has CD ROM available always; its drawback is that the user must always carry additional weight. The second design has the merit of allowing an inspector to leave the CD ROM drive (and its weight) behind when it is not needed; its drawback is that an inspector has to keep track of a second piece of equipment.

We envision providing samples of these computers to inspectors at the Atlanta [FSDO](#) prior to the actual field study. These inspectors will give us a first pass evaluation of the options; in turn, we can determine which computers offer the most promise for the field study.

## Chapter 2 - Appendix

### Job Aiding: Transition of Performance Enhancement System Concepts to Industry

#### Introduction

The Performance Enhancement System's success has brought the aviation industry's attention to the possibilities of supporting mobile maintenance technicians and auditors with portable computing technology. This is somewhat ironic, given that we started the research with these applications in mind but were unable to interest industry. During the last year, we have been working with a partner airline to transition [PENS](#) job aiding concepts to industry personnel. The following is a brief description of that work.

#### Airline Partner's Needs

Our partner airline has two groups of maintenance auditors within the Technical Standards office: Compliance Auditors and Vendor Surveillance Analysts. Both groups use a variety of forms to document the results of their audits. Both groups also have standards which they apply to the organizations that they audit, including Federal regulations (Federal Aviation Regulations,

Airworthiness Directives, etc.) and internal standards. Our partner airline wanted to support both groups of auditors.

The Vendor Surveillance group is responsible for auditing companies supplying materials and services to the airline to ensure that those companies are in compliance with Federal guidelines and with industry standards. Our partner airline is a member of the Coordinating Agency for Supplier Evaluations (CASE). The CASE organization is a consortium of airlines that pool their resources and auditing results. If a CASE member, e.g., our partner airline, evaluates a supplier and certifies that the supplier is in compliance with Federal regulations and CASE standards, then other CASE members know that they can use the supplier without having to perform their own audit. CASE provides both auditing forms and standards to its members. There are currently six CASE forms, although this number changes as new forms are added and old forms are retired.

The Compliance Auditor group is responsible for ensuring that our partner airline's maintenance operations are in compliance with Federal guidelines and with its own standards. The Compliance Auditors use approximately 32 forms.

## Software Prototype

We have developed prototype software to support both Compliance Auditors and Vendor Surveillance Analysts. Both prototypes were developed for use on pen computers because the auditors wanted capability similar to the clipboards they currently use. The collected data are stored in databases and can be printed out in standard report formats or exported to Microsoft Word. This is a vast improvement over the current method of manual transcription of handwritten paper forms.

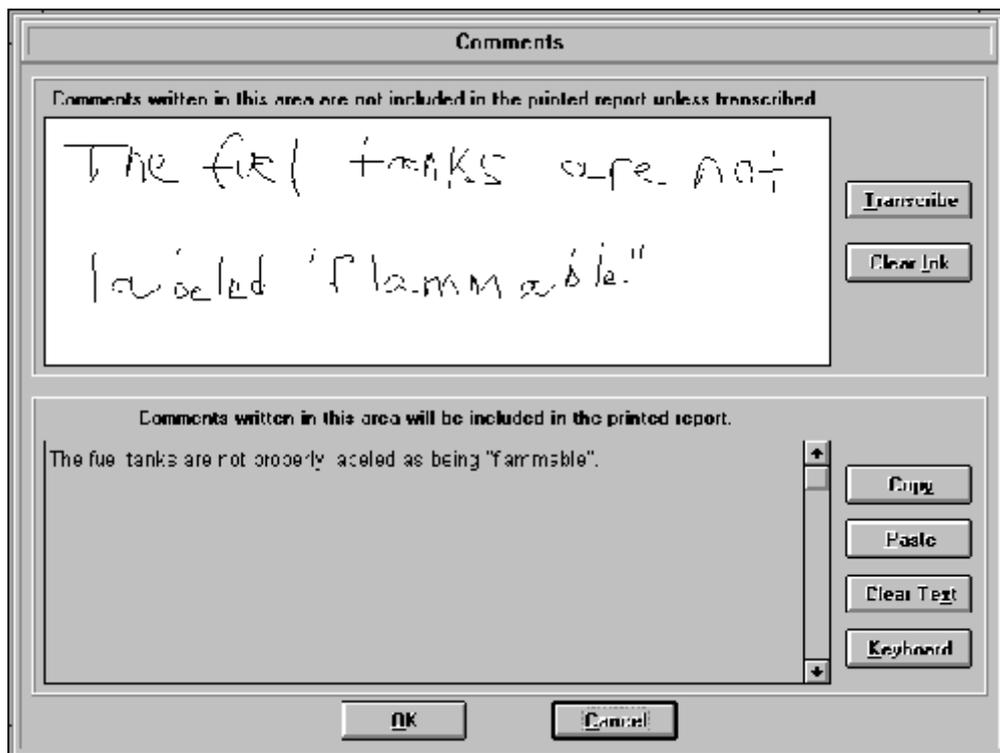
We developed an application that contains four of the forms Vendor Surveillance Analysts use most frequently. Each form is saved separately because a vendor normally provides only one supply or service. An example is shown in [Figure 2a.1](#). The application allows an inspector to identify whether a vendor is in compliance and to make a comment for each item on the form, as shown in [Figure 2a.2](#).

The screenshot shows a software application window titled "CASE - [CASE Air Carrier Section - Component Repair/Overhaul Vendor (Part A)]". The window has a menu bar with "Form", "Window", "Table of Contents", "General Comment", and "Help". Below the menu bar is a toolbar with various icons. The main content area displays a form with the following sections:

- 1. CERTIFICATION [continued]**
  - B. Record certificate number.
  - C. Obtain a copy of certificate and limitations.
  - D. Is the certificate displayed unobscured in an area accessible to the public? [IL]
    - YES  NO  N/A
    - Comment
- 2. ANTI-DRUG TESTING PLAN (TM) [TM]**
  - A. Does the ROV have an FAA approved anti-drug plan?
    - YES  NO  N/A
    - Comment
  - B. Record plan number.
  - C. The plan is:
    - A Vendor's  A Consortium's  An Air Carrier's

On the right side of the window, there is a vertical sidebar with page navigation buttons labeled "Page 1" through "Page 8".

Figure 2a.1 Example CASE Form



**Figure 2a.2 Example Comment**

The application also contains links to the [CASE](#) standards appropriate to the questions on the auditing forms. This allows an auditor quickly to access the standards for reference while performing an audit. As shown in [Figure 2a.3](#), there is a button next to a surveillance item ("Does ROV hold an [FAA](#) repair station certificate?") that identifies the standard. When an auditor pushes the button, the standard appears in Windows Help, as shown in the figure. Auditors like this capability because they can read the standard and because they can copy and paste it into their reports. Whereas their reports previously contained the auditor's recollection of the standard, they now contain the standard's exact wording.

We developed a similar application for the Compliance Auditors. Unlike the Vendor Surveillance application, forms are saved in "sessions"; all forms used in a given audit are saved together. This difference in design results from the fact that a given maintenance facility of our partner airline normally performs several different types of maintenance and requires multiple forms. Because the content of the forms is proprietary to our partner airline, we cannot publish examples. However, the format and content are very similar to the Vendor Surveillance forms. Because our partner airline has proprietary standards for evaluating their practices, its managers have been unwilling to share them with us so we could put them on-line.

## Evaluation

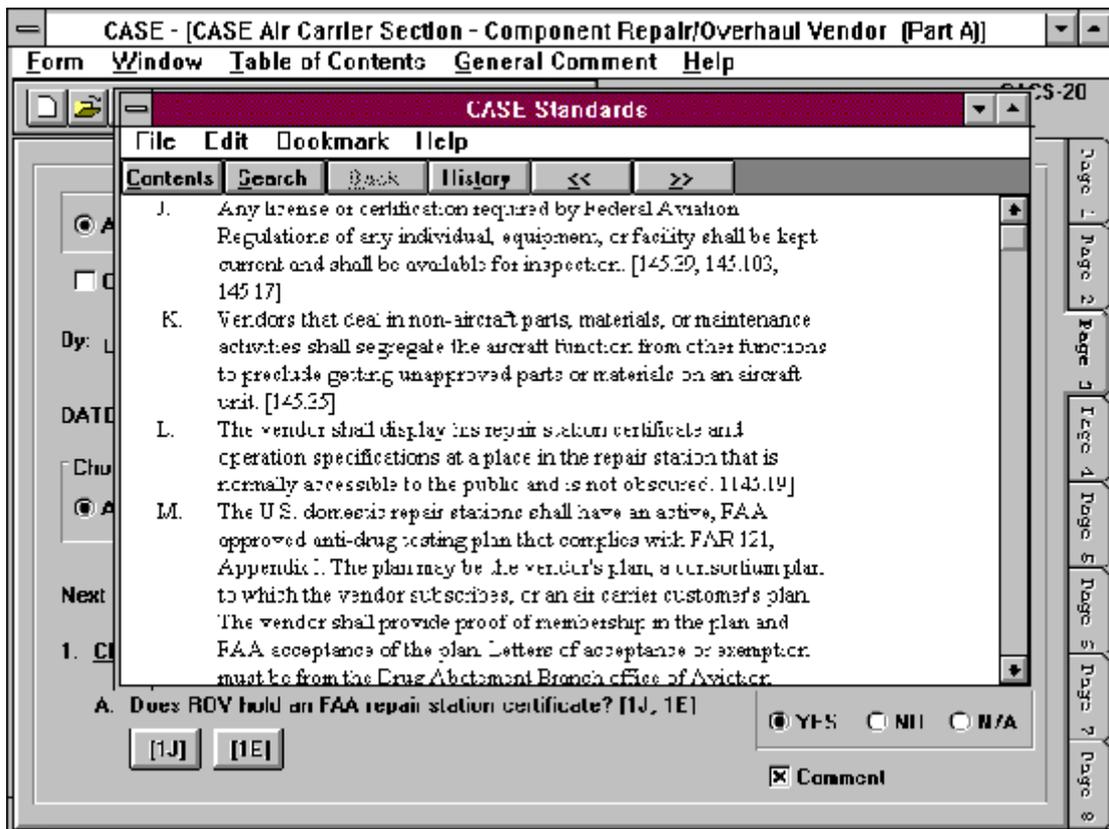


Figure 2a.3 Example of On-Line Standard

Both prototypes are currently under evaluation at the airline. We provided both groups of auditors with a number of pen computers and copies of the prototype software. Auditors are also using the software on their desktop computers. We expect the evaluation to run sixty to ninety days. Upon successful completion of the evaluation, we plan to work with the airline and the [CASE](#) organization to determine how these concepts can be applied within the broader aviation community.

# Chapter 3

## System for Training of Aviation Regulations

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### 3.0 Introduction

The ability to use [FAA](#) regulatory documents is a requirement for all who are associated with operations, maintenance, and surveillance of aircraft and associated air transportation systems and services. Schools, airlines, manufacturers, and the government require thorough knowledge, as well as reasonable appreciation, of the Federal Aviation Regulations (FARs) and the host of associated documents.

**Table 3.1** Sources of Information for Needs Assessment

- Mike Monroney Aeronautical Center
- Embry-Riddle Aeronautical University
- Clayton State College - Aviation Dept.
- Atlanta Area Technical School

Studying [FAA](#) regulatory documents is difficult. Instructors are given the arduous task of conveying the meaning of subtle and seemingly ambiguous material to a student body who do not always recognize the importance of what they are learning. The two most difficult aspects of learning the regulations are a) learning how to navigate through the [FARs](#) and other related documents and b) comprehending the meaning of particular statements within the FARs. FARs are legal documents written precisely to define the regulations pertaining to aviation. Unfortunately, it is not easy for most people to extract the intent of each statement from this style of writing. In addition, it is not always obvious where one needs to look to get a complete sense of the regulations' intent. Often, information relevant to a task is distributed across many parts of the FARs. For example, knowing one's eligibility to perform an [IFR](#) inspection may not be obvious when specifications for how to do the inspection are outlined in Part 43, Appendices E and F, but the privileges and limitations for who can perform the inspection are stated in 91.411b and 91.413c.

The purpose of the System for Training in Aviation Regulations (STAR) project is to aid instructors in teaching about the [FARs](#) (and other related documents) by providing a system that motivates the student to understand why learning the FARs is both relevant and necessary, develops students' study and cognitive skills in document research and understanding, and c) makes the content of the FARs more interesting and therefore more memorable.

Our approach to designing and developing [STAR](#) is to incorporate multimedia presentations and storytelling techniques within several different types of learning environments. The goal is to provide a comprehensive curriculum for acquiring the skills and content necessary for efficient document research and comprehension.

### 3.1 Phase V Overview

The project began in earnest on October 3, 1994. In the six months ending April 1, 1995, the project team will have conducted a needs analysis, developed a research approach guiding the design of [STAR](#), and built the initial prototype. A preliminary evaluation of the prototype will be conducted prior to April 1. A great deal of time has also been spent assessing the best way to integrate digital document products with government-owned multimedia training systems. A detailed discussion of

each of these areas is presented below.

### 3.2 User-Centered Design

We are employing a user-centered approach to technical design (Chandler, 1994; Rasmussen, 1992; Greenbaum & Kyng, 1991; Norman, 1986). Instructors from the [FAA](#) Academy in Oklahoma City, three Part 147 schools, and one flight training academy were interviewed regarding current instructional practices. [Table 3.1](#) shows the sources of information for our needs assessment.

Instructors were asked to identify the major issues preventing students from learning aviation regulations and to try to envision how a [CBT](#) system could address some of these difficult instructional issues. The responses to our inquiries were as varied as the people in attendance, but a pattern did emerge. [Table 3.2](#) summarizes the learning issues instructors identified and areas where CBT could support instruction.

As a result of these interviews, several general research questions emerged to guide the development of [STAR](#) and its evaluation. [Table 3.3](#) lists the research questions. Our answer to the question "How do we induce students to think deeply about the subject?" will embody our philosophical approach to instruction. This will become more apparent during the discussion below of the design overview. "Which learning situations are most effective for what types of learning?" is the question that will guide the experiments for evaluating STAR's success as an instructional system. The other three questions identify technical issues pertinent to user interface design and system functionality that we will need to address throughout the project.

#### Table 3.3 Research Questions

- How do we induce the students to think deeply about the subject?
- Which learning situations are most effective for what kinds of learning?
- When is it more effective to use what kinds of presentation types to convey the salient points in the learning environment?
- What kinds of information retrieval mechanisms are the most valuable to students? to instructors?
- How can we translate digitized material meant for a personal computer into a medium suitable for distance learning broadcasting?

We decided to focus our attention on the training of Aviation Maintenance Technicians (AMTs) for the first two phases of this project and, then to incorporate training for pilots later. We sought the assistance of Jack Moore, Dean of Clayton State College - Aviation Department, as our domain expert for this phase of the project. He and other instructors of Part 147 schools in Atlanta have provided stories, examples, strategies, technical information and documentation to be used as a basis for developing the curriculum. We will expand this information base to other Part 147 schools around the country during the second phase of the project.

### 3.3 Design Overview

#### Table 3.2 Summary Learning Issues and Where [CBT](#) Could Support Instruction

- Students need help in
- knowing who the players are (e.g., owner, [AMT](#), pilot, [FAA](#) maintenance inspector), what their responsibilities are to each other, and for what regulations each must be responsible
  - understanding the objectives of the [FARs](#) and when and how to apply them

- understanding the codependency of regulations to each other
- learning to extract the root meaning from the FARs' legalese
- performing document research procedures
- recognizing when appropriate (or optimal) procedures are applicable
- integrating the individual pieces of their job tasks into a total picture

CBT could support instruction with

- a system that supports multimedia presentations during class lectures
- a series of scenarios that elucidate the subtle applications of the regulation
- drill and practice sessions that show each student where his or her weak points are
- a mechanism that allows instructors to monitor how the students are doing
- technical aids that support students while they go through the learning process

When teaching subtle information such as aviation regulations, there are advantages to providing students with many vantage points to the same body of information. Experiencing complex material repeatedly under different circumstances provides the learner with multiple opportunities to gain a deep understanding of the subject. Each vantage point not only covers different aspects of the same material, but also reinforces different kinds of study skills. In addition, information conveyed through one learning environment may be more salient to a learner than another approach. Students with different learning styles are more likely to benefit when different vantage points are provided. In this way, we provide students not only with multiple ways of viewing the information, but also with multiple opportunities to learn.

The core of the system is a document browser that has full text searching capabilities both within and among documents. This allows students to search and view the documents in their entirety. It also gives students practice in manipulating the documents on-line, a practice that we anticipate will be the norm in the future.

Several instructors identified a desire to have multimedia clips punctuate important points they make during lectures about the regulations. They see this as a means for making their instruction more interesting and motivational for the students. Instructors at the [FAA Academy](#) in Oklahoma are particularly interested in this since they are developing a center for distance learning.

The document browser is designed to support efficient review of media clips to augment class presentations. Associated with each document are all the multimedia information clips presented in the other learning environments. For example, a video about instrument inspection will be indexed with the document section that discusses instrument inspection. The browser becomes an archive for the documents and all the media clips. Each media clip is further indexed by one of nine information types listed in [Table 3.4](#). A "Very Important Point" information type, for example, may warn students of a regulation that is often violated and why or how it gets violated. A "For Your Information" information type may point out the subtle difference between when an inspection must be completed every 2 years vs. every 24 months. A "For Example" may show a student what a correct log entry looks like. By using the documents themselves as indexes, augmented with classifying the media clips into information types, we have developed a simple system for organizing what is often a very difficult body of information to catalog. We see this as a natural way for instructors to review media clips relevant to the material they will be covering in class.

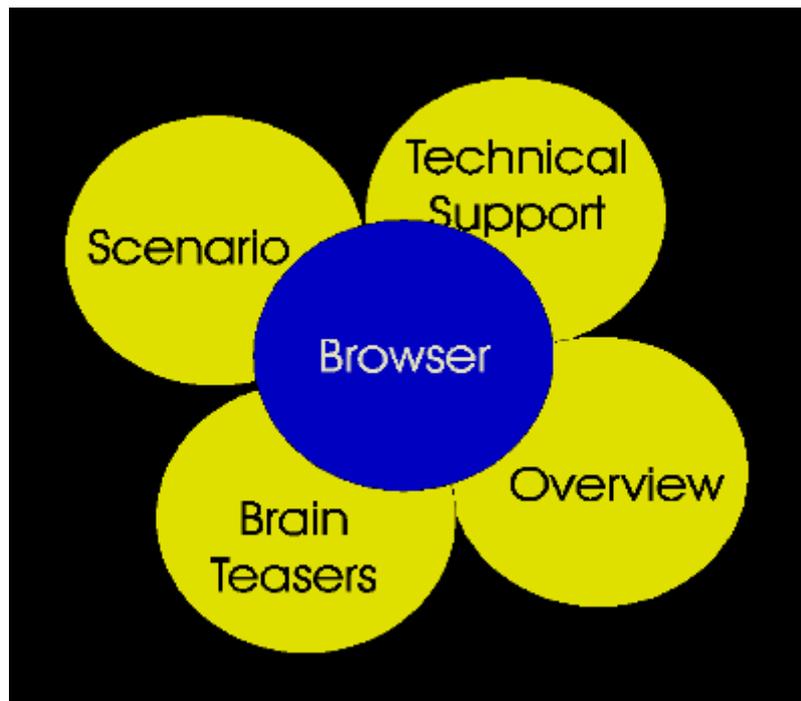
Surrounding the document browser ([Figure 3.1](#)) are four categories of learning environments: overviews, scenarios, brain teasers, and technical support. Overviews show students how [FARs](#) are organized, how different parts are related to each other, and who is responsible for what aspects of those regulations. Scenarios are interactive stories that set each student into a true-to-life situation where the regulations are often subtle. The scenarios present students with choices they need to make within the context of a given situation and show the students the consequences of those actions. It is important to note that there is often more than one right or wrong answer and that understanding why one action is wrong in a particular context is just as important as understanding why another action is

right.

**Table 3.4** Media Information Types

- General Procedures
- Strategies for Within Document Search
- Strategies for Between Document Search
- For Your Information (FYI)
- Very Important Point (VIP)
- For Example
- Personal Experience
- System Information
- Terminology

Brain teasers present challenges to the student. They require students to exercise certain skills they will need to develop in order to efficiently search the regulations and understand what they find. Brain teasers can vary in complexity. They can be of the "[FAR Jeopardy](#)" variety where students can practice quick responses to specific facts. Brain teasers can also be of the "project" variety where solving a challenge entails a deep understanding of both the search process and the regulations themselves. We see this area as a space where instructors can develop their own challenges for their own students.



**Figure 3.1 Learning Environments Identified for STAR**

Technical supports are comprehension aids such as a technical dictionary. Another example is an interactive timeline showing the progression of ownership of a particular type certificate by different manufacturers. These aids provide "as needed information" that can be explored in their own right or use in conjunction with other, more formal learning environments.

Each learning environment could be a stand-alone application. Together they provide multiple vantage points for the student to explore aviation regulations. Part of our assessment of the total project will be to identify which learning environments are most effective for what types of learning. By focusing on the evaluation in this manner, we not only will assess the effectiveness of the application, but gain a better understanding of what types of learning is occurring (or needs to occur) and how we should tailor our training systems to achieve specific learning objectives.

Our long-term goal is to develop authoring tools for the most successful learning environments so that the domain expert, i.e., the instructor, can contribute directly to the system rather than remain dependent on application engineers for knowledge acquisition and implementation. In this way, the system can take on a life of its own becoming a repository of pedagogical expertise in aviation training.

### 3.4 Cooperation with Digital Document Providers

Digital documentation is a critical component of [STAR](#) and other document-oriented training systems such as *The Human Factors Guide* (see [Chapter 4](#)) and *The Inspector Handbook* (see chapter 4), currently under development at Galaxy Scientific - Atlanta. Over the last four months, the digital documents group has identified what functionality such a system must support, who the key commercial publishers are, and the feasibility for a commercial vendor's product to be integrated into a government-owned multimedia training system.

The details of this evaluation are presented in chapter 4. To summarize our findings, it became apparent that what is needed are functions that give each system designer the power to do full text search of documents and, the flexibility to display the retrieved document in a manner consistent with the training system's interface. Though the group continues to evaluate the commercial market, the [FAA](#) Hypermedia Information System (HIS) seems to be best suited for providing that flexibility. We have begun the process of extracting the functional components from HIS so that they can be used by the different training systems.

### 3.5 The STAR Prototype

For the first phase of system development, we began building a prototype for the document browser and the scenario learning environment. Scenarios lend themselves to capturing the instructional information. When a Part 147 instructor tells of a typical situation where interpreting the regulations is subtle, personal experiences, examples, "By the Way" information, warnings, document search strategies, and general procedures naturally flow from the telling of the scenario. This information is not found in textbooks or the regulations themselves, but is crucial to an in-depth understanding of the regulations. The interchange of stories is not only the most common way that we exchange information, but is considered the optimal form for retention of the information received (Bruner, 1990; Shank, 1990). The document browser serves primarily to organize the information that is being collected.

Scenarios are essentially interactive stories. Through a slide show presentation, students are told of an unclear situation where several actions are possible. They are asked a question about what they should do given the situation and are presented with several actions that they could take. Following is the textual passage presented to the user for the opening scene of the special inspections scenario.

You are a technician with both A and P ratings. During a 100 hr inspection on an [IFR](#) equipped C-172, you notice that the altimeter and transponder have not been tested and inspected in the last 24 months. When you inform the owner that these tests and inspections are due, he asks: "If these tests and inspections are due, why didn't you do them as part of the 100 hour inspection?" How do you respond to this question?

Once a student chooses an answer, a new scene in the scenario is presented. The new scene shows the consequences of the action and the rationale for why the student should or should not have made that choice. Imbedded in each explanation are references to relevant [FAR](#) passages and other supporting documents and examples. For example, a student might be shown a sample of a correct log entry for the type of maintenance work he or she did or a comparison between two passages from the FARs where a distinction needs to be made.

Although for each scenario there is the "best" path to take, our objective is not to train students to take that path. Rather, to get the most out of the scenario, they should explore all the paths. By doing so, they acquire a deep understanding of the situation and an appreciation for the subtle distinctions they need to make with respect to fully comprehending the intent of the regulations. In this sense, there is no right answer, only deeper understanding. How we entice students to explore all of the scenario paths rather than just to find the "right" answer is part of the larger research question about inducing students to think deeply about the subject.

While each scene in the scenario has a multimedia presentation that "tells the story", students also have access to other relevant material that has bearing on the situation. In the gray scale background graphic used to set the scene seen in [Figure 3.2](#), there are colored items in the picture. When a user clicks on one of the colored items, a video or detailed graphic or explanation of the item is presented. In our instrument flight scenario, for instance, clicking on the altimeter will bring up a video that explains the functionality of an altimeter in the aircraft. Also, along the bottom of the screen are buttons that access other related information categorized by information type, e.g., [FYI](#), Personal Experience, General Procedures, etc. Students may navigate through the scenario but also can explore the details of each scene in its own right.



**Figure 3.2 Colored Items Can Be Selected For Detailed Explanations**

As stated previously, the most important research question that we will be addressing in this project is, "How do we induce the students to think deeply about the subject?" The cognitive and educational literature claims that to achieve this goal the student needs to be actively involved in the learning task (Brown, 1992; Scardamalia & Bereiter, 1992; Resnick, 1991; Bransford et. al., 1990; Papert, 1980). They need to be asking the hard questions and trying to answer them. There is always a risk of losing the students by challenging them with something that is beyond their technical knowledge, skill level, imagination, or, on the opposite end of the scale, boring them to death. While scenarios in their present "canned" state do not necessarily induce the students to think for themselves, they may serve as a stepping stone to the more open-ended challenges presented in the brain teaser learning environment. Scenarios do show the students the kind of thinking process they need to employ in order to make sophisticated decisions about ill-specified problems. By mimicking the reasoning presented in the scenarios, students should be able to solve the brain teaser challenges. It will be important, when developing the brain teaser learning environment in the next phase of research, that some of the brain teasers are similar in structure to those in the scenarios so that students can practice transferring reasoning skills to new situations.

### 3.6 User Acceptance and Training Effectiveness

The culminating event for this phase of the project is to present the [STAR](#) prototype at the 34th Annual Conference of [ATEC](#) in April 1995. The conference will provide a wide audience of aviation instructors from across the nation. We will use this forum as a vehicle to give us feedback on the STAR concept and design, and also an opportunity to tap conference attendees expertise. We will set-up several vehicles (including a video camera) for capturing their stories and experiences for further development of the system.

In preparation for the conference, the project team will first conduct an in-house technical evaluation at Galaxy Scientific. That session will focus primarily on compatibility issues in the user interface design (Maddox & Johnson, 1986). The instructors and a select group of students at Clayton State College will also have an opportunity to evaluate the [STAR](#) prototype. We will ask them to focus on system understandability, content accuracy, information presentation and ease of use (Maddox & Johnson, 1986). Formal evaluations of the system in a classroom setting will begin in Phase VI.

### 3.7 Future Research Phases

Phase V will draw to a close in April 1995.

#### **Table 3.5** Tasks for Phases VI and VII.

##### Phase VI

- Convert the scenario and document browser into fully functioning Learning Environments.
- System evaluation - non-directed setting.
- System evaluation - formal classroom setting.
- Develop prototypes of the overview, technical support and brain teaser learning environments.

##### Phase VII

- Convert the overview, technical support and brain teaser into fully functional Learning Environments.
- Conduct comparative study between traditional instruction and instruction incorporating [STAR](#).
- Expand content of system to include curriculum for Aviation Flight Schools.
- Assess potential for converting training systems into authoring systems.

[Table 3.5](#) outlines the tasks for Phases VI and VII. System Evaluation will be an important part of Phase VI. We will be analyzing what the students learn from the system in both a non-directed and a directed setting. First, we will evaluate the robustness of the system and how students explore the system when it is not tied to a formal class activity. A history trace will be kept of each student's activity on the system. The second part of the evaluation will be in a more formal classroom setting where students will be asked to use the system in the context of one or more classroom tasks. The focus here will be on what the students learn. Pre- and post-testing will be one instrument for this analysis. Another instrument will be based on the pedagogical dimensions developed by Reeves (1994) for evaluating interactive learning environments. Analysis of students' history trace will also be made to see if patterns emerge between learning success and application use. These results will be the bases for making decisions with regard to incorporating intelligent tutoring agents into [STAR](#).

In preparation for the extensive evaluation of the system, the scenario and document browser will be developed into fully functional learning environments. The major task to fulfill this goal is producing the curriculum and multimedia materials to build at least one complete instructional unit. An example unit could be a series of scenarios about [AMT](#)'s privileges and limitations. To show the extent of the instructional possibilities, we will also create several different types of scenarios that are not part of the core unit. In tandem with these other efforts, prototypes for the "overview",

"technical support" and "brain teaser" learning environments will be developed and initial evaluations of their interface design, robustness, and content accuracy will be conducted during Phase VI.

A comparative study between traditional instruction and instruction incorporating [STAR](#) as an integral part of the curriculum will be made during Phase VII. In preparation for this study, the overview, technical support, and brain teaser prototypes will be developed into full learning environments. The content of the training system will be expanded to training pilots and the potential for converting the training systems into authoring systems will be assessed.

### 3.8 Summary

The [STAR](#) project gives us an opportunity to bring out the complexity, subtlety, and interesting aspects of what is normally thought to be a dry subject. It provides a vehicle for practicing skills in document research and complex decision-making. It gives students practice with computerized tasks that they will be expected to use with facility in the near future. It provides a vehicle for interacting with the subject matter from several different vantage points, increasing the chances of each student acquiring an in-depth understanding of the material. And, as researchers, it gives us the opportunity to evaluate what instructional vehicles are best suited to achieve the learning objectives we have set for our students. This indeed is an opportunity.

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# Chapter 4

## Digital Documentation Systems

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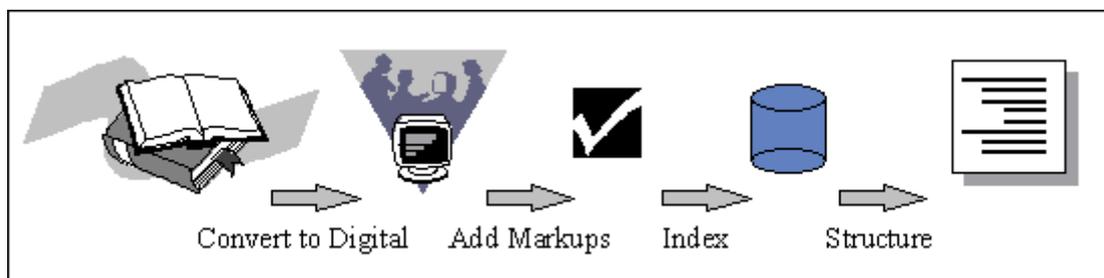
### 4.0 Introduction

Digital documentation systems are a key component of the Human Factors in Aviation Maintenance research program. This study of digital documentation systems was undertaken in an effort to address problems associated with the publication, distribution, and use of large quantities of printed information in the aviation industry. Digital documentation systems have an advantage over paper or microfiche documents in terms of compactness of information. For example, a bookshelf of manuals and reference materials can be stored electronically on a single CD-ROM. Other advantages of electronic documents include the potential cost savings and faster, more effective access to needed information. With a paper/microfiche system, a maintenance technician could spend considerable time researching information for a given maintenance task on an aircraft. With a properly developed digital documentation system, the time can be substantially reduced, perhaps to only a few hours. Air carriers will save money from quicker turn-around times on maintenance tasks. General Aviation will benefit from reduced paper-based research associated with Annual Inspections.

The conversion from printed to electronic information, however, is not without costs, and the research program is investigating ways of efficiently creating, accessing, and maintaining digital documentation with a focus on ensuring an interface that is compatible with the aviation users. The Hypermedia Information System (HIS) has been developed to investigate digital documentation storage and retrieval issues. Hypermedia is a computer-based technology that allows non-linear access to information. The information may be in the form of text, graphics, audio, video, or animation. For more information on the HIS system, see [Chapter 6 of the Phase IV report](#) (FAA/AAM & GSC, 1994).

This chapter describes research and development activities related to digital documentation completed in the past year. [Section 4.1](#) details the process for converting documentation from paper to electronic form. [Section 4.2](#) describes how the initial prototype of the digital *Human Factors Guide* was designed and developed. [Section 4.3](#) describes the contents of CD-ROM #3. Finally, [Section 4.4](#) discusses future plans for digital documentation research.

### 4.1 Digital Documentation Process



**Figure 4.1 HIS Digital Documentation Process: Four Basic Steps**

The process of converting a document into digital form requires several steps. [Figure 4.1](#) illustrates the basic digital documentation process. This section describes basic steps used to process a paper document for the [HIS](#): convert it to digital form, add markups, index the text, and structure the

topics.

#### 4.1.1 Convert to Digital Form

If no electronic version of the document is available, the first step is to convert printed text to digital form. For small documents, it may be feasible to type the document using a word processor; for larger documents, typing may be too labor-intensive. Fortunately, commercially available hardware and software semi-automates this process. A scanner is similar to a photocopier; it is attached to a personal computer. Optical Character Recognition (OCR) software converts a scanned image of text into an ASCII text file, i.e., OCR software "recognizes" bitmap characters and "types" the corresponding ASCII character into a text file. OCR software does not preserve formatting such as bolding or italics. For more information on the OCR process and a review of commercial OCR software products, see Mantelman, 1994.

Since neither typing nor [OCR](#) conversion is error-free, a major part of this step is to verify the output for accuracy. Verification can also be time-consuming and tedious, although standard word processing tools like spell checkers can assist. Some other techniques have been developed to locate errors quickly. For example, the same document may be processed by two typists, or by two OCR packages. Resulting files are compared using a software utility program that locates any differences between the two files. Since differences often correspond to errors, this technique helps automate the verification process.

Since many documents contain figures and images, as well as text, the conversion to digital form is not complete until non-text portions of the document are processed. Scanners can also assist in this process. Depending on the quality of the original paper document and the capabilities of the scanner, varying amounts of post-scanning cleanup may be necessary to obtain good quality graphics. In instances where the item does not scan well, it may be necessary to recreate the graphic or figure using a software drawing package.

It is difficult to offer a general rule for how long it takes to complete this first step. The necessary time depends on several factors, including: the document's quality and length, the number and complexity of graphics, and speed and capabilities of personnel, tools, and techniques. A simple document with few graphics can be processed relatively quickly, but a large document with special layout can take substantial time. For example, the Air Transportation Operations Inspector's Handbook is approximately five hundred pages long, laid-out in columns. The conversion took over three person-weeks to complete.

Given the labor intensive nature of conversion, it is extremely beneficial to omit this step. This is possible only when an electronic version of the original document exists. However, even when an electronic copy exists, some processing may be needed to have electronic data in a format compatible with [HIS](#) tools running on IBM PC-compatible computers. For example, if the digital document exists on a mainframe, the data would need to be converted to an IBM PC-compatible text file format.

#### 4.1.2 Add Markups

As soon as an electronic version of a document is available, the next step is to add special markups to the file. Markups are standardized sequences of characters used to "mark" portions of the text with formatting and hypermedia information. [Figure 4.2](#) shows Galaxy Markup Language (GML) syntax for some common markups. GML was developed a few years ago for the [HIS](#) system and is similar to standard markup languages like SGML (Standard General Markup Language) and HTML (Hypertext Markup Language).

[HIS](#) allows for three methods of completing the markup step: *use the point and click authoring mode in the HIS viewer, write and use a macro, or write and use a filter program*. Each method is described below. The markup method chosen depends on the size of the document, the number of

markups to be made, the format of the electronic file, and the programming capabilities of the person doing the processing.

<b>Common Formatting Markups</b>	
Bold:	<code>&lt;B&gt; ...text... &lt;/B&gt;</code>
Italics:	<code>&lt;I&gt; ...text... &lt;/I&gt;</code>
Underline:	<code>&lt;U&gt; ...text... &lt;/U&gt;</code>
Font:	<code>&lt;F"(font),(fontsize)"&gt; ...text..</code>
Indent:	<code>&lt;indent"(level),(pre-indent string)"&gt; ...text... &lt;/indent&gt;</code>
Center:	<code>&lt;center&gt; ...text... &lt;/center&gt;</code>
Flush Right	<code>&lt;right&gt; ...text... &lt;/right&gt;</code>
Margins	<code>&lt;margin"(left margin),(right margin)"&gt; ...text...</code>
<b>Common Hypermedia Markups</b>	
Tag:	<code>&lt;TG"(tag reference),(caption)"&gt;</code>
Hot Table:	<code>&lt;HT"(file),(caption)"&gt; ...text... &lt;/HT&gt;</code>
Hot Graphics:	<code>&lt;HG"(file),(caption)"&gt; ...text... &lt;/HG&gt;</code>
Hot Media:	<code>&lt;HM"(file),(caption),(start),(end)"&gt; ...text... &lt;/HM&gt;</code>
Hot Executable:	<code>&lt;HE"(command line)"&gt; ...text... &lt;/HE&gt;</code>
Hot Link:	<code>&lt;HL"(tag reference)"&gt; ...text... &lt;/HG&gt;</code>

**Figure 4.2 Examples of Common Markups (GML Syntax)**

#### *4.1.2.1 Use HIS Author Mode*

A person with no programming skills can use the [HIS](#) viewer's authoring mode for adding markups to a document. Author mode allows a text file to be loaded into the viewer and marked up manually. Manual markups are accomplished by a user selecting portions of the text and then choosing the type of markup desired, e.g., bold, topic, or hotword.

For example, if a user wants to create a hotword linking to a graphics file, he or she would select the portion of the text he or she wants to be the hotword, and then select the menu option to create the link. As shown in [Figure 4.3](#), a dialog box is then displayed that allows the user to specify the type of link to be created. The authoring system interprets the user's point and click actions as instructions to add the proper markup to the text file. At the end of each authoring session, the user must save changes to save markups that were added. While this method is feasible for small documents with few markups, it is too tedious and time-consuming for large documents with a substantial number of markups.

#### *4.1.2.2 Write and Use a Macro*

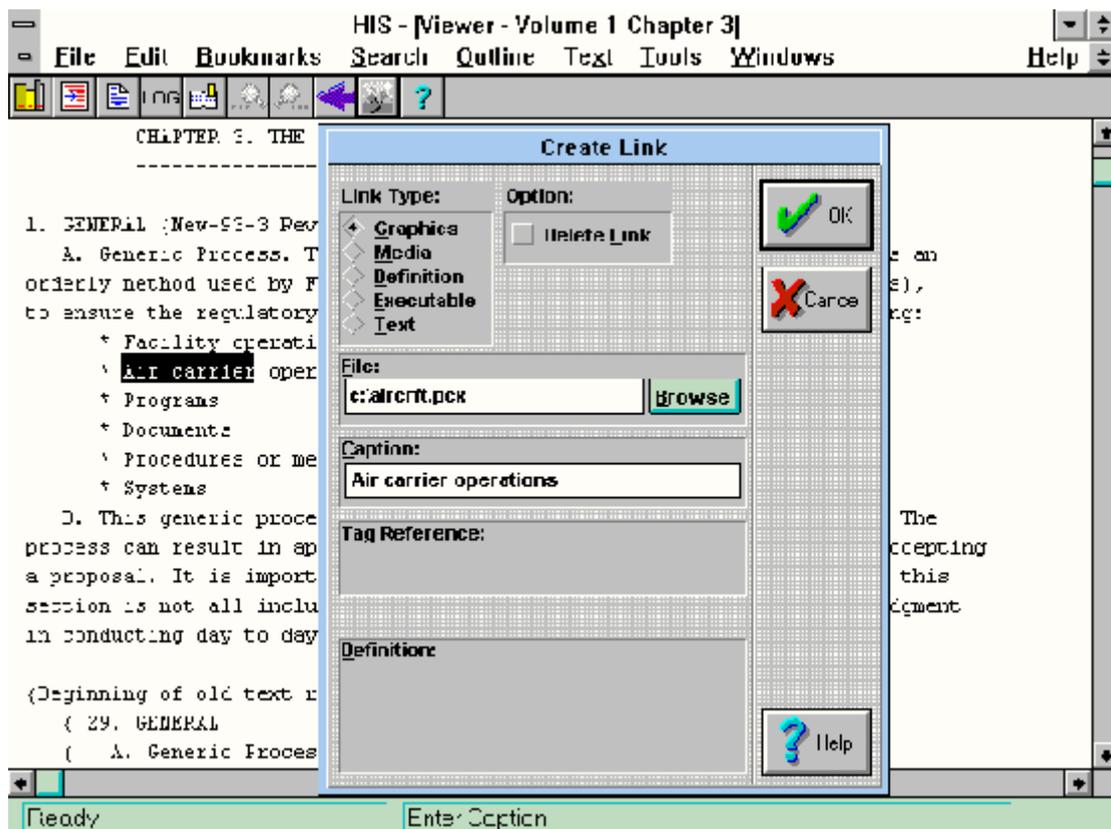
The process of adding markups can be automated with the help of macro facilities in some word processing packages. For example, Microsoft Word contains a macro facility which records a series of mouse and keyboard actions in a Word Basic program. A user needs only minimal programming skills to edit these macro programs. Such commercial tools can be used to convert formatting information in Word files to corresponding [GML](#) markups and to add other GML markups such as topic tags and hotword links.

One of the greatest benefits of such automation is that an unlimited number of files can be processed once the macro is written and tested. If the contents of a document change over time, a filter automating the markup process saves time and money by keeping the on-line system current with

changes. If the documents to be processed are Word files (or a format easily converted to Word), this method is the obvious choice for adding markups.

#### 4.1.2.3 Write and Use a Filter Program

Writing a filter program to add markups to a file requires the most programming skill. Before the program can be written, one must analyze the document to see how it is organized, i.e., Volumes, Parts, Chapters, Sections, etc. A user can then write a filter that uses lexical tools automatically to place markups in the appropriate places. Once the filter is written, it can be tested on a representative file to locate and fix any mistakes. If the document is fairly uniform, writing and debugging a filter does not take very long. However, the filter for [FARS](#) took approximately a week to write because FARS are not uniform, i.e., [SFARS](#) and appendices are intermingled with Parts.



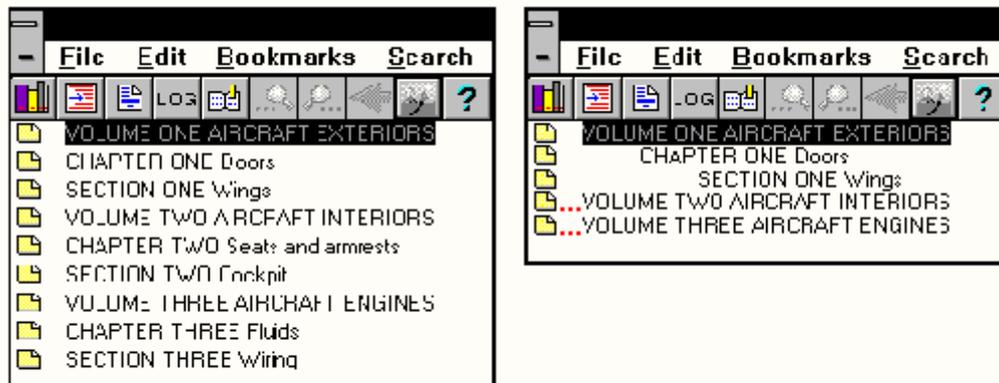
**Figure 4.3 Adding a Hotword in HIS Authoring Mode**

After the filter is debugged, a user can write a batch file to run the filter on all of the document's files. Depending on the document's size and the number of markups to be added, run-time may take from 3 to 20 minutes per document. Although filter programs are useful for automating the bulk of the mark-up process, it is likely that some markups will need to be added manually. A user can add these additional markups directly to the [GML](#) file with a text editor; the [HIS](#) Authoring mode can also be used to add a small number of mark-ups.

#### 4.1.3 Index

The third step in the process is to index marked-up files. *Indexing* is a technical term for building a database to support full-text searching and hypermedia linking. For full-text searching, the database stores every word in the document and its location in the document. Certain words are not indexed because no one would want to search for them; these "stop Galaxy Markup Language words include articles (e.g., a, an, the) prepositions (e.g., of, at, in) and pronouns (e.g., she, he, it, you).

For hypermedia linking, the database stores information for two primary types of markups: tags and hotwords. The tag markup designates topics for the Table of Contents. The database stores the location of each tag markup so the user can jump directly from the topic in the Table of Contents to the associated text. The hotword markup designates words or phrases in the document which link to other information. The database stores the location of each hotword and the location of its associated text, graphic, video, or audio.



**Figure 4.4 HIS Table of Contents: Unstructured vs. Structured Topics**

HIS tools include an indexing program that processes GML files. For a single small document, indexing may take only a few minutes; for large documents, it can take several hours. The HIS indexing tool allows a developer to index a group of files as a batch job. The developer can set up the job and allow it to run unmonitored overnight. This feature minimizes the impact of a slow indexing process. This process can be repeated over several nights to index very large documents. For example, it took about eighteen hours to index the FAR text into an HIS database.

#### 4.1.4 Structure Topics

In the HIS system, topics correspond to items listed in the Table of Contents, such as the chapter, section, and subsection headings. In the markup step, all topics are identified with the tag markup. The indexer stores each topic's location in the database, so a user can jump from the Table of Contents to any topic's beginning. The final step in the conversion process is to structure topics into an outline so the HIS Table of Contents viewer displays the topics hierarchically.

To illustrate the effect of the structuring process, [Figure 4.4](#) shows HIS displaying the Table of Contents for an example document, both before and after structuring. For the *unstructured* document, notice that all topics are listed without any indenting. After the topics are structured, HIS displays only topics at the highest level of the outline, such as the chapter titles. When the user clicks a page icon, the next outline level appears.

The structuring process does not require a lot of time, compared with the time required for other steps in the process. This step is partially automated, so a small program must be written to add level information to topics in the HIS database. A structuring program is customized to the syntax of the topics in a document; therefore, it will only be valid for documents with the same syntax. For small documents, run-time can take less than an hour; for larger documents such as the FARs, run-time may take several hours.

#### 4.1.5 Discussion

The digital documentation process obviously requires some investment of time. The actual time

required depends on several factors, including the size and state of the original document. To illustrate all the steps for the HIS system, in this section, we discussed the four basic steps necessary if a large document does not exist in digital form. There are substantial time savings to be gained if the process can start with an electronic, rather than a paper, document.

We did not discuss additional steps required if audio, video and/or animation are to be included in the digital documentation. Additional time and effort is required to locate and/or create such media, as well as to process it into a form the HIS system can use. If the additional media already exists, and is easily located, costs are lower than if original media must be created. Appropriate footage may not exist, or may take a long time to locate. When appropriate footage is located, copyright permissions must be obtained before it can be used in the project.

The benefits of digital documentation, with or without additional media, must be weighed against the costs for converting and maintaining on-line documentation. Informal evaluations of the HIS system have been conducted, with positive results. The benefits of quicker and more accurate access to information, as well as portability of electronic data, provide sufficient benefits to warrant conversion of a variety of aviation maintenance data to digital form.

## 4.2 The Electronic Human Factors Guide for Aviation Maintenance

One of the major digital documentation projects completed during the past year was the design and development of a prototype Electronic Human Factors Guide. This Electronic Guide (E-Guide) is the digital counterpart of the paper-based *Human Factors Guide for Aviation Maintenance (the Guide)*. The *Guide* describes fundamental human factors concepts and guidelines for aviation maintenance supervisors and technicians. Its goal is to provide practical, usable guidance to supervisors and planners in the aviation maintenance industry.

The E-Guide utilizes the HIS functionality to improve access to the *Guide's* content. It provides the HIS full-text search capability, as well as hypertext linking between chapters. The E-Guide expands on the *Guide's* content by incorporating video that supplements the paper-based *Guide's* text and still images.

The HIS authoring tools were selected for development of the E-Guide over commercially available tools for three primary reasons. First, the HIS technology met the functional requirements that were desired. Second, most commercially available tools that meet the functional requirements do not meet the cost requirements. That is, substantial fees are required for distributing the commercial software used to view the electronic information, typically around \$50/copy. Documents developed with HIS authoring tools do not incur any "per copy" costs. Finally, customization is possible using the internally developed HIS software. If a new feature is needed or a change in an existing function is required, the HIS authoring tools can be modified. Such control is not possible with commercial software tools.

In this section, we describe design issues and interface features of the prototype system. We conclude with a summary of initial user feedback about the E-Guide and the modifications we are implementing.

### 4.2.1 Designing the Electronic Guide

The E-Guide was designed in coordination with the paper-based *Guide*. As with the paper-based *Guide*, there were three design goals for the E-Guide:

- it should be readily accessible to the aviation community
- it should be easy to maintain
- it should be easy to use.

In this section, we discuss how we achieved these goals during the design and development of the

initial E-Guide prototype.

#### 4.2.1.1 Achieving the Accessibility Goal

One goal of the *Human Factors Guide* research program is to provide wide and easy access to the information written for the *Guide*. The E-Guide will be accessible in two ways: CD-ROM and Internet. A CD-ROM disc holds approximately 650 megabytes of data; this is sufficient space for the *Guide's* text and media, as well as relevant documentation such as the FAA/AAM meeting proceedings and phase reports. Because such a large quantity of information can be stored on one CD-ROM disc, the E-Guide can easily be distributed to the aviation community at a reasonable cost. The cost to replicate each disk, including packaging materials, is approximately \$1.65.

The research team is investigating the Internet as an alternative means for information distribution (see Chapter 5, *Skyway*). The *Guide's* complete text will be on the Internet to ensure wide distribution of the information, especially to those without a CD-ROM player. To date, one draft chapter of the E-Guide has been successfully converted to [HTML](#) and placed on the Internet.

#### 4.2.1.2 Achieving the Maintenance Goal

The *Guide* is intended to provide practical guidance to aviation maintenance supervisors and planners. Since issues and problems of maintenance constantly change, the *Guide* needs periodic updating to address new problems. The challenge is to keep the information in the *Guide* current at minimal cost.

The paper version solves this problem by providing the *Guide* in a three-ring binder, instead of in book form. A chapter can be added, eliminated, or upgraded without discarding the whole book. This keeps the cost to upgrade and distribute information at a minimum.

The cost to upgrade the system includes the cost of modifying both digital documentation and interface software, as well as the cost to redistribute the software. Redistribution costs are minimized by using CD-ROM and the Internet. The cost of modifying software depends on the effort involved in reprocessing portions of the digital documentation. We streamlined the HIS digital documentation process in the following ways to minimize this cost:

- The *Guide* is being developed in Word to eliminate the need to convert from paper to digital form.

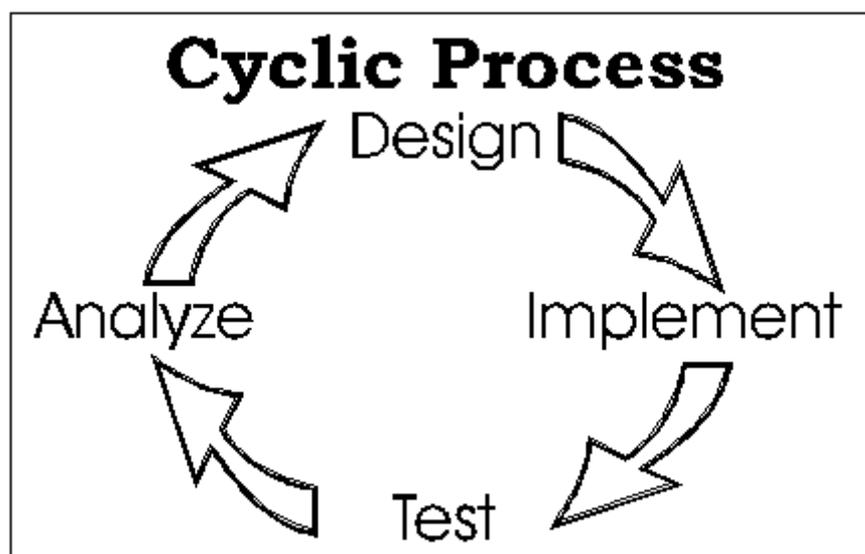


Figure 4.5 The Cyclic Design Model

- We created a customized Word macro to automate markup. The macro automatically deletes

unnecessary formatting information from the Word files, adds the required hypermedia commands, and saves the file in the proper [HIS](#) text format.

- We created a separate [HIS](#) database for each chapter. This modularizing of the databases allows a chapter to be added, deleted, or modified without reprocessing the contents of other chapters.

#### [4.2.1.3 Achieving the Ease of Use Goal](#)

Both the paper and electronic versions of the *Guide* are designed to be easy to use. The E-Guide retains ease-of-use features of the paper *Guide*, including its organizational structure of the sections and the chapter icons. There are other factors to be considered in designing and implementing a useable software interface that go beyond the features inherited from the paper version.

User interface design is a critical project element because it plays such a major role in users' acceptance of the electronic version. A user, especially a computer novice, is more likely to use the E-Guide if the interface allows him or her to focus on finding and using the *Guide's* information, rather than focusing on navigating and using the software. The research team developed a customized interface for the E-Guide which exploits the *Human Factors Guide's* specific structure, rather than simply using the Hypermedia Information System's (HIS's) generic interface.

To ensure an intuitive, user-friendly program for the custom interface, we are using the cyclic design model to design and develop the E-Guide. [Figure 4.5](#) shows the four iterative steps involved in the process: analyze, design, implement, test. We have completed one cycle to date.

To further ensure a usable, commercial appearance for the E-Guide, the researchers evaluated interface features of twelve commercial CD-ROM applications. Each application was evaluated for its ease of navigation, overall ease of use, screen layout, and media integration. For details of this evaluation, see Hartzell, 1994. The E-Guide prototype design was based on this evaluation, as well as human interface design research findings and guidelines.

## **4.2.2 The Interface Features**

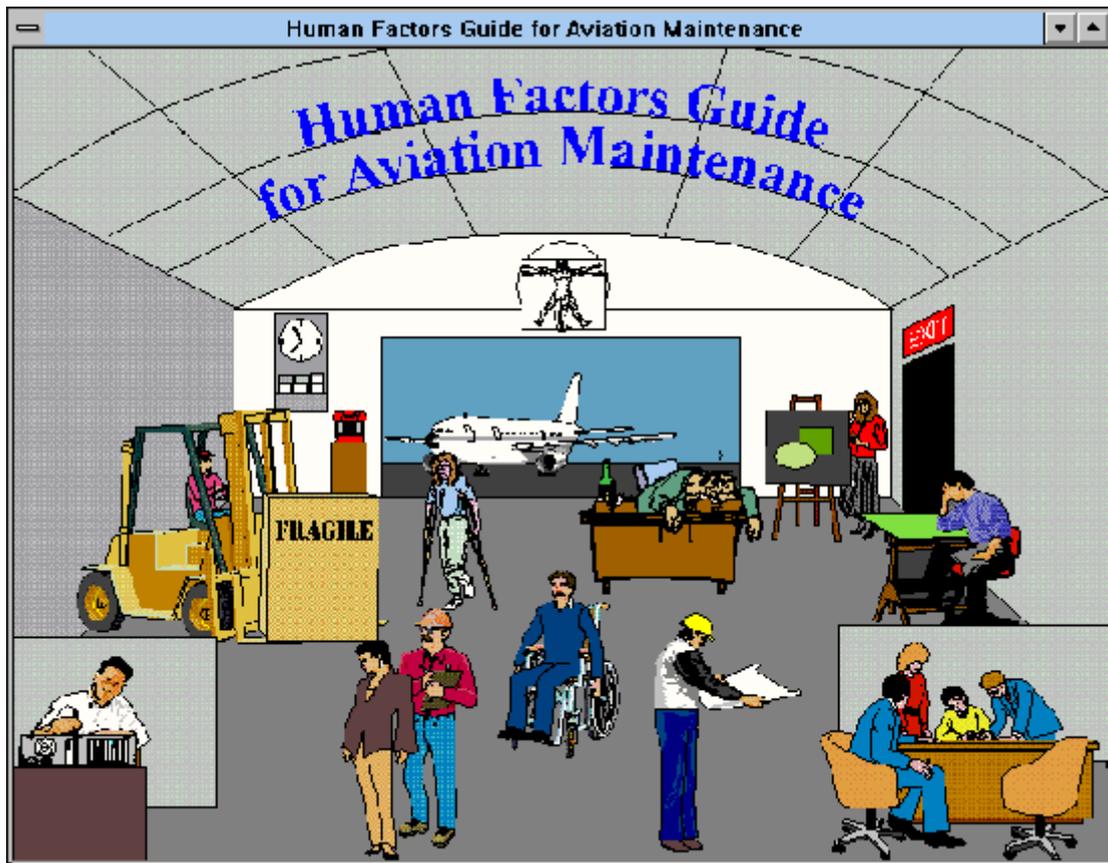
In this section, we describe interface features of the E-Guide's initial prototype. We follow this section with a summary of initial user evaluation feedback and a description of the resulting modifications we will make to the initial prototype software.

### [4.2.2.1 The Introduction](#)

The E-Guide's introduction is a real "attention-getter." It starts animation of the title: *Human Factors Guide for Aviation Maintenance*. A video clip introducing the [FAA/AAM](#) research program follows the animation. This introduction plays until a user presses any key or clicks a mouse button; the system proceeds to display the Table of Contents.

### [4.2.2.2 The Table of Contents](#)

The Table of Contents in the paper *Guide* is in the form of a conventional text outline of chapter titles. The E-Guide presents the Table of Contents as a unified scene ([Figure 4.6](#)). Since the *Guide* is intended for members of the aviation community, we chose a hangar for the scene. Each graphical image in the hangar represents a chapter in the *Guide*. We chose each image to illustrate the chapter it represents, while always maintaining the aviation maintenance theme. For example, a time clock with punch cards represents the chapter on Shiftwork Scheduling. This pictorial Table of Contents serves as an overview map from which the user can access any chapter. Pointing at an image with the cursor displays a pop-up displaying the chapter's title; selecting the image displays the chapter's Introduction in the Information Viewer.



**Figure 4.6 The Electronic Guide Table of Contents**

#### 4.2.2.3 The Information Viewer

The Information Viewer displays the *Guide's* content ([Figure 4.7](#)). The Information Viewer's design is critical for meeting the ease-of-use goal; this is the primary screen for accessing information in the *Human Factors Guide*. We conducted an analysis of user needs to identify displays and controls to include in the viewer. We designed the Information Viewer to use dedicated locations for all display areas and controls: all information and program functionality is visible on the screen. In this section, we describe key features of the Information Viewer: the Section buttons, the Text Window, the Media Window, and the E-Guide Control Buttons.

#### 4.2.2.4 Section Buttons

Each of the *Guide's* chapters is divided into twelve sections: *Introduction, Background, Issues and Problems, Regulatory Requirements, Concepts, Methods, Reader Tasks, Guidelines, Related Issues, Where to Get Help, References, and Further Reading*. In the E-Guide, sections are represented by twelve section buttons grouped together just above the Text Window (which displays the section's text). Each of the twelve section buttons has a distinct icon. The icons are metaphors for familiar objects; this allows users to have quicker recognition of each section button. If a user is unsure what an icon represents, the section's name is displayed in a help balloon near the button whenever the user places the cursor on top of the button.

A user selects a section button to view a different section of the current chapter. When the user selects a section button, the button is inverted, and the mouse cursor changes to an hourglass until the Information Viewer has retrieved the section text. This design gives users immediate access to information in any section and allows them quickly to identify what text is currently displayed by noting which section button is currently inverted.

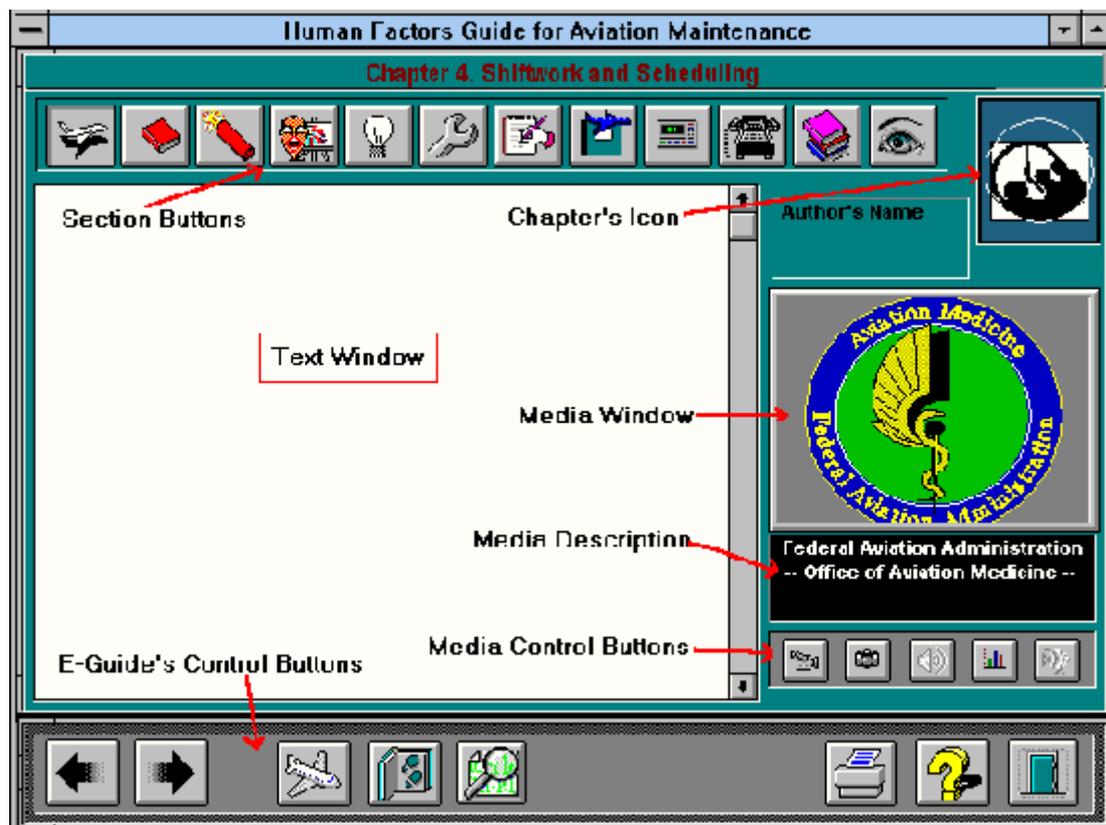


Figure 4.7 The Electronic Guide Information Viewer

#### 4.2.2.5 Text Window

As mentioned above, the Text Window is located below the section buttons. This window displays the selected section's text in the same format as the paper-based *Guide*. The text's size is slightly larger than the paper version's to make it easier to read the computer screen.

Within the text, some words are displayed in a different color; such words are called *hotwords*. A hotword indicates that there is associated text or media related to that word. The association is called a *hyperlink*; it provides a software connection between the hotword and another document, graphic image, or definition. Hotwords give users rapid access to information; selecting the hotword displays its associated text or media. Section text is displayed on the left side of the screen; graphics and other media are displayed in the Media Window on the right. A user can view text and its corresponding media simultaneously.

#### 4.2.2.6 Media Window

The Media Window displays tables, figures, video, and animation associated with the current chapter's content. In the Information Viewer, the Media Window is located to the right of the Text Window. Below the Media Window, the Media Description box contains a short description of the image currently displayed in the Media Window. Until a user selects a figure or media file, the Media Window displays the [FAA AAM](#) logo. The logo serves as a filler, blending the Media Window into the background and preventing the user from being distracted by an empty window.

The Media Control Buttons are directly beneath the description. The graphic on each button illustrates the media the button controls, e.g., a video camera for the video control, a camera for the photo/figure control, and a chart for the table and charts control. When the current chapter has no media of a given type, the corresponding control button is disabled. A user may select an enabled media button to display a list of associated media for the current chapter. For example, when a user

clicks on the video control button, a list of video clips relevant to the current chapter is displayed. A user can select any item in the list to view the associated video. When a user selects a figure, table, or other media file, the Media Window replaces its previous contents with the newly selected file. The transition effect draws the user's focus to the Media Window.

The Media Window's default size is a relatively small 180 x 130 pixels. This size is appropriate for video clips or animation playback; however, a table or a figure is typically much larger. The Media Window displays a scaled-down version of tables and figures in overview. To see the image's details, the user can enlarge the table or figure to its original size. The enlarged table or figure is displayed in a separate window with the caption as the window's title. The main Information Viewer window is deactivated while this enlarged window is displayed, preventing the user from getting lost or confused by there being too many windows on the screen.

Tables and figures in the E-Guide are taken directly from the paper *Guide*. The graphics are stored as image files, preserving their format and color. The audio, video, and animation media, which are not part of the paper *Guide*, had to be collected and processed for the E-Guide. The current design of the Information Viewer allows the following file formats: *WAV* files for audio, *AVI* files for video, *FLI* and *FLC* files for animation, *GIF* and *BMP* for still images.

#### [4.2.2.7 Electronic Guide Control Buttons](#)

E-Guide control buttons access navigational and system functions. These control buttons are located at the bottom of the Information Viewer screen. The basic functions of the buttons are as follows:

- Next and Previous chapter buttons display the next or previous chapter in the Text Window
- Table of Contents button displays the Table of Contents overview map
- Go To button allows a user to go directly to any section of any chapter
- Search button allows a user to search the *Guide* for specific words or phrases
- Print button allows a user to print selected text or graphics from the *Guide*
- Help button displays the on-line E-Guide Help window
- Exit button exits the E-Guide.



**Figure 4.8 Electronic Guide "Go To" Dialog Box**

Many of these functions are straightforward. A user simply clicks the appropriate control button and its corresponding action occurs. Some functions require additional input, typically supplied in a dialog box. For example, [Figure 4.8](#) shows the "Go To" dialog box in which a user must give the desired chapter and section.

"Search" is one of the E-Guide's most useful functions; it requires additional user input. This function is used much as one might use a combination of the Table of Contents and the Index in the paper-based *Guide*. If a user wants information on a specific topic in the paper-based *Guide*, he or she might scan headings in the Table of Contents or look up the specific topic in the Index.

In the E-Guide, a user selects "Search" to locate relevant material. A dialog box helps a user provide information necessary for the search (see [Figure 4.9](#)) with options to search the current section, the current chapter, or the whole book. A user must specify one or more words or phrases. To search for a single word or a phrase, a user types the desired term or phrase in the "Find" box and selects the Search button.

When a user has supplied necessary information, he or she executes the search by clicking on the Search button. The hourglass cursor is displayed until the search is complete. A dialog box then displays a list of chapter numbers and section names in which the term is found. As shown in [Figure 4.9](#), the system automatically highlights a search term contained in the currently displayed section.

The E-Guide is also capable of complex searches with wildcards. A wildcard search means that a user can use wildcard characters to search for variations of a word. The E-Guide supports two standard wildcard characters: "?" represents any single character, and "\*" represents one or more characters. For example, a search for "circ\*" would find terms such as "circa," "circadian," "circular," and "circumstances." A search for "circ?" would yield only "circa" from the above list.

### 4.2.3 User Feedback and Interface Modifications

We demonstrated the first prototype of the E-Guide at the Ninth [FAA AAM Meeting](#) on Human Factors in Aircraft Maintenance and Inspection. In addition, several attendees used the prototype in a workgroup setting, identifying several interface and usability issues. The issues, notes, and "wish-list features" are summarized below, along with the modifications we will make to the E-Guide:

- **Text Display:** An attendee suggested implementing an option to display the text in a full-screen window. Although while in the full-screen mode, the user cannot view the supporting media simultaneously. There may be times when the user is only interested in reading text. We will implement this option.

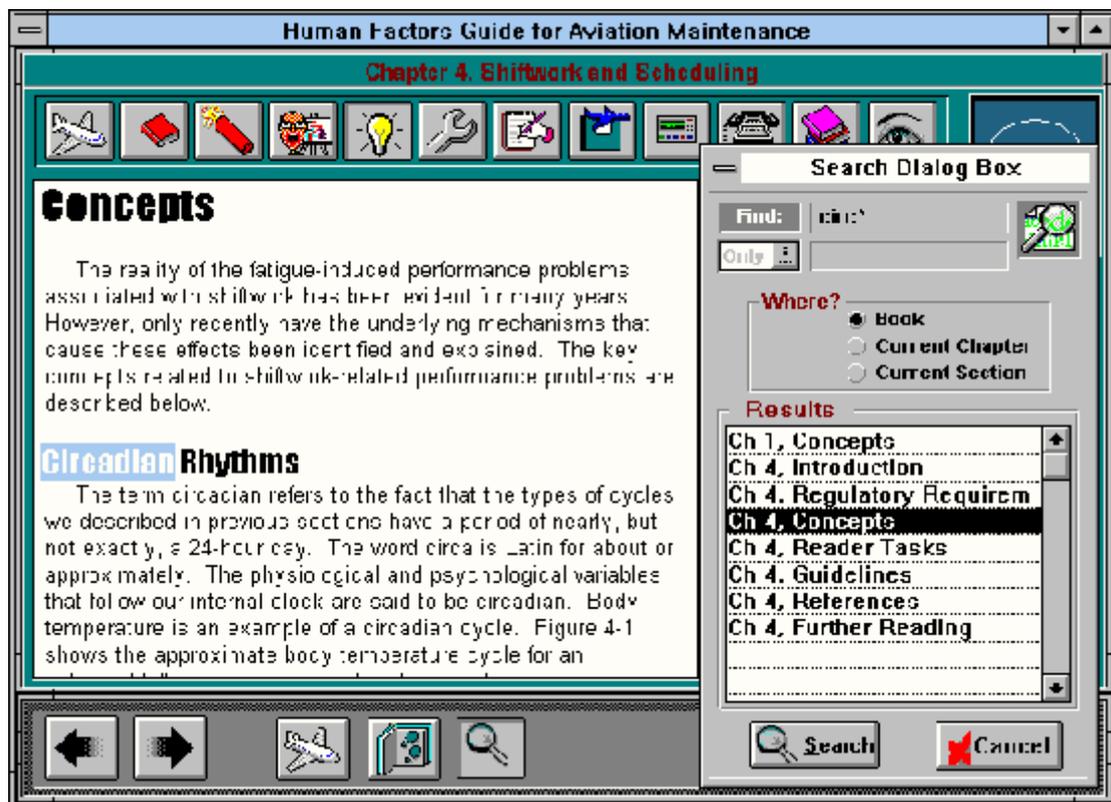


Figure 4.9 The Search Dialog Box

- **Table of Contents:** The Table of Contents represents each chapter in the *Guide* with a graphic image. Although this approach provides a unifying theme and lends a commercial look to the prototype, some users may be more comfortable with a traditional Table of Contents. Participants suggested that the E-Guide include an option to switch between the two Tables of Contents. We will implement this option.
- **Iconized-Section Buttons:** Due to users' unfamiliarity with icons and contents of the *Human Factors Guide*, they did not utilize the section buttons very much. Participants recommended adding a menu list of all sections as an option to the section buttons. We will implement a menu that allows a user to make a selection with the mouse or the keyboard.
- **Tables and Figures:** Since current tables and figures are image files, users cannot perform searches on their information. Users identified expanding the search capability to include this information as a necessary modification: important information resides in tables and figures. We will investigate the feasibility of adding such a feature.
- **Hyperlinks:** At the time of the conference, we had not implemented linking from one portion of the text to another. Participants indicated their desire to have footnotes linked to the associated reference. They were also interested in links among the E-Guide and other [FAA](#) and [DOT](#) documents referenced in the text. We will implement hyperlinks to references; we will implement linking to additional documents as time and money permit.

Other general feedback participants gave us on both the paper-based and electronic versions of the *Human Factors Guide* included the following:

- **Glossary:** Attendees commented that many aviation maintenance managers may not be familiar

with the technical meaning of terms (e.g., *fatigue*) we use in the *Guide*. Some attendees suggested including definitions from an aviation dictionary. We plan to add a glossary to both versions of the *Guide*.

- **Examples:** The attendees recommended adding a section in the *Guide* of "Examples of Best/Current Practices" from the airline industry. We will include two new sections in both versions of the *Guide*: Example Scenarios and Acknowledgments.

### 4.3 FAA/AAM CD-ROM #3

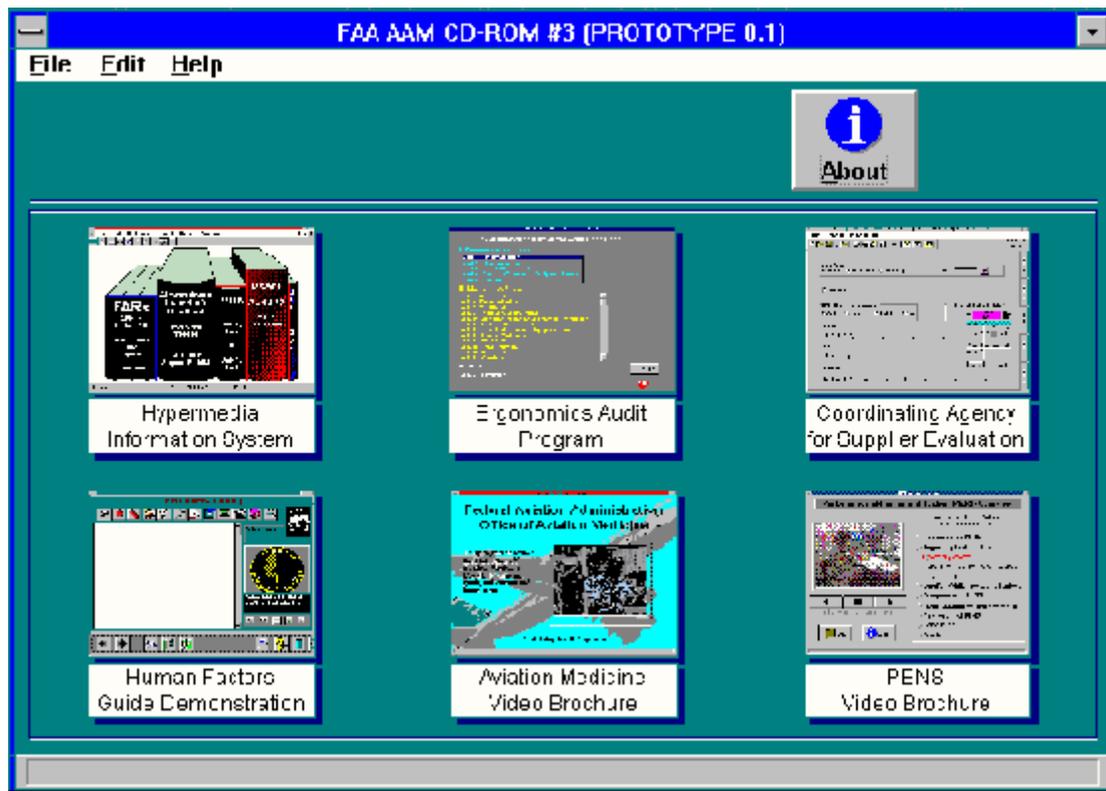


Figure 4.10 FAA AAM CD-ROM #3 Main Menu

For the third consecutive year, one of the digital documentation task's major deliverables is a CD-ROM. As in the past, the current CD-ROM contains several software programs produced as part of the [FAA AAM](#) Human Factors in Aviation Maintenance research program (Figure 4.10). In this section, we briefly describe the contents of CD-ROM #3. Readers may find additional details on a particular application by referring to the corresponding chapter in this report.

#### 4.3.1 Hypermedia Information System (HIS)

The Hypermedia Information System (HIS) project provided the impetus for developing the first CD-ROM. During the past year, we have improved and expanded the HIS' features and contents. The 1995 version of HIS provides over 5,000 pages of information related to aviation maintenance and inspection, including the following: Human Factors in Aviation Maintenance Phase Reports and Meeting Proceedings, Federal Aviation Regulations (Parts 1-200), the Airworthiness Inspector's Handbook (Order 8300.10), and the Air Transportation Operations Inspector's Handbook (Order 8400.10).

The [HIS](#) program contains a graphical user interface that makes it easy for a user to browse through these documents, and hypermedia technology affords rapid access to specific information. The full-

text search function allows searching within and across all documents in the system. Storing digital documentation electronically on CD-ROM is one feasible method for improving distribution and access to information.

### 4.3.2 Electronic Human Factors Guide

Since the paper-based *Human Factors Guide* will not be published until later this year, CD-ROM #3 contains only a demonstration version of the Electronic Human Factors Guide that is similar to the initial prototype described in this chapter. However, since the text for all chapters is under revision, only two revised Chapters are included in the demonstration program: Chapter 1 (Human Factors) and Chapter 4 (Shiftwork and Scheduling).

### 4.3.3 Ergonomics Audit Program-ERNAP

The ERgoNomic Audit Program (ERNAP) is a computerized job aid that helps managers evaluate or design ergonomically efficient procedures and systems for maintenance or inspection. ERNAP is simple to use; it evaluates existing and proposed tasks and setups by applying ergonomic principles. If an evaluation is unfavorable, ERNAP suggests ergonomic interventions.

The complete [ERNAP](#) system contains twenty-three modules spanning Pre-Maintenance, Maintenance, and Post-Maintenance. The CD contains an initial prototype of the software. A complete version is to be published on the Electronic Human Factors Guide CD-ROM in June 1995.

### 4.3.4 Coordinating Agency for Supplier Evaluation (CASE)

The vendor audit program for the Coordinating Agency for Supplier Evaluation (CASE) Air Carrier Section is an adaptation of the Aviation Safety Inspector job-aiding software. Auditors from each participating airline perform inspections of their respective vendors and contribute their findings to CASE resources. The software is designed to help auditors collect required data during on-site inspections of vendors.

The fully functional [CASE](#) program is designed to operate on a pen computer running Microsoft Windows for Pen Computing. The CD-ROM contains a demonstration program illustrating the main features without requiring the special operating system.

### 4.3.5 Office of Aviation Medicine Video Brochure

The Office of Aviation Medicine Video Brochure describes the [FAA](#)'s Office of Aviation Medicine (AAM) goals, organization, and work in a series of short video clips. The software is designed to be used either on a "public access" computer (video kiosk) or on a personal computer. The AAM Video Brochure uses the Microsoft Video for Windows system, which displays digital video on a computer without requiring special hardware.

### 4.3.6 PENS Video Brochure

The PENS Video Brochure describes the Performance Enhancement System (PENS) research program in a series of short video clips. The Video Brochure software is designed to be used either on a "public access" computer (video kiosk) or on a personal computer. The PENS Video Brochure displays digital video on the computer without requiring special computer hardware.

[PENS](#) is an electronic performance support system designed for Aviation Safety Inspectors. It provides data entry and validation support, as well as on-line access to policy guidance such as Federal Aviation Regulations, Airworthiness Directives, and Inspector's Handbooks. The system is currently used by the [FAA](#) Flight Standards Service.

## 4.4 Future Plans for Digital Documentation Research and Development

Some current digital documentation research and development efforts continue through the next year. We will continue work on the Electronic Human Factors Guide. The first complete E-Guide will be published on CD-ROM in June 1995. As we revise the paper-based *Human Factors Guide*, the E-Guide will also be updated.

Work on the [HIS](#) system continues. As our work the E-Guide demonstrated, there are specialized needs for digital documentation, i.e., a generic interface like the HIS may not always be desirable. However, a custom interface may well want pieces of the HIS' functionality. We now have the idea of carving modules out of the HIS software for use in other programs. We used this process for the Search function used in the E-Guide. We are likely to continue modularization of the HIS during the coming year. We will publish a new HIS on CD-ROM #4 in March 1996. This CD will also contain software developed for other projects within the overall research program.

We have new research and development avenues to address in the coming year. Current systems have demonstrated the feasibility of digital documentation for the aviation industry, but technological and organizational changes have occurred since we began our research. New hypermedia and multimedia development tools are available. Commercial systems providing large-scale imaging tools for document management have been developed. New digital documentation standards are evolving as commercial companies enter the market with products providing aviation-specific digital documentation libraries. Our research and development work should not replicate services now available commercially.

Our future research will adapt to the aviation maintenance industry's current needs. We have to pose questions as to what needs commercial suppliers are already meeting (or will be meeting in the near future) and what needs remain for further research and development. In conjunction with this type of needs analysis, we need to review new tools, standards, and techniques formally. We can then define further investigations to match technology and needs.

## 4.5 References

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Mantelman, Lee. (1994). "Windows OCR packages put a typist in your tank". *Imaging Magazine*. Vol. 3, Number 12, December, 1994. pp. 8-26.

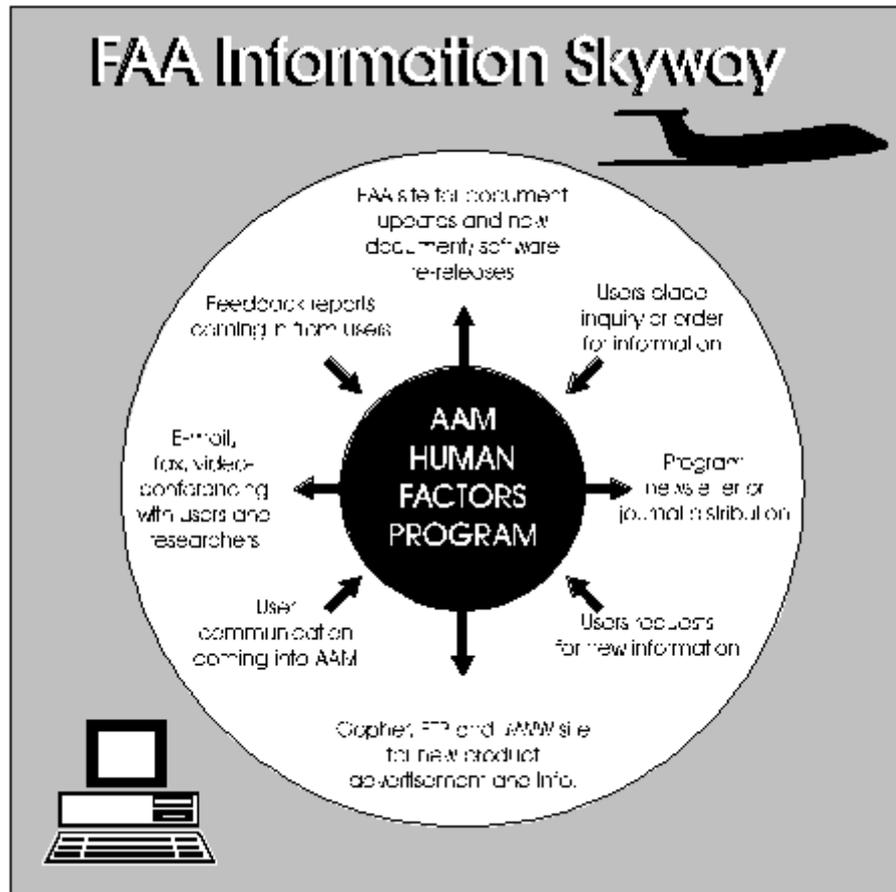
## Chapter 5

# The FAA Information Skyway

Thomas Coonan  
Galaxy Scientific Corporation

### 5.0 Introduction

The Office of Aviation Medicine (AAM) Human Factors in Aviation Maintenance research team has been exploring alternative methods for disseminating the products from the research program. Examples include publication of project results on CD-ROM, the *Human Factors Guide for Aviation Maintenance*, and annual meetings and reports. The program has included efforts to involve the research and user communities in its decision-making processes. Another avenue for disseminating information is through an on-line electronic information source. This new distribution channel has been termed the [FAA Information Skyway](#).



**Figure 5.1 AAM Use of the Internet (Adapted from Nejme, 1994)**

This report presents our vision of what the Skyway is, of our progress with our User Needs Survey, a survey of existing services, and a snapshot of the World-Wide Web (WWW)-based Skyway to date.

As shown in [Figure 5.1](#), the [AAM](#) will use the Information Skyway to:

1. Disseminate information from the Human Factors Research Program, Office of Aviation Medicine, and the [FAA](#) to all Internet users
2. Maintain and update official aviation-related documents and standards generated by the

Office of Aviation Medicine for immediate world-wide use

3. Provide additional Maintenance Human Factors-oriented Internet services, such as notification bulletins, information archiving and retrieval, and conducting world-wide discussion groups.

A substantial portion of the FAA Information Skyway will be based on the [WWW](#), a Standard General Markup Language (SGML)-based hypermedia information layer available through the Internet. The WWW allows hypertext access across all WWW hosts and documentation. Most WWW hosts are government- sponsored research organizations or commercial publishers.

Internet and the WWW are explosively growing mediums for information access (Stefanac, 1994). Previously restricted to government research and educational firms, Internet recently opened access to general business organizations. Seven thousand businesses and organizations now have 15 million Internet users-there are one million more users each month. Over a recent 12 month period, WWW traffic increased 341,634%; and a new *network* is joining the Internet every 10 minutes. Twenty-one large Bulletin Board Systems (BBSs) have also connected to the Internet, at least for e-mail transfer. More than half of all registered networks are now commercial. Surveys have also been done on existing WWW users (Pitkow, 1994).

Immediate benefits for the [AAM](#) of the [FAA](#) Skyway include publicity and immediate distribution of the Office's public information, research results, and official notifications. Previous AAM experiences with electronic distribution of research information, by way of CD and [SGML](#), technically position the AAM to pursue this form of publication.

Long-term benefits of the [FAA](#) Skyway are based on current research and development activity among commercial aviation manufacturers and [FAA AAM](#). Commercial aviation manufacturers are beginning to distribute documentation electronically in an [SGML](#) format. (Remember that [WWW](#) is SGML-based, too.) Current AAM and FAA research projects are evaluating how to use portable computers to support maintenance and inspection activities. The merging of portability, world-wide access, and a plethora of electronic aviation-related documentation will serve to bring timely information to our maintenance and inspection users.

## 5.1 User Needs Survey

The Information Skyway User Needs Survey has been created empirically to determine needs in the community. The survey's intent is to establish what members of the Aviation/Human Factors community have, need, and want from existing or potential on-line electronic information services. Specifically, the survey includes questions on what classes of [FAA](#) information and services community members desire, what computer resources users have access to, and individual affiliations and job functions. The survey will be distributed to people across the airline, academic, and government sectors. The survey is included in this report as [Chapter 5 - Appendix](#).

The question arises as to how innovative an approach the Skyway should take. An innovative strategy attempts to identify, refine, and specialize emerging technologies and prepare users for the new and hopefully ubiquitous technology. Alternatively, a more conservative and applied strategy minimizes risk by employing only the most widely available tools, if not innovative tools.

The Skyway occupies the more innovative position on this scale. The Internet is a major information technology and, while not yet on every desktop, is here to stay. We predict that the Internet will be a primary source for electronic information - including Aviation and Human Factors information.

## 5.2 Potential Skyway Services

The User Needs Survey will help us determine what the Skyway should do, what information it should include, and how it should be accessed. There are two immediately apparent ways for

members of the public to access computerized on-line information: the Bulletin Board System (BBS) and the Internet.

BBSs are typically accessed with low-speed modems over standard telephone lines. A BBS is often hosted on a PC with many modem ports. One advantage of BBSs is that they require modest equipment: a PC with a low-speed modem and modest graphics, and no pre-established account. BBS services typically include E-Mail (amongst users of the BBS), real-time CHAT conversations, and uploading and downloading files. Usually, these systems do not offer advanced services such as document searching, hypertext, or multimedia.

The Internet is a computer network pioneered in the 1960s. Today, many millions of users in the public, academic and governmental sectors share in this global fabric. Internet services are typically more advanced than a BBS's and include E-Mail, file up/down loading, hypertext, multimedia, video conferencing, etc. Until recently, it was difficult to connect to the Internet. Only university researchers or government officials could afford the specialized communications connections or could use the UNIX environment. However, access is now much easier. New protocols (such as Serial Line Internet Protocol or SLIP), modems, public domain software and commercial Internet Service Provider (ISP) companies make access feasible for many people. This trend continues; in fact, reports are that the upcoming Windows 95 will come bundled with Internet software and that the Internet will reside on most desktops.

The Internet, specifically the World Wide Web, is our first experiment in the Information Skyway. We do not see the Skyway necessarily as a single medium or service, so our initial foray into an Internet-based Skyway does not preclude future work with BBSs or any other means of effectively delivering information electronically.

### 5.2.1 Internet Services

Before discussing Internet services, we will briefly discuss methods of access. Until recently, Internet connectivity required high-speed digital communications found only in sophisticated labs and large offices. With the introduction of SLIP protocol and high-speed modems, a typical PC can cost-effectively establish a true Internet connection. ISPs offer a SLIP dial-up bridge into the Internet for a few dollars per month. In fact, Internet access is now as easy as dialing up a bulletin board.

We made a survey of Internet Services, seeking out both mainstream and emerging Internet technology. Services we investigated included E-Mail, Gopher, video conferencing, Lotus Notes, WWW, File Transfer Protocol (FTP), ListServers, and Multiple User Domains (MUDs). We gave most attention to WWW and FTP as potential services due to their widespread use, high growth, and appropriateness for digital documentation.

#### 5.2.1.1 Electronic Mail

E-Mail is a core Internet service and is available in many environments other than the Internet. Different E-Mail systems typically communicate via Gateways. For example, E-Mail is routinely exchanged between CompuServe, America On-Line (AOL), and the Internet users, as well as many localized proprietary LAN-based E-Mail systems such as ccMail, PROFS, and Microsoft Mail. Text-based E-Mail can be enhanced with multimedia attachments, as well as with groupware-oriented enhancements such as ListServers (see Section 5.2.1.5).

#### 5.2.1.2 The World Wide Web

The WWW, commonly referred to as "the Web", is one of the fastest growing Internet services. A user views WWW documents called "pages" by using a WWW viewer or browser. Many browser programs are available for most platforms, including NCSA Mosaic, CELLO, NetCruiser, and NETSCAPE. Web pages may include text, graphics, or multimedia. Links within the text allow the user to branch off to other WWW pages or other Web sites anywhere in the world. The ability to

move between documents and/or host computers by using links embedded in the text is called "hypertext". WWW pages may also be searched for key words or phrases.

WWW documents use the HyperText Markup Language (HTML) format for providing text and graphical hypertext. The HTML format is standardized and extensible. Web servers may provide back-end programs triggered by the reader's manipulation of the page. For example, a WWW page may present an interactive *form* or provide a front-end to a large database system.

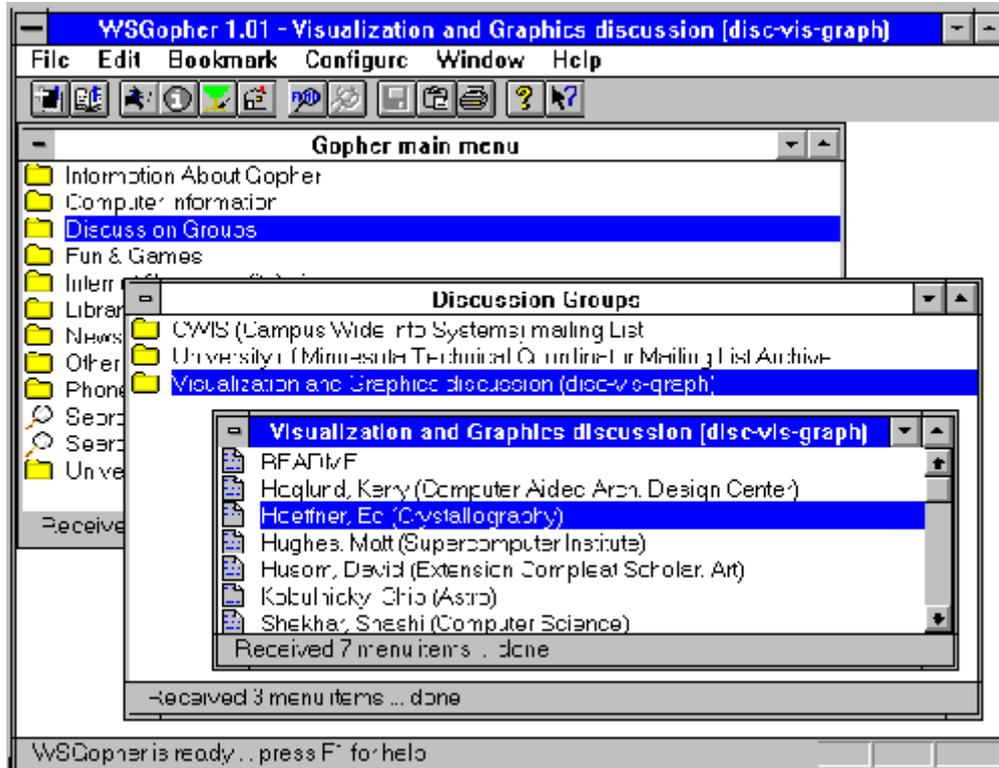
WWW pages may include references or links to the other Internet services. For example, the user may click on a link that triggers an [FTP](#) download of a particular file or that makes a link to a Gopher menu. In this way, WWW subsumes many other Internet services.

### 5.2.1.3 FTP

File Transfer Protocol (FTP) is perhaps the oldest Internet-based service. Simply put, FTP allows users to retrieve files from sites on the network. FTP archives are maintained throughout the Internet. FTP users access files organized in hierarchical directories on specific hosts. There are many topic-specific FTP archives. For example, Microsoft maintains an archive for Visual Basic software and there are FTP general archives dedicated to electronic versions of popular manuals.

### 5.2.1.4 Gopher

Gopher is a precursor to [WWW](#) and presents information in a hierarchical menu. Users view a linear list of items which lead to other Gopher menus or to text. Gopher's simplicity allows it to easily run on almost any client interface, including text-based terminals. Like the WWW, Gopher items link easily to other Gopher items on other distant nodes. [Figure 5.2](#) shows one example series of Gopher menus.



**Figure 5.2** Example of an Internet Gopher

### 5.2.1.5 ListServers

One popular service is the *ListServer* (also known as a mail reflector). ListServers are an extension to E-Mail. ListServers are established for particular topics (similar to UseNet groups). Users send specific E-Mail "command" messages to the server to subscribe and unsubscribe from the list and to request lists of current subscribers. Once subscribed, users send messages to the group and, likewise, receive messages from the entire group. Since a ListServer is based on simple E-Mail mechanisms, any E-Mail user, on the Internet or not, may utilize the service. A potential Skyway service is one or more ListServers for topics such as "Human Factors in Aviation."

#### 5.2.1.6 Other Services

Other, more exotic Internet services include [MUDs](#) and Video Conferencing. MUDs are text-based groupware programs originally intended for multi-player role-playing games. MUDs have been suggested as a new vehicle for real-time conferences where participants interact with each other in 'rooms' based on a particular sessions, topics, etc.

While seamless video requires higher bandwidth links, several real-time video conferencing systems exist on the Internet. The CU\_SeeMe video conferencing system is a simple, low-bandwidth video system which has been employed in K-12 schools. The DRUMS system from Sprint integrates Silicon Graphics Indy systems, video cameras, and high-speed TCP/IP (Transmission Control Protocol/Internet Protocol) links to bring together professional studio video producers and their clients.

There are other important network-based services which are not necessarily Internet-based at all, but still may be accessed by the Internet. For example, Lotus Notes is a groupware product running on LANs (Local Area Networks) such as Novell. Corporations are using Lotus Notes for E-Mail, group scheduling, group coordination, etc.

### 5.3 The Skyway Internet-WWW Implementation

The present accessible Skyway is a collection of [WWW](#) documents. This implementation will be added to and changed as the results of the User Needs Survey are analyzed. The following sections of this report detail the status of this WWW effort. The first section considers how we access the Internet, and the following sections consider the actual WWW implementation.

#### 5.3.1 Internet Service Providers

When discussing services, it is often important to distinguish between providing the service and consuming the service. Computer terminology for this is *client* vs. *server*. It is typically easier to be the client of an Internet service than to be the server. For example, there are now many popular and inexpensive packages in any bookstore that allow a user to access the Internet (and become a client). For instance, it is relatively easy to setup an IBM PC (or a Mac) to access the many [FTP](#) and [WWW](#) information sources now on the Internet. The Skyway must be a *server* publishing WWW information.

Several alternatives exist for the Skyway server. The server is where the Skyway information resides and is where the [WWW](#) and [FTP](#) protocols are implemented. One approach is to employ an Internet Service Provider's (ISP) UNIX machine and a [SLIP](#) connection. The ISP's machine maintaining the actual data storage is continuously connected to the Internet. Galaxy Scientific corporation connects to the ISP's machine as needed over a low-speed modem and uploads our information. This method is the most cost-effective for small scale prototyping, but offers the least control and poor cost-per-bit for larger scale data storage. Another approach is to establish an on-premises host which provides all data storage and server implementation. This approach requires more extensive set-up and hardware.

We are now using an off-site [ISP](#) host. Specifically, an Atlanta-based ISP named MindSpring, Inc., provides us with disk storage, [FTP](#), and [WWW](#) server access, and a [SLIP](#) account for approximately \$50/month plus \$1/Mbytes/Month storage fee.

We have investigated establishing an on-site host. Some cost estimates for doing so are shown in [Table 5.1](#).

**Table 5.1** Cost Estimates for Establishing On-Site Skyway.

Item	Cost	UA	Description
Sparc Server 5	\$15,351	one time	includes storage and software
ISDN Setup	\$250	one time	high-speed communications
ISDN	\$95	monthly	dedicated line cost
Dedicated TCP/IP link	\$375	monthly	link to the Internet

With our off-site [ISP](#), our responsibility included authoring and uploading our [HTML](#) documents. With an on-site host, we would be responsible also for installing and maintaining the service, specifically for managing a [WWW](#) and [FTP](#) server.

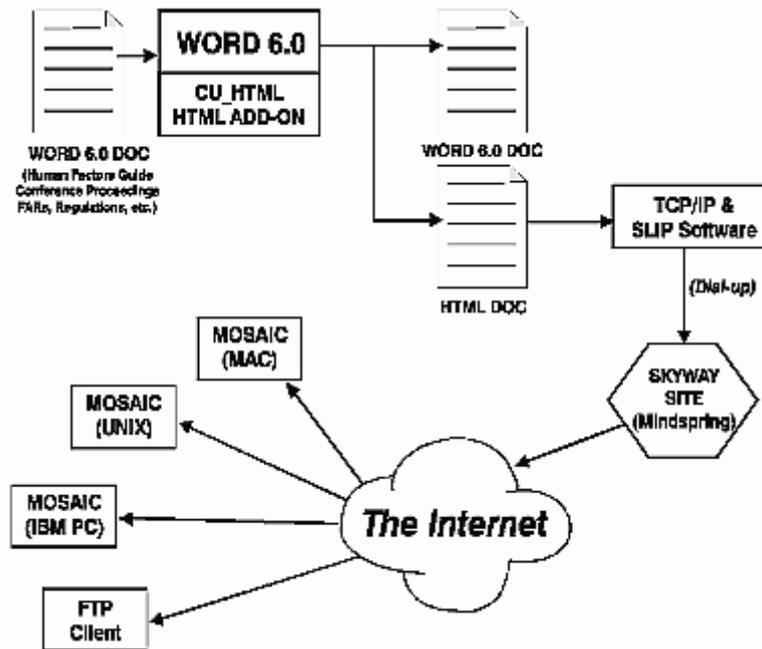
### 5.3.2 The Skyway, WWW, HTML, and HTML Authoring

Initially, we implemented parts of the *Human Factors Guide* on the World-Wide Web. WWW provides adequate support for the text and graphics in this document. Future FARs, reports, etc., may also be published in WWW format.

Internet users work with Universal Resources Locator (URLs) when navigating on the net. URLs function as precise addresses by which Internet resources are located. It has become increasingly common for organizations to include a central [WWW](#) URL along with their standard business address. The current Skyway URL is:

**<http://www.mindspring.com/~galaxy/skyway.html>**

One significant advantage of the [WWW](#) is its widespread availability. Web browsers are available for most common platforms. The popular MOSAIC viewer, for example, is available for MS-Windows, for the Macintosh, and for UNIX platforms.



**Figure 5.3 Current Skyway Implementation**

Authoring the [HFG WWW](#) version (and WWW information in general) requires utilizing the [HTML](#) format. HTML is a dialect of [SGML](#); a much larger specification. HTML is a simple text-based markup language like LaTeX or TROFF. Much HTML markup work is done manually. While this method works fine for typical 'pages,' larger document databases, such as the Skyway, require a more sophisticated and scalable approach. Since Galaxy primarily utilizes Microsoft Word 6.0 for desktop publishing, we investigated tools that directly convert Word to HTML. CU\_HTML is one such tool; it meshes well with Word 6.0. CU\_HTML uses Word 6.0 templates and macros to transform Word 6.0 documents automatically into the HTML format. This approach is depicted in [Figure 5.3](#).

Currently, the Skyway consists of an introductory Skyway [WWW](#) page which can be reached from any Internet Web browser using the [URL](#):

**<http://www.mindspring.com/~galaxy/skyway.html>**

[Figure 5.4](#) shows this page viewed from MOSAIC running on MS-Windows.

There are two hypertext links. One link takes the user to the Galaxy Scientific homepage; the other, to the *Human Factors Guide*. [Figure 5.5](#) shows the MOSAIC page introducing the *Human Factors Guide*.

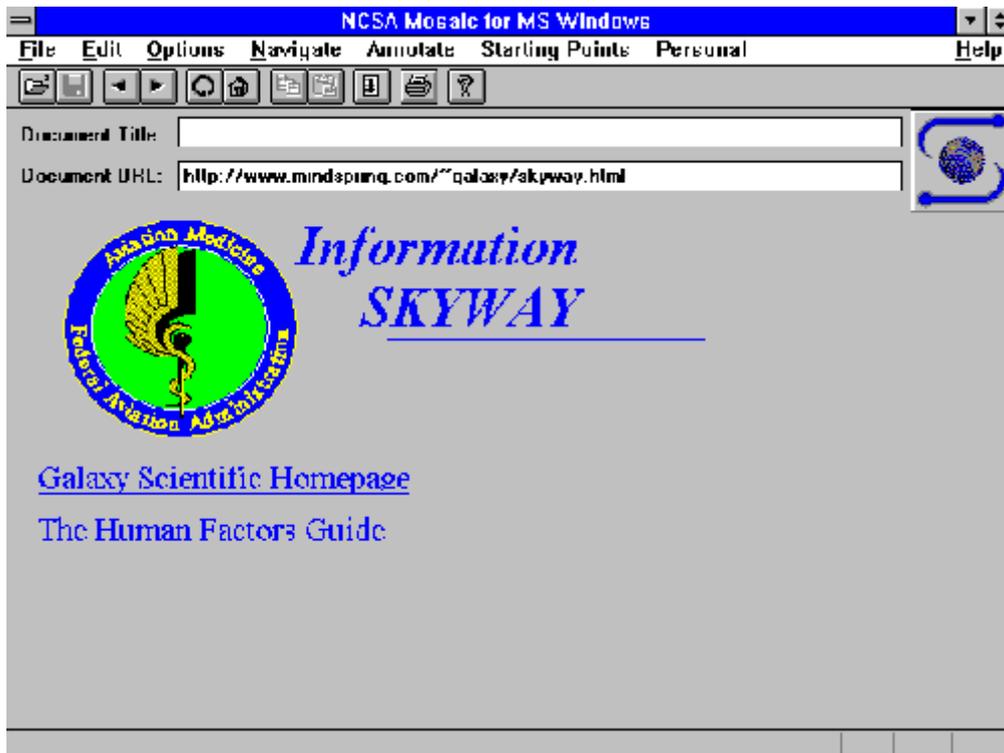


Figure 5.4 Skyway WWW Page as Viewed from MOSAIC Viewer

Only Chapter 1 is present now. The text of Chapter 1 is broken into several subpages for general hypertext organization and to minimize the amount of time a user must wait while information is being downloaded. In addition to the text, chapter figures and tables can be found. For example, [Figure 5.6](#) shows the MOSAIC page containing one particular graphic.

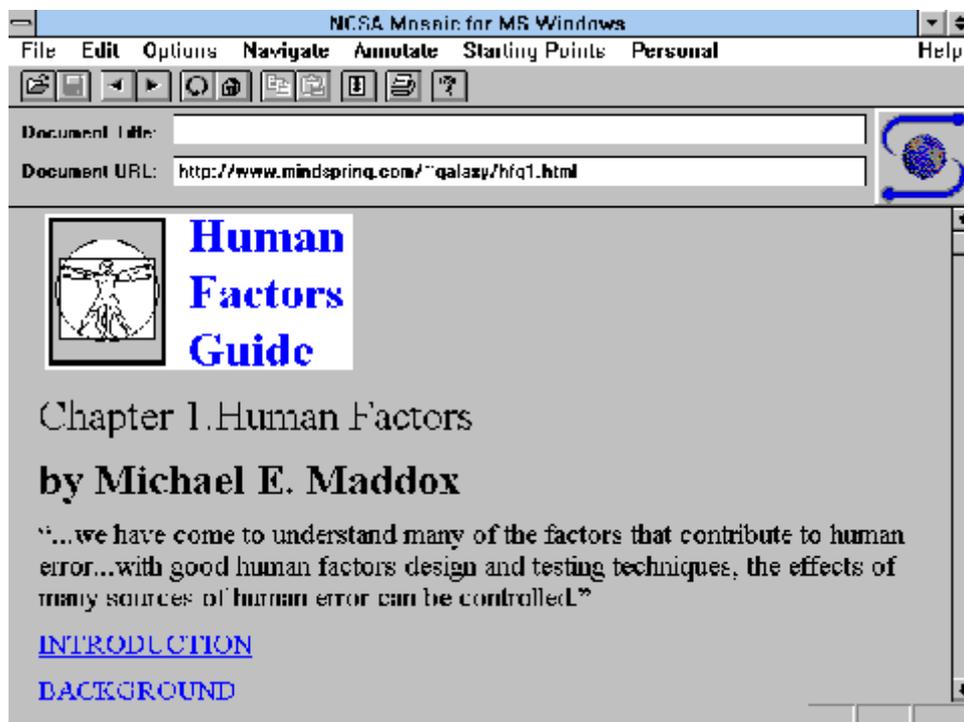
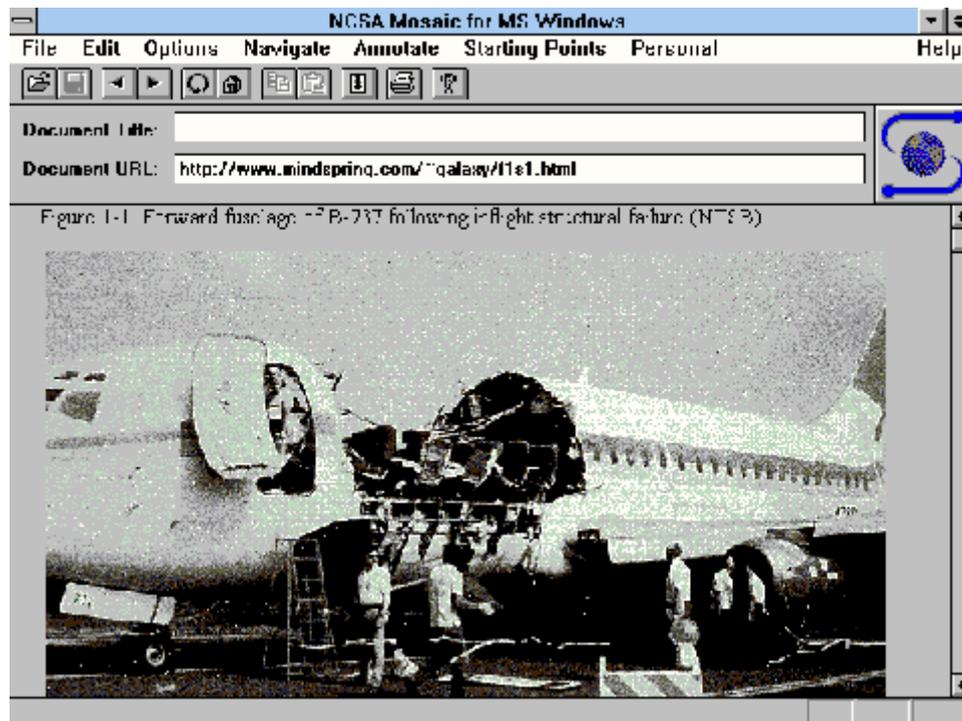


Figure 5.5 Human Factors Guide WWW Page



**Figure 5.6 Graphic from Chapter 1 of the Human Factors Guide**

Encoding Chapter 1 of the *Human Factors Guide* has shown that the [WWW](#) is a viable medium for disseminating information. While many existing WWW pages are quite small, our effort explores issues associated with larger documents. Advantages of WWW publishing include world-wide immediate access, multi-platform support, and instantaneous updates.

## 5.4 Existing Aviation and Human Factors On-Line Resources

**Table 5.2** [FAA](#) Supported Public Access On-Line [BBSs](#)

Name of Service	Phone #
Airports BBS	(202)267-5205
Air Traffic Operations Service BBS	(202)267-5331 (800)446-2777
Air Transport Division BBS	(202)267-5231
Pilot Examiner BBS	(405)954-4530 (800)954-4530
FAA Headquarters BBS	(202)267-5697
Office of Environment & Energy BBS	(202)267-9647
Navigation and Landing BBS	(202)267-6547
Aviation Rulemaking Advisory BBS	(202)267-5948
Orlando <a href="#">FSDO</a> BBS	(407)648-6963 (407)648-6309 (800)645-3736 (800)645-FSDO
Portland <a href="#">MMEL</a> BBS	(207)780-3297

Safety Data Exchange BBS (800)426-3814

Aeromedical Forum BBS (202)366-7920

Contel Dual User Access Terminal System (DUATS) (800)767-9989

CompuServe Information Service (CIS) GO AVIATION

We surveyed existing public aviation- and human factors-related sources. While this survey is incomplete, if for no other reason than that these sources change continuously, the results provide a glimpse of the existing electronic landscape and indicate the existing demand in this area. The first area we explored was dial-up Bulletin Board Systems (BBSs), as shown in [Table 5.2](#). We then surveyed existing Aviation/Human Factors Internet-based services, as shown in [Table 5.3](#). Finally, we surveyed Aviation/Human Factors CD-ROM databases, as shown in [Table 5.4](#).

**Table 5.3** Aviation/Human Factors Internet-Based Services

Type of Service	Reference	Information Provided
WWW	<a href="http://www.faa.gov">http://www.faa.gov</a>	FAA Home Page
WWW	<a href="http://www.dtic.dla.mil/iac/cseriac/iac.html">http://www.dtic.dla.mil/iac/cseriac/iac.html</a>	CSERIAC Home Page
WWW	<unable to locate at this time>	Embry-Riddle Avion WWW Site
WWW	<a href="http://www.virtual-airline.co.uk/virtual/">http://www.virtual-airline.co.uk/virtual/</a> OR <a href="http://www.demon.co.uk/virtual/">http://www.demon.co.uk/virtual/</a>	"The Virtual Airline" "Knowledge and Resources for the Airline Industry."
WWW	<a href="http://www.sonic.net/aso/">http://www.sonic.net/aso/</a>	Aircraft Shopper On-line
WWW	<a href="http://www.CdnAir.CA/">http://www.CdnAir.CA/</a>	Airline: Canadian Air
WWW	<a href="http://www.iconz.co.nz/airnz/airnz.html">http://www.iconz.co.nz/airnz/airnz.html</a>	Airline: Air New Zealand
WWW	<a href="http://www.winternet.com/~tela/nwa-info.html">http://www.winternet.com/~tela/nwa-info.html</a>	Airline: Northwest
WWW	<a href="http://www.winternet.com/~tela/nwa.html">http://www.winternet.com/~tela/nwa.html</a>	Northwest (travel survey)
WWW	<a href="http://www.seanet.com/Bazar/Aeroflot/Aeroflot.html">http://www.seanet.com/Bazar/Aeroflot/Aeroflot.html</a>	Airline: Aeroflot
Usenet	rec.aviation.....	(hierarchy of many subgroups)
Usenet	sci.aeronautics	Discussion group for Aeronautics
Usenet	sci.aeronautics.airliners	Airliner Technology
Mailing lists	listserv@cunyvm.cuny.edu	Discussion Group for Airline Industry Message to send: subscribe airline

**Table 5.4** Aviation/Human Factors CD-ROM Databases

CD-ROM	Summit Aviation	Database of <a href="#">FARs</a> , <a href="#">ACs</a> , <a href="#">ADs</a>
CD-ROM	<a href="#">ATP</a>	Database of FARS, <a href="#">JARs</a> , <a href="#">SBs</a>
CD-ROM	<a href="#">ACS</a>	Database of FARS, JARs, SBs

CD-ROM CounterPoint Publishing Database of [CFR](#) and [FR](#)

## 5.5 Summary and Conclusions

We need more analysis to determine Skyway requirements accurately. This is proceeding. Meanwhile, the [WWW](#) is proving to be a promising delivery vehicle for digital documentation. Purely as a hypermedia delivery system, it works well. Advanced WWW features and other Internet services promise innovative new ways to integrate and engage the Aviation and Human Factors community.

## 5.6 Future Plans

Once we have received and evaluated more User Needs Surveys and obtained a clearer picture of our user, we will discuss with the [FAA](#) how the Skyway should fit into the overall FAA information plan. Also, we are in the process of implementing the next-generation Skyway node, which will be much more powerful and flexible.

Finally, we are planning the next set of Skyway services including archives, newsletters and more experimental services.

## 5.7 References

Nejmeh, B.A. (1994). *Internet: A strategic tool for the software enterprise*. Communications of the ACM, Vol. 37, No. 11, pp. 23-27.

Pitkow, J. and Recker, M. (1994). Results from the First World-Wide Web user survey. Computer Networks and ISDN Systems, 27, pp. 243-254.

Stefanac, S. (1994). *Multimedia Meets the Internet*. NewMedia, Nov., pp. 56-63.

## Chapter 5 - Appendix Draft of User Needs Survey

The "Information Skyway" will be an electronic system for disseminating safety-related information from the Federal Aviation Administration (FAA). This system may also be used to distribute other types of FAA-produced information, such as regulations concerning commercial and general aviation. As the first step in producing this system, Galaxy Scientific Corporation is conducting a survey and designing a proof-of-concept prototype for the FAA. The survey and prototype will be used to determine the feasibility of hosting and maintaining an on-ramp to the Information Superhighway.

Please help design the Information Skyway by filling out this survey. The data from this survey will be used to determine the form and content of an electronic information system being built by the [FAA](#) Office of Aviation Medicine. The information obtained from this survey is confidential, and you do not need to identify yourself.

This survey is designed to be easy to fill out electronically; for multiple choice questions, replace the '\_' character with an 'X'. For questions that require text, just type your answer after the question.

After you have filled out this survey, please return it to Galaxy Scientific. E-Mail is preferred, but you can also return it via fax or regular mail.

ATTN: Electronic Information Survey



Galaxy Scientific Corp.

2310 Parklake Drive NE, Suite 325

Atlanta, GA 30345

phone: 404-491-1100

fax: 404-491-0739

email: galaxy@mindspring.com

----- Notice -----

This information collection conforms to legal and administrative standards established by the Federal Government to assure confidential treatment of statistical information. The information you provide will be used only for statistical purposes and will not be published or released in any form that would reveal specific information reported by an individually identifiable respondent. This questionnaire has been approved by the Office of Management and Budget, and has been given OMB Approval Number 2120-0587.

AGENCY DISPLAY OF ESTIMATED BURDEN:

The public reporting burden for this collection of information is estimated to average five minutes per response. If you wish to comment on the accuracy of the estimate or make suggestions for reducing this burden, please direct your comments to [OMB](#) and the [FAA](#) at the following addresses:

Office of Management and Budget US Department of Transportation

Paperwork Reduction Project Federal Aviation Administration

MS 2120-0587 Office of Aviation Medicine AAM-240

Washington, DC 20503 Washington, DC 20503

-----  
----- Electronic Information Survey -----  
-----

A. INFORMATION NEEDS

1. What types of FAA-produced aviation information do you currently use? (choose all that apply)

- FARs
- Airworthiness Directives
- Guidance materials (Advisory Circulars, etc.)
- Technical publications

- General Aviation Airworthiness Alerts
- Other (please describe below)

2. What FAA-produced information WOULD you use if given easy access?

- Regulations (FARs, Airworthiness Directives, etc.)
- Guidance materials (Advisory Circulars, etc.)
- Technical publications
- General Aviation Airworthiness Alerts
- Human factors information
- Other (please describe below)

3. What non-FAA safety-related aviation information do you currently use? (choose all that apply)

- Service Bulletins
- Government and Commercial Standards (please describe)
- Conference proceedings and magazines
- Informal discussions
- Other (please describe below)

4. What non-FAA safety-related aviation information WOULD you use if given easy access? (choose all that apply)

- Service Bulletins
- Government and Commercial Standards (please describe)
- Conference proceedings and magazines
- Informal discussions
- Other (please describe below)

5. What computer data transfer and communications hardware do you have access to?

- CD-ROM
- Modem
- Internet

6. What type of computer(s) do you use?

- DOS without Windows
- DOS with Windows
- Macintosh
- UNIX
- Mainframe

Other (please describe)

7. What aviation-related electronic resources do you currently use?

FAA bulletin boards

Commercial on-line services (America On-line, CompuServe, etc.)

CD ROM-based Commercial Services (Aircraft Technical Publications, Aviation Compliance Services, Summit Aviation, etc.)

Internet newsgroups and mailing lists

Other (please describe below)

8. Do you take part in any electronic discussion groups related to aviation?

Yes

No

9. If (8) is No, would you take part in any aviation-related electronic discussion groups if you had access?

Yes

No

10. If you are involved in General Aviation, what electronic information resources would you use?

Flight training material

Maintenance information

Aviation medicine

Accident/incident reports

Other (please list below)

11. Would you use a computer to submit safety-related information if you had a computer and appropriate software?

Yes

No

12. Do you use any of the following PC-based flight simulation software?

Microsoft Flight Simulator

IFT-PRO

AssureSoft

FS-100 Desktop Cockpit

Other

-----

## B. OTHER COMMENTS

1. Describe what you would like to see in the Information Skyway.
2. What do you like/dislike about existing aviation-related electronic information sources?
3. How would an electronic repository of safety-related aviation information affect your decision making?

-----

## C. ABOUT YOURSELF (OPTIONAL)

1. Your main job responsibility:

- Aviation maintenance
- Researcher
- Student
- Pilot
- Document management
- Regulatory
- Management
- Other (please describe below)

2. Sector of your work:

- Part 121 airline
- Part 135 airline
- General aviation
- Military
- Government (other than military)
- Academic
- Other (please describe below)

3. What is your most advanced pilot certificate?

- Student
- Recreational
- Private
- Commercial
- Airline Transport
- Certified Flight Instructor

None

4. Do you have an instrument rating?

Yes

No

5. About how many TOTAL flying hours do you have?

6. Contact information (may be used to gather more information, but will not be disclosed or distributed)

Name:

Address:

City/State/Zip:

Phone:

Email:

-----

Thank you for your cooperation, please return this survey to Galaxy Scientific Corp. via fax or E-Mail.

**fax: 404-491-0739**

**email: galaxy@mindspring.com**

# Chapter 6

## Human Factors Program Development and Implementation

*Colin G. Drury, Ph.D., Caren Levine and Jacqueline L. Reynolds  
State University of New York at Buffalo*

### 6.0 Study Background

This project was initiated to provide a practical demonstration of human factors/ergonomics implementation in an airline maintenance organization and, hence, to give airlines guidance on implementing their own programs. Ergonomics, and its American synonym Human Factors, is "the science that facilitates maximum human productivity, consistent quality, and long-term worker health and safety" (Burke, 1992). Human factors measures the job demands imposed by the workplace, environment, and schedule. It then compares these with the workforce's capabilities to meet these demands consistently. Where task demands exceed human capabilities, performance will break down, leading to human errors, which can manifest as safety-compromising incidents and/or on-the-job injuries. A better (safer) match between task demands and human capabilities can be achieved by changing the task demands (workplace, environment, organization design), by changing human capabilities (training, placement), or by both. Whether the organization's initial motivation for the human factors program is public safety, improved productivity, or reduced injuries, the analysis is the same. Indeed, the same analysis can be used to specify system interventions, e.g., workplace changes, or personnel interventions, e.g., training.

The motivation behind the current project arose specifically from human factors analyses conducted in 1993 on restrictive spaces in aircraft inspection tasks (see Reynolds and Drury, 1993). As part of that project, on-the-job injuries (OJIs) analyzed were found to be space-related. Hence, when we sought a site for demonstrating human factors/ergonomics intervention, it was natural to choose inspectors and to consider OJI reduction, as well as performance improvements, i.e., error reduction.

### 6.1 Human Factors Task Force Formation

The human factors program at Northwest Airlines was created with the mission "to redesign work environments to prevent on-the-job injuries." The program was initiated by the formation of the Human Factors Task Force made up of members of both management and the hangar workforce. The job titles of task force members included Safety Manager, [IAM](#) Safety Representative, Inspector, Lead Inspector, and Northwest Airlines Process Specialist (Training Department). Representatives from the University at Buffalo were assigned to act as task force advisors. The initial focus of the program was the inspection department at the Atlanta Maintenance Base.

The inclusion of inspectors on this task force was critical to its potential for success. Inspectors have unparalleled expertise in their jobs and domain knowledge that leads to an understanding of what changes are most necessary and to what solutions may or may not work. Inspectors on the task force were encouraged to communicate with other inspectors and to act as spokespeople for their entire crew. Typically, inclusion of work force representatives in analysis and redesign of their own jobs makes them more inclined to accept ergonomic solutions task force implements. This is because they actively contributed to the solution-development process.

#### 6.1.1 Task Force Objectives and Guidelines

Burke (1992) emphasizes the benefits that can be obtained when a human factors task force

addresses human factors issues within an organization. A team approach gives the organization maximum input from various people who will be affected by any changes. For a task group to be successful, its members must be comfortable working together and must fully understand the importance of their commitment and contribution to the task force. In recent years, Northwest Airlines has emphasized team activities. There are well-established procedures for teams to form, gain confidence, organize their activities, and implement their findings.

The initial objectives of the Northwest Airlines Human Factors Task Force were as follows:

1. Develop a process for identifying and addressing ergonomics issues within the inspection department that could later be expanded to all Northwest Airlines departments
2. Involve employees in the ergonomics process
3. Reduce the number of [OJIs](#)
4. Develop ergonomic solutions that could be implemented, with results that could be measured
5. Teach employees about ergonomics, so they could help widen the task force's focus
6. Commit to transfer the technology and the processes this task force used to other areas at Northwest Airlines.

The task force's guidelines were as follows:

1. Focus on inspection jobs and tasks in the hangar area
2. Identify the jobs and tasks to analyze
3. Establish an action plan to effect short- and long-term improvements
4. Members should commit to a one-year participation in the task force
5. The group leader to be elected by the entire task force
6. A task force member may work on this project up to 100% of his or her time
7. After its initial start-up meetings, the task force will establish its own agenda
8. The group leader will communicate a weekly report to all task force members.

### 6.1.2 Program Development

The steps that the Northwest Airlines Human Factors Task Force took closely followed the seven general steps in an ergonomic process, as described by Burke (1992).

1. Determine the measurement criteria and target the jobs to be studied.
  - Determine which areas should be targeted for analysis and intervention.
  - Choose the specific criteria which will help determine target areas, e.g., injury rate.
2. Gather job background information.
  - Document the job to be analyzed, including the job description, the tools necessary to perform the job, physical dimensions of the workspace, etc.
3. Identify ergonomic risk factors.
  - Identify conditions likely to act as barriers to optimal productivity and consistent quality and/or that have been associated with a high incidence of injuries.
4. Discover ergonomic interventions.
  - Brainstorm about all possible interventions to each risk factor, considering the following:

- changing inputs/materials
- changing output/product
- changing machine/environment
- changing procedures dealing with workers, e.g., training.

5. Screen interventions.

- Choose interventions to implement based on decision criteria such as cost, benefits, utility, consequences of no action, injury rate, etc.

6. Implement interventions.

- Orient those affected about why the intervention was chosen, what its expected impact is, and who to contact with questions/comments/concerns.

7. Track the effectiveness of the interventions.

- Assess each intervention's effectiveness and decide whether to expand, amend, alter, or abandon the particular intervention.

Once the human factors task force was selected, it was necessary to educate its members about what human factors is and how human factors can be used to improve the workplace. The University at Buffalo conducted a one-day training seminar, using materials developed from previous [FAA/AAM](#) projects and [ICAO's SHEL](#) model of human factors. The training specifically built on the University at Buffalo's previous involvement with Northwest Airlines' Atlanta Maintenance Base and its inspection activities.

The task force selected jobs to be analyzed in the first phase of the human factors program. The following jobs were identified by inspectors as five of the longest, most-difficult inspection tasks: Electrical and Equipment Compartment Inspection (E&E Compartment), Keel Inspection, Fuel Tank Inspection, Combustion Chamber Inspection (PS4 Drain Box), and Nose and Forward Accessory Compartment Inspection (Forward Access Compartment).

Four of the jobs were analyzed using the electronic inspection audit program the University at Buffalo developed (see Koli and Drury, 1995). Inspectors on the task force conducted the audits. The audit results for the keel inspection are provided in [Appendix 6-A](#) as an example of their work. To progress from analysis to redesign for each of these audits, a list of ergonomic risk factors was identified. A few risk factors from all four tasks were combined into problems with workcards and problems with lighting. The list of ergonomic risk factors for each area is included in [Appendix 6-B](#). The nominal group technique was utilized to rank each risk factor for each of the six main areas, for four specific tasks ([E&E](#) compartment, forward accessory compartment, keel, and PS4 Drain Box), and for two general areas (workcards and lighting).

As follows, the three risk factors with the highest rankings were chosen for closer study in each of the six areas:

- Workcards
  - Card content inaccurate
  - Breaks between cards inappropriate
  - Card contrast varied
- Lighting
  - Fixtures dirty
  - Lighting inadequate at the back of the hangar

- No preventive maintenance program for lighting
- Keel Inspection
  - Body positioning
  - Cleaning
  - Lighting
- PS4 Drain Box Inspection
  - Body positioning
  - [NDT](#) equipment
  - Cleaning
- [E&E](#) Compartment Inspection
  - Lighting
  - Temperature
  - Equipment
- Forward Access Compartment Inspection
  - Ladder design
  - Ladder control
  - Work planning

From this list, task force members took responsibility for pursuing specific potential solutions in the following areas:

- Improved cleaning
- Ladder purchase and control
- Workcard design
- Improved task lighting.

An action plan provided a time line for these activities that ensured analysis, implementation, and measurement of results within the time frame of this [FAA/AAM](#) project.

### **6.1.3 Redirection of the Ergonomics Task Force**

Initially, the Task Force followed-up on members' assignments to track progress according to the action plan. However, it became apparent that the Task Force as a whole was not progressing on developing solutions, as agreed. The researchers met with the task force and management to learn the reasons for the lack of progress and to help develop alternative strategies.

A number of factors that had not prevented progress in team formation, job analysis, and solution generation surfaced when it was time for implementation.

1. The workforce members of the task force felt that they had no mandate to pursue their assignments as part of their busy schedules.
2. Some of the solutions had, or appeared to have had, implications beyond the Task Force's control. For example, workcard design is a headquarters function, not easily controlled or changed at a remote base.
3. Other solutions required expenditure, e.g., task lighting, which was not immediately seen as

available in the current fiscal climate.

4. Perhaps most importantly, although task force members were opinion leaders within their groups, and a senior management person acted as "champion" of the effort, neither management nor the workforce felt a groundswell of support for the Task Force's activities.

For these reasons, the task force was disbanded, and the ergonomics efforts were refocused on a different problem that could have broad-based support *and* be entirely under control at the maintenance base. Specifically, many task force members recognized communication between shifts as one area in need of improvement. Also, communication between shifts needed no 'outside' assistance to implement a solution. Instead of having task force members implement the ergonomics audit program, which worked very well to identify human factors problems, a broad-based instrument was designed to obtain input about communication issues from inspectors on all three shifts. We reasoned that such input would produce buy-in to potential solutions, thus easing implementation. Of course, broader participation meant that expectations would be raised for more people, forcing at least some implementation if management/workforce trust was to be preserved. Fortunately, improving communication of technical information between participants has a good history in human factors generally, and in aircraft maintenance specifically (see Taylor, 1992).

## 6.2 Communications at the Atlanta Maintenance Base

As in any industry, effective communication within an organizational unit, and among organizational units, is critical for maintaining productivity in airline inspection and maintenance. Taylor (1992) writes, "Effective communication is no longer limited to merely acquiring the information that an individual needs to make decisions. Communication is increasingly a systems issue-it is inextricably bound to cooperation, coordination, and otherwise working together in a joint task or job for which individuals cannot succeed by working separately." Airline inspectors often help drive the heavy maintenance of aircraft. They are the first to look over an aircraft and have the task of identifying all the problems with it. Inspectors decide which problems maintenance must fix before an aircraft can leave the hangar, as well as which problems can be delayed until the next maintenance check. After the maintenance work is performed, inspectors must ensure that it was done properly. An aircraft cannot leave the hangar until all work is signed off by the appropriate authority, usually the inspectors. An inspector must be able to share information with management and other employees so that everyone understands an aircraft's current status. At Northwest Airlines' Atlanta Maintenance Base, for example, an inspector may find it necessary to communicate with the following people:

- other inspectors on the same shift
- inspectors on the two other shifts
- mechanics
- the lead inspector
- the inspection manager
- the maintenance manager
- engineers
- other management
- the flight crew.

The inspector must have the communication tools and skills to share information with other members of the organization, as necessary. Although communication is an important aspect of aircraft maintenance, it fails at times. To understand possible failure modes, a national source of error data (Aviation Safety Reporting System, or ASRS) was analyzed specifically to identify communication errors in the maintenance environment.

## 6.2.1 Typical Airline Industry Communication Problems (ASRS Reports)

Fortunately, human errors in aircraft maintenance are rare. Since errors are unlikely to be observed during a study such as ours, possible errors must be inferred from other sources. A review of [NASA's ASRS](#) mechanic reports identified that serious consequences can occur when inspectors and mechanics are unable to communicate efficiently with their co-workers. It is important to remember that ASRS reports are reported by individuals on a voluntary basis. In many cases, the reports have not been corroborated by the [FAA](#) or [NTSB](#), and the data cannot be used to infer the prevalence of a particular problem within the national aviation system. The incidents discussed here occurred over many years (January, 1987-February, 1994) at many airlines. They are **not** Northwest Airlines incidents.

Some common communication problems present themselves upon a close review of the [ASRS](#) reports. First, many incidents are caused by mechanics becoming distracted in the middle of performing a task. Mechanics often do not write down what they have accomplished, or what parts of a task need to be completed. At times, a mechanic may have to allow someone else to finish a task. This may lead to difficulties when the second mechanic does not clearly understand the situation or does not realize specifically what remains to be done. Other times, a mechanic intends to come back and finish a task but forgets that the task was not completed. This could lead to serious problems if the uncompleted task is not detected before the plane takes off. This type of problem may also occur at shift changes, when mechanics cannot finish a task before their shift ends. The next shift assigned to finish the work may not clearly understand where the previous shift left off. This may result in duplication of effort on some tasks or, more seriously, the omission of some tasks completely, e.g., the second shift assumes that the previous shift has performed a certain task and does not verify this to be the case.

I was assigned to aircraft work release items....I was in the process of reinstalling the plug and covers for the turbine section when another mechanic asked if I needed any help. I asked him if he would install the ignitors. I saw him install the outboard ignitor. Then he went under the engine to what I thought was to install the inboard ignitor. While he was under the engine, I saw him install the screen back on the starter, but I did not go back and check his work, because I trust the work he does. I am the one who signed off the block on the paperwork....The inboard ignitor was never installed. ([ACN #250135](#))

Another mechanic was assigned the open and close of the engine. He opened all plug panels and ignitors. I stopped to help him close the engine. I installed the outboard ignitor and installed the starter air deflector, only per maintenance manual 72. The inboard ignitor was never installed. I did not know [if] the inboard ignitor was left out, or [was even] out at all. ([ACN #250330](#))

Another problem, somewhat related to the problem described above, is that generally one mechanic must sign off on the completion of a task, although more than one person may have actually worked on the task. Thus, it is difficult to pinpoint who actually completed the work when a problem arises. The mechanics who assisted may later forget, or deny, that they participated in completing the task in question.

Oil was serviced to full by another mechanic. However, he was reassigned to another aircraft before completing the log entry. At departure time, I completed [the] maintenance sign off in [the] logbook. The oil tank cap apparently was not latched in the closed position. ([ACN #245568](#))

Maintenance inspected [the] aircraft and found all six securing screws missing from left-hand most outboard wing trailing edge panel....Further investigation shows several individuals were involved in the close-up of the aircraft at completion of the check, but no one person assumes responsibility or full knowledge of this one particular panel. However, there is a signature of a supervisor who specifically signed stating, "All panels were secured." ([ACN #101899](#))

A third problem occurs when mechanics are given incorrect verbal descriptions of discrepancies or

descriptions varying from the written description in the log book. Similarly, a mechanic can be assigned to perform a task without receiving all the correct paperwork which accompanies the task. This can lead to the mechanic making an incorrect diagnosis of the problem and, consequently, taking incorrect action to correct the problem. In some cases, inaccurate diagnosis led a mechanic incorrectly to defer maintenance that should have been completed immediately.

I was told [verbally] that the roll spoiler outboard ground caution light was illuminated. I sent an [A&P](#) down to check [it] out and defer the system. He was unable to duplicate any problem, but we, by phone conversation, decided to defer the system in case the pilots had a problem on the morning departure. [Later,] when reviewing the logbook, I discovered I had been given wrong information from maintenance control about which light had illuminated. The roll spoiler outboard hydraulic light was the light that actually was written up, and this would not be something you would defer. ([ACN #243444](#))

These problems emphasize the importance of written communication in the airline industry. Verbal communication, although often more convenient, is more error-prone, especially when information must be remembered for long periods of time or must be passed sequentially through a number of people. The "telephone" game provides a good example of this problem: as information is passed from one person to another, the message tends to become increasingly confused. Written communication can serve as a permanent record of events and is less subject to the frailties of human memory. However, since written records may be used as an investigative tool to prove the actions a maintenance crew took, workers may feel, "It gives them something to hang you with!" There is understandable reluctance in all branches of the airline industry to write anything not specifically required to be committed to paper.

### 6.2.1.1 Summary of Communication Failures

[Table 6.1](#) presents the types of communication failures contributing to the incidents reported in the [ASRS](#) database. The data in this table are representative only of the twenty-eight ASRS reports we analyzed.

Type of Failure:

**Table 6.1** Communication Failures

#### Communicates To:

Originator	Mechanic 1	Mechanic 2	Inspector	Logbook	Flight Crew	Supervisor
Next Shift						
	F F F F F					
Mechanic 1	M M M M M	F V V V	W W W W		F F F V V	F V V
Inspector	W	F				
Flight Crew	V W W	W	V			
Supervisor	F V V V V V	V	W W	F V		

- F = failure to communicate
- V = verbal communication wrong/inadequate

- W = written communication wrong/inadequate
- M = memory failure (forgot to do something)

(See [Table 6.1](#))

## 6.2.2 Identification of Communication Problems Within The Inspection Department

[Table 6.1](#) shows that certain failure types are associated with different communication needs. While [ASRS](#) data is not a statistically valid random sample of errors, it can be used to identify forms of failure.

Obviously, a mechanic communicating with himself or herself at a later time can have a memory failure (M). When this happens, the mechanic usually relied on memory rather than a written note or a job aid, such as a checklist, that would have prevented memory failure. Mechanics communicating with flight crew are subject to failures of both written (W) and verbal communication (V).

Communication problems in the opposite direction, i.e., from flight crew to maintenance, are either failures to communicate at all (F) or a breakdown of the written process (W). Perhaps this results from the widely different background training of Flight Operations and Technical Operations and the lack of opportunities for verbal communication between these groups. Clearly, methods of improving communications between these groups are needed, e.g., extensions of [CRM](#) and [MRM](#) to joint training.

Communication problems between mechanics, and between mechanics and supervisors, are all either failure to communicate at all (F) or a failure of verbal communication (V). This also includes shift change communication in the final column of [Table 6.1](#). Clearly, written communication does not fail; if people use written communication, then this is adequate. The main emphasis for addressing these problems should be ensuring that mechanics and supervisors use written communication. Thus, the new focus of this project became redesigning communication forms so mechanics and supervisors can use them more easily.

Since communication is critical to the successful performance of airline inspectors, we decided to examine the communication system for inspectors currently in place at the Atlanta Maintenance Base to see if improvements could be made. We expected that an inspector's (or a mechanic's, or a supervisor's) effectiveness can be improved by providing better communication tools that make it easier to collect necessary information and to pass that information to other supervisors and mechanics.

After interviewing many inspectors, it was obvious that each inspector views the job (and the larger system) differently. The shift on which the inspector usually works (and thus the inspector's lead inspector), as well as years experience as an inspector, are just two factors that appear to affect each inspector's perceptions. Due to such wide variations among inspectors, we decided to question all inspectors to gain a broad view of the actual communication system in the inspection department. The user needs analysis was designed to identify tools currently supporting communication within the inspection department and between inspectors and other departments. The user needs analysis we used is included as [Appendix 6-C](#). As a follow-up to the communication user needs analysis, we conducted further personal interviews with many inspectors. These interviews did not follow any pre-defined format; their purpose was simply to allow inspectors to talk about communication issues at Northwest Airlines and to provide background information to help interpret the user needs analysis responses.

A particular focus of the communication user needs analysis was the shift turnover log. Currently, the shift turnover log is a bound book with numbered pages. Entries are made in the log each day, usually by the lead inspectors. Information in the log includes personnel issues, e.g., who called in sick, who left early, who is working overtime, etc., and aircraft issues, which are usually only a quick summary of each aircraft's status, e.g., in buy-back, shakedown, etc. An entry occasionally includes a description of a problem an inspector encountered during the shift. It is difficult to identify who made an entry in the log, and few entries are ever followed-up with another entry

describing how the problem was resolved. The existing shift turnover log does not serve as a communication tool, showing the tasks with multi-shift implications, nor does it provide the information necessary for subsequent shifts to "pick up" where a previous shift left off. Thus, our communication user needs analysis was designed to identify whether inspectors use the existing shift turnover log as a helpful source of information and/or whether a different type of log would better serve inspectors' needs.

### 6.2.3 Results from the Communication User Needs Analysis

We received 17 responses to our user needs analysis from the approximately 30 inspectors at the Maintenance Base. User needs analysis responses are summarized in [Table 6.2](#).

User needs analysis responses identified a general problem with inspectors' job satisfaction. Many inspectors report having difficulty obtaining information they need to perform the job. They are unwilling to share information with others, unless it is absolutely necessary. This reluctance to communicate is a serious problem and must be addressed if inspection productivity is to be improved. The inspectors also identified shortcomings in the communication system at Northwest. Inspectors do not use the shift turnover log regularly, almost always need to search for more information after being assigned a job, have experienced on-the-job problems caused by miscommunication, and deal with each other almost always verbally. The shift turnover log is seen as a managerial tool, not as a way to communicate.

It is important to note that the average years of experience of inspectors responding to the user needs analysis is 6.6, with a standard deviation of 3.6. Previous studies have indicated that it is common in the aircraft industry to have mechanics with long service and with very short service, with very few in the middle (Taylor, 1990). At the Atlanta Maintenance Base, the less-experienced inspectors tended to return completed user needs analysis (over half had only 3-5 years experience); our results reflect their particular dissatisfaction with the current communication system. This result is not altogether unexpected. Experience as an inspector often means increased knowledge, information, and familiarity. Less-experienced inspectors may require more external information to perform a task (they cannot so easily rely on internal knowledge) than more experienced inspectors. Less-experienced inspectors also may be less able to respond to verbal instructions and information. Therefore, they may be less satisfied with, and more able to recognize problems in, current modes of communication. Experienced inspectors are accustomed to the way things are done and may be reluctant change. Our results may reflect a communication system designed to meet the needs of experienced inspectors, and of those with managerial responsibilities, while de-emphasizing the increased information demands of those with less experience.

User needs analysis responses also indicate that many inspectors perceive a lack of what is termed *situational awareness* in human factors; they do not understand how their specific tasks fit into the larger picture of airline maintenance. Inspectors may be unaware of what is happening beyond their own work assignments and of how their assignments affect (and are affected by) other departments. For example, jobs are often assigned to inspectors in what they perceive as a random manner, e.g., large jobs may be assigned only early in a shift, more difficult jobs may be delayed until easier ones are completed, etc. Many times, there seems to be little consideration of how job scheduling affects the maintenance department.

**Table 6.2** Summary of User Needs Analysis Results

Question	Summary of Results
Number of Years Experience	average = 6.6 years median = 5 years
Sources of Information	lead inspector, manuals, managers (inspection, maintenance), engineering, other inspectors
Nature of Information Received	mostly verbal, some written

Destinations of Information (inspection, maintenance),	lead inspector, mechanics, other anyone who asks	inspectors, managers
Nature of Passed Information	mostly verbal, some written	
Is All Information Available	No - 11 (65%)	
	Yes - 5 (29%)	
	NA - 1 (6%)	
Do You Read Shift Turnover Log? How Often?	No - 9 (53%)	
	Yes, When Acting Lead - 5 (29%)	
	Yes, (Almost) Every Day - 3 (18%)	
Do You Write in Shift Turnover Log? How Often?	No - 9 (53%)	
	Yes, When Acting Lead - 3 (18%)	
	Yes, When A Problem Arises - 2 (11%)	
	Yes, (Almost) Every Day - 3 (18%)	
Purpose of Shift Turnover Log?	lead turnover information, personnel notes,	status of aircraft, communication between shifts, written account of daily activities
Information to be Included in Shift Turnover Log?	more information about the aircraft status of long-term projects	more cautions and warning important work in progress what tasks managers want done on a shift
Should <u>STL</u> Be On Sceptre, a Book, or Both?	Book Only - 11 (65%)	
	Sceptre - 2 (12%)	
	NA - 4 (23%)	
Time Between Shifts, and Is It Sufficient?	Time Is Sufficient [5-20 min.] - 12	(70.5%)
	No Time Needed - 4 (23.5%)	
	Time Is Sufficient, But Inefficiently Used -	1 (6%)
Attendance at Regular Crew Meetings?	No - 7 (41%)	
	Yes - 8 (47%)	
	NA - 2 (12%)	
Are Regular Crew Meetings Beneficial?	No - 4 (23.5%)	
	Yes - 8 (47%)	
	Sometimes - 4 (23.5%)	
	NA - 1 (6%)	
Problem Caused by Miscommunication?	No - 3 (18%)	
	Yes - 10 (59%)	
	NA - 4 (23%)	

#### 6.2.4 Results From Personal Interviews with Inspectors

During site visits to the Atlanta Maintenance Base, we spoke personally with many inspectors about communication at Northwest Airlines. These conversations generally support the results from the user needs analysis, although they provide more insight into inspectors' specific communication needs. Some points inspectors made in these conversations include the following.

1. Inspectors acknowledge that they almost always communicate verbally with their lead inspector and with other Northwest employees. Most inspectors had never really considered the consequences if, at some later time, there was a problem with an inspection they conducted. Although workcards and non-routine cards provide a written account of the completed tasks, there is important, not legally required information that is never permanently recorded. Without written records, it is

impossible to remember exactly what occurred and what steps had been taken. Even if an inspector did everything correctly, there would be no way to prove this in an investigation.

The following incident is taken from the [ASRS](#) database: this is **not** data collected at Northwest Airlines. It illustrates the potential danger in failing to maintain accurate written records of all maintenance activities.

A 'visiting' mechanic was assigned to repair an engine. While performing the work, he accidentally dropped a rag into the gearbox cavity. After searching, unsuccessfully, for the rag, the mechanic notified (verbally) the lead mechanic of the problem. The lead mechanic ordered a boroscope of the engine, which did not show that the rag was inside. Although the mechanic continued to say that the rag was still inside the engine, the lead mechanic ordered that the repair be completed so that the plane could be released for a flight. The mechanic was sent home before the leak check on the engine was completed. On its initial flight, the plane was forced to turn back to the originating airport due to a low oil pressure warning. The engine was removed for further repair. During the investigation, the rag was found to have clogged the scavenge pump filter screen. The mechanic was interviewed twice by airline quality assurance, and the incident was written up in a report submitted to the [FAA](#). ([ACN #233249](#))

From an analysis of this incident it is clear that: if the mechanic had made a written entry in the maintenance log concerning this incident, there would have been little question that his actions were totally appropriate. He could have recorded that he dropped the rag inside the engine and was unable to locate it. The lead mechanic was informed of the incident and eventually decided on his own that the rag was no longer inside the engine because his search had not located the rag.

Without the written log, it is difficult to determine the actual events surrounding this incident. The lead mechanic could insist that the mechanic was unsure if the rag actually was inside the engine or that he was never informed of the problem, especially since the mechanic signed off on the repair. Alternatively, if the problem had not manifest immediately, the mechanics involved in this incident may then have been unable to provide accurate information to the quality assurance people investigating the incident.

2. The weekday day shift and early part of the weekday afternoon shift currently have far better information resources available. During weekdays (Monday through Friday, 8:00 a.m. - 5:00 p.m.), each department in the organization is fully staffed. Management, engineers, planners, and the most experienced inspectors are all readily available for consultation. During the second half of the afternoon shift, on the night shift, and on weekends, it is difficult and time-consuming to get information from these resources. For example, an inspector on the weekend shift must call an engineer at home for consultation on a technical problem. The engineer, if he or she happens to be at home, generally first tries to solve the problem over the telephone or, if appropriate, to postpone addressing the problem until the next weekday shift. The engineer may be required to come into the hangar in an emergency, but this is generally the last resort.

3. Inspectors receive most of their information, including work assignments and any important items from the previous shift, from their shift lead. Therefore, they receive only information that the shift lead chooses or remembers to pass along. For example, an entry in the [ASRS](#) Database ([ACN #196273](#)) describes the following incident, which illustrates potential danger in filtering critical information through the lead inspectors.

Several mechanics noted [that the] #1 engine [was] making a loud unfamiliar noise. This information was passed on to the lead and supervisory personnel by second shift mechanics so as to alert third shift mechanics who were to work the aircraft that night and early morning. I, the third shift mechanic, was assigned to work this particular aircraft. However, I received no information concerning this particular loud engine noise until about ? am that morning, and then it was passed on to me by another mechanic, not [by] the lead man who assigned me to work on the aircraft. Based upon the information that was made available to me, a pilot write-up [of an] indication problem, [I] replaced [the] #1 engine tac indicator.... Had I been informed about the true condition of the engine, I would have treated the write-up quite differently.

4. Updates to maintenance manuals usually have a cover letter that each inspector must sign off. These documents are maintained in a notebook kept in the inspection office. Inspectors are expected to check the book daily and to read and sign off any new entries. This is easy when the workload is light and when there are few updates. However, when inspectors are busy or when there are a lot of updates, many inspectors fall behind. No supervisor or lead inspector ever seems to question inspectors about failing to keep current with the updates. An inspector may learn about updates only when they happen to relate to a particular problem he or she is addressing.

5. Inspectors receive much information, from updates and elsewhere, that they see as irrelevant to their current responsibilities. For example, they often receive service alerts for DC-10s and Boeing 727s; only DC-9 maintenance is performed at the Atlanta Maintenance Base. Inspectors feel overloaded with information and are concerned that they are not always able to filter out relevant DC-9 information.

### **6.2.5 Results from Conversations with Management**

We also met with managers connected with the inspection department to discuss their perceptions of the communication system at Northwest Airlines. Many managers had never recognized that communication problems existed, although our user needs analysis results helped convince them that there was room for improvement. From discussion of the user needs analysis results, we made the following recommendations.

1. It is important to train inspectors how to communicate. Inspectors must learn what is expected, so they understand what information must be communicated and why it is important. Inspectors should be trained in both verbal and written communication skills. Training also helps standardize communication so every inspector is able to pass and receive useful information.
2. Inspectors must be challenged to understand the importance of good communication. They must understand benefits that are to be gained by improving communication. Any new communication procedures must not add to inspectors' workload or be at all difficult for them to use.
3. Communication tools must be developed for shift turnovers, for passing general information such as management memos and aircraft alerts, for recording detailed problems and follow-ups, as necessary, etc. The medium of communication, e.g., logbook, verbal, blackboard, etc., must be chosen that best meets different communication needs. It is important to provide only the information inspectors need and not to overload them with unnecessary information. Information should be presented in a form that is easy to use and that allows inspectors easily to elicit specific details, as necessary.
4. New communication tools must meet the needs and the expectations of all involved with the inspection department, including managers, leads, and inspectors. These individuals need to have input into redesigning the communication system.
5. At the Atlanta Maintenance Base, there are three distinct inspection groups: support shops, engine shops, and major maintenance. The communication system, especially the shift turnover log, should be standardized for all these groups. Such standardization would make it easier for inspectors to move among groups, effectively obtaining necessary information, and allowing better, more-effective cross-utilization of personnel.
6. The maintenance department holds a daily 8:00 a.m. production meeting; the inspection department is invited to attend this meeting. The information from this meeting should be used to help schedule tasks for the afternoon and night shifts. The day shift attendee at this meeting must relay information through a shift turnover log to the other shifts. It should become standard practice to use the shift turnover log to communicate such information.

## **6.3 Possible Solutions to Communications Problems**

After we completed the broad-based user needs analysis of workers and management, we considered possible solutions for improved communication at the maintenance base.

### 6.3.1 Communication Tools

As discussed above, communication could be facilitated by implementing a new communication system. However, in choosing the most appropriate tool for improving communication, it is necessary to consider who is trying to communicate with whom and what is being communicated. The human factors principle of fitting the tools to the user applies here no less than in designing hand tools. It may be necessary to use different communication tools to satisfy different types of communication requirements; in fact, it is improbable that one communication tool could address all communication needs.

#### 6.3.1.1 Available Communication Tools

A **formal written log**, e.g., the shift turnover log, is a permanent written record of activities within the inspection department. The document can serve legally as evidence for scheduling/staffing considerations and job control, and as a written account of problems inspectors encountered. A formal written log is usually bound so that pages and the information on them cannot be removed.

**Informal written notes** can substitute for the current reliance on memory and verbal communication. Inspectors may forget to pass on information to the lead inspector or to inspectors on the next shift. Writing down information relieves the inspector of relying on memory for the transfer of information. Informal notes can be addressed to an individual or to an entire crew.

**Tape recorders** can replace informal written notes ([discussed above](#)). Many inspectors do not like to write down information because the process of doing so is cumbersome and time-consuming. Allowing each inspector to make personal notes and notes to others on a tape recorder eliminates the need for written notes. The tape can then be transcribed into a written log and/or passed to the oncoming shift for the next inspector. This allows an inspector to replay verbal information during a shift. Tape recorders are best suited for recording information for self-reminding or for another individual in a closely related occupation.

**Computer software tools** can be developed to meet inspectors' communication needs. Tools such as electronic mail, electronic bulletin boards, electronic turnover logs, electronic databases, etc., can transfer information among people. A computer tool allows more than one person to access information simultaneously; this is not feasible with a formal written log since there is only one copy. Electronic tools provide flexibility in the presentation of information. For example, each inspector may request only information directly pertaining to the task at hand, and the inspector will not have to read irrelevant information (see [comments in #5 of Section 6.2.4](#)).

**Blackboards/Whiteboards** are quite useful for recording information that only needs to be used for a short time. Blackboards/Whiteboards should be utilized for communicating information to an entire crew since the information becomes general knowledge. Information could be left on the board for each of the three shifts to see and then be erased. It is important not to erase information that might be needed later, unless it is transcribed into a permanent written log. For example, inspector work assignments are generally written on a whiteboard during every shift. This board is erased at the end of every shift, and work assignments are not recorded. It is therefore difficult quickly to trace previous work assignments; one must research completed workcards to do so.

**Formal crew meetings** are useful for presenting information to all inspectors. Meetings permit two-way discussions about the information, as well as the opportunities for questions. Since the same information can be presented to all three shifts, this ensures that all inspectors receive the same information. However, crew meetings are often ineffective in meeting inspectors' communication needs. Inspectors often ask questions at these meetings that are never answered, and the meetings

can turn into gripe sessions.

Although **informal verbal communication** is used in many information exchanges, it is not well-suited for many tasks. Verbal communication is short-lived. If the person receiving verbal information forgets something, it is very difficult for his or her memory to be refreshed. An inspector could be in the position of having to call an off-duty inspector at home to have information repeated. On the other hand, an inspector may refer to a written record of information as many times as necessary. Thus, written communication is less demanding on an inspector's memory. In addition, relying on memory for recording information is ineffective if the information needs to be kept for a long time. For example, an inspector who discovers and resolves a particular problem on an aircraft may not recall details of what occurred five months later, when the [FAA](#) is questioning him or her about a critical incident with that aircraft. Generally, verbal communication to more than one individual is difficult because it is nearly impossible to relay verbally exactly the same information, in exactly the same manner, more than once.

Inspectors use **non-routine workcards** (NR W/Cs) to identify areas on an aircraft that require maintenance. The workcards are a formal recording procedure that allows inspectors to communicate their findings to the mechanics who will perform the needed repairs. Each non-routine workcard is then bought back to the inspector, who rereads the original write-up to ensure that the work is completed as specified.

[Table 6.3](#) illustrates how various tools can be used to meet communication needs between various inspection and maintenance personnel.

As [ASRS](#) report analysis indicates, the issue in choosing an appropriate communication tool is one of ensuring ease of use so that necessary communication occurs. [Table 6.3](#) shows a matrix of which tools can be useful for which tasks. For example, a small tape recorder, such as a micro-cassette dictating machine, provides easy and rapid memory augmentation. In some organizations, inspectors have such a device taped to their flashlight so as to have it instantly accessible. This is an example of improving ease of use and, hence, of decreasing the probability of missed communication.

Another example is a board which can be used for rapid communication with many people. Although [Table 6.3](#) indicates that a board can be used by leads and managers, it can also serve as a source of situational awareness when it carries notes from inspectors or mechanics. Again, the primary function of this tool is to promote ease of use.

**Table 6.3** Communication Tools Matrix

	computer log notes	computer recorders	blackboard/ tools	whiteboard	N-R meetings	verbal	W/Cs
inspector to self	*	*	*	*			
inspector to inspector (same shift)	*	*	*	*	*	*	*
inspector to inspector (other shift)	*		*	*	*	*	
inspector to mechanic (same shift)	*	*	*	*	*	*	*
inspector to mechanic (other shift)	*		*	*	*	*	
inspector to lead inspector (same shift)	*	*	*	*	*	*	
inspector to lead inspector (other shift)	*	*	*	*	*		
inspector to manager	*		*	*	*		
lead inspector to lead inspector (other shift)	*	*	*	*	*		
lead inspector to inspector (same shift)	*	*	*	*	*		

lead inspector to inspector (other shift)	*	*	*	*	*	
lead inspector. to crew (same shift)	*	*		*	*	*
lead inspector to crew (other shift)	*	*		*	*	*
lead inspector to manager	*	*		*	*	*
manager to lead inspector	*	*		*	*	*
manager to inspector	*	*		*		*
manager to crew (all shifts)	*	*		*	*	*
mechanic to lead inspector	*	*		*		*
mechanic to inspector	*	*		*		*

As [Table 6.3](#) shows, computer systems are available to facilitate almost any activity, but their ease of use is not always appropriate for the demands of communication. If people need to be trained and then must later remember how to access the tool, or how to direct a notice, then the tool's frequency of use will drop. Fortunately, advances in human-computer interaction (HCI) have improved interface design, particularly for infrequent users.

The other major cluster of tool use is in handwritten logs. The shift turnover log is the basis for human factors intervention in this project.

### 6.3.2 Proposed Shift Turnover Log

The proposed shift turnover log was designed to improve communication among inspectors from different shifts. The present shift turnover log is used mainly by the lead inspectors and does not contain much information that inspectors can utilize. It does not record activities that took place during a shift or help the next shift know what they need to accomplish.

The proposed shift turnover log is intended for use by all inspectors. It allows an inspector to record activities during a shift, leaving a written account of what needs to be accomplished and helping prevent rework. Rework in inspection, i.e., more than one inspection of the same area, is often caused by miscommunication between two inspectors. This is especially true when an inspection is carried over from one shift to the next, and the second inspector does not understand where to start and stop the inspection. In this situation, an inspector typically does "a bit more" so there is no doubt the workcard was covered.

#### 6.3.2.1 First Draft General Information: Proposed Shift Turnover Log

This proposed shift turnover log ([Figure 6.1](#)) will allow inspectors easily to obtain necessary information about an aircraft to which they are assigned. This log is organized into five separate, bound books. Each book has sequentially numbered pages to prevent any pages from being removed.

The first book is the general shift turnover log. It can be used, as the current log is used, to pass information between shift leads.

Information included in this log includes any personnel information such as assigned overtime, call-ins, and field-trips, as well as any general problems. The shift lead inspector should complete this log for the following shift.

The other four logs correspond to the hangar bays ([Figure 6.2](#)). Each book, including the pages, is color-coded to match the bay color. The book should contain enough pages for it to be used during the estimated duration of the aircraft's stay in the hangar: three pages for each day, plus a few extra. A new book can be started for each new aircraft; therefore, each book contains the complete

inspection history for one aircraft. The log can be filed when the aircraft leaves the hangar. Inspectors assigned to a particular aircraft should complete this log.

The specifications and instructions for the proposed shift turnover log are included as [Appendix 6-D](#).

### Figure 6.1 Inspection Shift Turnover Log (First Draft)

#### General Shift Information

Date: To Be Read By: Morning Afternoon Night Shift

Lead Inspector: Manager:

Filled In By:

#### Personnel Information

Call-Ins

Name Reason Time

Overtime

Name Reason Number of Hours

Field Trips

Name Destination Departure Time Return Time

#### Special Instructions/General Problems

Problem Needed Action/Alert Resolution Date Time

### Figure 6.2 Inspection Log: Blue Bay (First Draft)

Aircraft number: Day: Shift (Please circle): Morning Afternoon Night

Inspectors Assigned:

Aircraft Status (Please Circle): Line Initial Shakedown Inspection Buyback

General Information/Notes:

Long Term Projects

Project Status Needed Action/Alert Inspector

Other Projects/Problems

Insp. Project/Problem Needed Action/Alert Resolution Date Time

### 6.3.2.2 Evaluation of First Draft

A sample of the inspectors was asked to evaluate the proposed shift turnover log. Responses of the seventeen inspectors are summarized in [Table 6.4](#).

**Table 6.4** Evaluation of Proposed Shift Turnover Log

User Needs Analysis Question	Average	Std. Deviation
How useful is a separate log (for lead inspectors) for personnel information and general problems? 0 - Of No Use      4 - Useful      8 - Extremely Useful	5.44	2.49
How useful is a separate log for each hangar bay? 0 - Of No Use      4 - Useful      8 - Extremely Useful	4.09	2.72
How useful is the practice of maintaining a separate log for each aircraft? 0 - Of No Use      4 - Useful      8 - Extremely Useful	3.88	2.5
Rate the ease of understanding of the proposed shift turnover log: 0 - Not At All Easy      4 - Easy      8 - Very Easy	4.53	2.18
Rate the usefulness of the information in the proposed turnover log: 0 - Of No Use      4 - Useful      8 - Extremely Useful	4.24	2.14
How often would you read all sections of the proposed turnover log? 0 - Never      4 - 3 times/week      8 - Every Shift	4.63	2.8
How often would you read the section of the log for the aircraft that you are assigned to? 0 - Never      4 - 3 times/week      8 - Every Shift	6.33	2.54
How often would you make an entry into the turnover log? 0 - Never      4 - 3 times/week      8 - Every Shift	4.21	2.93
Rate the amount of information in the general section of the proposed turnover log: 0 - Not Enough Info.      4 - Right Amt. of Info.      8 - Too Much Info.	4.09	1.85
Rate the amount of information in the aircraft section of the proposed turnover log: 0 - Not Enough Info.      4 - Right Amt. of Info.      8 - Too Much Info.	4.29	1.99
Rate the type of information in the general section of the proposed turnover log: 0 - Of No Use      4 - Useful      8 - Extremely Useful	3.81	1.78
Rate the type of information in the aircraft section of the proposed turnover log: 0 - Of No Use      4 - Useful      8 - Extremely Useful	3.83	1.85
How does the proposed turnover log compare to the current turnover log? 0 - Less Useful      4 - As Useful      8 - More Useful	5.38	1.51
How often would you use the proposed log, as compared to your use of the current log? 0 - Sig. Less      4 - About the Same      8 - Sig. More	4.85	1.61
How do you like the format of the general section of the proposed turnover log? 0 - Not Easy To Use      4 - Easy To Use      8 - Very Easy To Use	3.91	1.11
How do you like the format of the aircraft section of the proposed turnover log? 0 - Not Easy To Use      4 - Easy To Use      8 - Very Easy To Use	3.64	1.31
How useful is the current shift turnover log? 0 - Of No Use      4 - Useful      8 - Extremely Useful	4.35	1.63
How useful is the proposed shift turnover log? 0 - Of No Use      4 - Useful      8 - Extremely Useful	4.64	1.38

These results indicate that the proposed shift turnover log offers many improvements over the current version. A One-Sample Wilcoxon test was performed to determine whether the median response for each question was significantly different from the 0, mid-point(4), or end-point of the rating scale(8). After performing this analysis, we find that the inspectors felt that the use of a separate log for recording personnel issues and general problems was significantly better than useful (median = 5.65,  $p=.038$ ). They also indicated that they would read the turnover log for the aircraft to which they were assigned more than three times per week (median = 7.0,  $p=.009$ ). Inspectors also felt that the proposed turnover log was more useful than the current turnover log (median = 5.225,  $p=.002$ ) and that they would use the proposed turnover log more often than they use the current turnover log (median = 4.5,  $p=.037$ ).

Other trends in the data, although not statistically significant, are that the inspectors generally found the proposed log easy to understand and that both the general and the aircraft sections contain the right amount of information. Unfortunately, inspectors indicated that they would be likely to make an entry in the log only three times per week, not every day as the log would require. Comments from the user needs analysis indicated that many inspectors feel that maintaining the log is the lead inspector's duty. There are clear issues of culture, expectations, and training surrounding any change

in the shift turnover log.

The inspectors indicated that the proposed shift turnover log does not meet their needs for information, as indicated by the less-than-useful ratings given to the type of information the log contains. They do not find the proposed shift turnover log's layout particularly easy to use. Finally, inspectors rated the usefulness of the proposed shift turnover log (Questions 17 and 18: mean 4.64 compared to 4.35) as only slightly higher than the usefulness of the current shift turnover log; a Mann-Whitney analysis indicates that this difference is not statistically significant.

### **6.3.3 Version 2 of the Shift Change Log**

#### *6.3.3.1 Design of Second Version of Shift Change Log*

From these results, it appears that inspectors approve of the idea of developing a new format for the shift turnover log and will utilize an improved log, especially its sections pertaining to their specific work assignments. However, more work is necessary to find a layout that will meet inspectors' information needs.

After analyzing the results, we concluded that inspectors supported the idea of maintaining a separate log for each hangar bay; however, they were not satisfied with the information on or the format of the proposed log. More work was needed to design a log better meeting the inspectors' information needs. We decided to use a team approach for the next phase of shift turnover log design. We held meetings with each inspection shift to discuss how the log should be designed. Inspectors were encouraged to contribute to the process by indicating the information they would like to see included in the turnover log.

Unfortunately, of the 10 to 15 inspectors in each meeting, only a few provided input for redesigning the shift turnover log. Their overall suggestions were to simplify the proposed shift turnover log and to reduce the writing required to complete it. One inspector suggested that the log should include only a simple heading (aircraft number, date, shift) and a blank space for inspectors to write; this is basically the same as the current turnover log (it is not being utilized effectively).

Although user needs analysis results had indicated otherwise, most inspectors reacted negatively to the idea of a redesigned turnover log. Some of their opinions were the following: 1) inspectors would not use a redesigned log unless it was mandated by upper management; 2) separating the log by hangar bay would make the log too difficult for leads to use; 3) leads are the only ones who need a shift turnover log; 4) inspectors depend on leads to pass along information; and 5) it is not the inspectors' responsibility to pass information during a shift turnover. These comments were symptomatic of inspectors' general attitudes, implying that communication between shifts is not the most serious problem within the inspection department.

In addition, the shift schedule (7:00 a.m.-3:00 p.m., 3:00 p.m.-11:00 p.m., and 11:00 p.m.-7:00 a.m.) does not allow for overlap of oncoming and outgoing shifts. Many inspectors felt that a shift turnover log (either verbally or written) would require too much time and would place too many additional requirements on the inspectors. What the inspectors fail to realize is that this is the exact reason an effective shift turnover log is essential.

Inspectors also indicated that it is the lead inspector's responsibility to perform a shift turnover. The lead should extract the important information from each crew member and pass this information to the next shift. The oncoming lead is responsible for reading the information in the log and distributing it, as necessary. Although many inspectors indicated that they require information passed between shifts, they believe that someone else is responsible for providing this information.

Many inspectors indicated that they would find a log for the particular aircraft to which they were assigned helpful. This would allow them quickly to 'get a feel' for the aircraft's status. These inspectors also stated that it is most important for leads to understand what is happening, and the proposed shift turnover log should be designed for leads, not for other crew members. This is

troubling; as one sees in the [ASRS](#) reports, it is critical for inspectors working on an aircraft to have a good understanding of the problems previous shifts encountered.

In addition, many inspectors have regular opportunities to serve as the lead for a shift, e.g., when the permanent lead takes a day off, and many inspectors eventually become permanent leads. Although inspectors do not feel responsible for knowing information in the turnover log, they are expected to have a full understanding of it when they act as lead for a shift. An effective turnover log could ensure that an acting lead inspector is quickly able to extract necessary information. If all inspectors regularly read the redesigned log, there will be less information to absorb when he or she becomes a temporary lead inspector.

There also seems to be a large mismatch between the inspectors' need for information and the effort they are willing to make to obtain it. On the original communications user needs analysis, inspectors indicated that they rarely if ever have enough information, that they often must search for information to perform their jobs, and that they would like information to be readily available. However, when inspectors were asked to provide more information about events occurring during their shift through the shift turnover log, most were extremely reluctant to do so. They felt that completing a written log at the end of each shift would be too time-consuming and difficult. Inspectors seem to want to receive information from the previous shifts, but not to provide information to the next shift.

Inspectors are reluctant to write down any information not specifically required. They feel that their signatures on workcards fulfill their legal record keeping requirements. They do not want to record additional information in a log which could be used against them in an investigation; they do not realize that information in a written log could protect them in an investigation. This is also part of a current national debate: can maintenance and inspection personnel be disciplined merely for providing information which could help the system?

Many inspectors seem unwilling to make an effort to improve the communication process. They are unhappy with how management treats them and, thus, have little motivation to improve the situation. Most simply want to perform their jobs and to take on as little responsibility as possible. Inspectors are distrustful of management and do not believe that management wants to aid the inspectors by trying to improve communication. During small group (or one-on-one) discussions, inspectors offered suggestions for improving internal communication in the inspection department. During the shift meetings few people were willing to discuss a need for improved communication. Even individual inspectors who want to improve their jobs do not want to appear sympathetic to management's needs or wants. Some inspectors had a hard time believing that management had not sent us. Sociotechnical problems between management and inspectors must be resolved before any proposed shift turnover log can meet information needs of both groups. As is true of many human factors issues in aircraft maintenance and inspection, searching for a consensus solution to a technical problem reveals broad social issues when it is time for implementation.

Based on input we received in evaluation meetings, we simplified the shift change log for its final version. We did this to address inspectors' (other than leads') unwillingness to provide shift information, although the changes somewhat reduce the information's utility to the reader. Figures [6.3](#) and [6.4](#) show the second draft of the shift change log.

**Figure 6.3** Lead Inspector Shift Turnover (Second Draft)

### General Shift Information

Date: To Be Read By: Morning Afternoon Night Shift

Lead Inspector: Manager:

Filled In By: on the Morning Afternoon Night Shift

### Personnel Information

Call-Ins

Name Reason Time

Overtime

Name Reason Number of Hours

Field Trips

Departure Time Return  
Name Destination Time

## Special Instructions/General Problems

Problem Needed Action/Alert

### Figure 6.4 Inspector Shift Turnover Log (Second Draft)

Aircraft Number: Date: Shift (Please Circle): Day Afternoon Night

Inspectors Assigned: Projected A/C Departure Date:

Problem Workcards

Card Number Problem

General Problems

#### 6.3.3.2 Evaluation of Version 2 of the Shift Change Log

We used the same evaluation form as in [Section 6.3.2.2](#) to obtain feedback on Version 2 of the new shift change log. Nineteen inspectors evaluated the log shown in Figures [6.3](#) and [6.4](#). [Table 6.5](#) summarizes these results in the same way [Table 6.4](#) summarized those for the first version.

A One-Sample Wilcoxon test showed that inspectors still appreciated the idea of separating personnel information from aircraft information (median = 5.025,  $p = .011$ ), that they found information in the proposed log more than useful (median = 4.95),  $p = .003$ ), that they would read all sections of the log more than three times per week (median = 5.300,  $p = .036$ ), that they would read the section of the log for the aircraft to which they were assigned almost every shift (median = 7.375,  $p = .001$ ), and that they would make entries into the log more than three times per week (median = 6.00,  $p = .023$ ).

Inspectors also thought that information in the log's general section is more than useful (median = 4.562,  $p = .015$ ), and that information in the aircraft section is more than useful (median = 4.600,  $p = .012$ ). They preferred the proposed to the current turnover log (median = 5.450,  $p = .001$ ) and would use the proposed log more than they use the current log (median = 5.150,  $p = .005$ ). Inspectors found the new format of both general and aircraft sections better than easy to use (median = 4.650, 4.738,  $p = .015$ ,  $.016$ ). Finally, they indicated that the proposed log is more than useful (median = 5.200,  $p = .002$ ).

#### Table 6.5 Evaluation of Proposed Shift Turnover Log

User Needs Analysis Question	Average	Std. Deviation
How useful is a separate log (for lead inspectors) for personnel information and general problems?	5.08	1.56
0 - Of No Use	4 - Useful	8 - Extremely Useful
How useful is a separate log for each hangar bay?	4.09	2.10
0 - Of No Use	4 - Useful	8 - Extremely Useful
How useful is the practice of maintaining a separate log for each aircraft?	3.50	2.27
0 - Of No Use	4 - Useful	8 - Extremely Useful
Rate the ease of understanding of the proposed shift turnover log:	4.70	1.69
0 - Not At All Easy	4 - Easy	8 - Very Easy
Rate the usefulness of the information in the proposed turnover log:	5.05	1.34
0 - Of No Use	4 - Useful	8 - Extremely Useful
How often would you read all sections of the proposed turnover log?	5.35	2.57
0 - Never	4 - 3 times/week	8 - Every Shift
How often would you read the section of the log for the aircraft that you are assigned to?	6.98	1.64
0 - Never	4 - 3 times/week	8 - Every Shift
How often would you make an entry into the turnover log?	5.96	2.19
0 - Never	4 - 3 times/week	8 - Every Shift
Rate the amount of information in the general section of the proposed turnover log:	4.16	1.01
0 - Not Enough Info.	4 - Right Amt. of Info.	8 - Too Much Info.
Rate the amount of information in the aircraft section of the proposed turnover log:	4.14	1.02
0 - Not Enough Info.	4 - Right Amt. of Info.	8 - Too Much Info.
Rate the type of information in the general section of the proposed turnover log:	4.77	1.25
0 - Of No Use	4 - Useful	8 - Extremely Useful
Rate the type of information in the aircraft section of the proposed turnover log:	4.83	1.29
0 - Of No Use	4 - Useful	8 - Extremely Useful
How does the proposed turnover log compare to the current turnover log?	5.48	1.42
0 - Less Useful	4 - As Useful	8 - More Useful
How often would you use the proposed log, as compared to your use of the current log?	5.20	1.51
0 - Sig. Less	4 - About the Same	8 - Sig. More
How do you like the format of the general section of the proposed turnover log?	4.86	1.49
0 - Not Easy To Use	4 - Easy To Use	8 - Very Easy To Use
How do you like the format of the aircraft section of the proposed turnover log?	4.93	1.52
0 - Not Easy To Use	4 - Easy To Use	8 - Very Easy To Use
How useful is the current shift turnover log?	4.12	1.69
0 - Of No Use	4 - Useful	8 - Extremely Useful
How useful is the proposed shift turnover log?	5.26	1.43
0 - Of No Use	4 - Useful	8 - Extremely Useful

It is possible to use data in Tables [6.4](#) and [6.5](#) directly to compare the two versions of the shift change log. A two-sample turnover test was performed to compare results from the evaluations of the first and second drafts. [Table 6.6](#) presents the results of this analysis.

These results indicate that inspectors rated the second draft significantly higher in both information content and format (at the  $p < .01$  significance level). Since these were the first draft's main weaknesses, the second draft appears better able to meet inspectors' communication needs.

Although the result was not significant, inspectors felt that the second draft was more useful (mean = 5.26 versus 4.64 in first draft) and that they would be more likely to make frequent entries in the second draft (mean = 5.96 versus 4.21). These data support the findings that the second draft is better suited to inspectors' communication needs. We therefore proposed that this version become the base's standard shift change log.

### 6.3.4 Other Communication Solutions

During 1995, Northwest Airlines management will implement two programs to improve communication with its workforce. First, they will introduce a bulletin board for posting company news and announcements. Each shift will have its own copy of each announcement, and each inspector will sign off after reading each posting. This system is designed to ensure that all

inspectors are aware of important company business.

**Table 6.6** Comparison of First Draft and Second Draft

1st Draft	2nd Draft				
User Needs	Analysis	Question	Mean	Mean	P Value
How useful is a separate log (for lead inspectors) for personnel information and general problems?	5.44	5.08	0.61		
0 - Of No Use	4 - Useful			8 - Extremely Useful	
How useful is a separate log for each hangar bay?	4.09	4.09	1.0		
0 - Of No Use	4 - Useful			8 - Extremely Useful	
How useful is the practice of maintaining a separate log for each aircraft?	3.88	3.50	0.64		
0 - Of No Use	4 - Useful			8 - Extremely Useful	
Rate the ease of understanding of the proposed shift turnover log:	4.53	4.70	0.79		
0 - Not At All Easy	4 - Easy			8 - Very Easy	
Rate the usefulness of the information in the proposed turnover log:	4.24	5.05	0.19		
0 - Of No Use	4 - Useful			8 - Extremely Useful	
How often would you read all sections of the proposed turnover log?	4.63	5.35	0.43		
0 - Never	4 - 3 times/week			8 - Every Shift	
How often would you read the section of the log for the aircraft that you are assigned to?	6.33	6.98	0.40		
0 - Never	4 - 3 times/week			8 - Every Shift	
How often would you make an entry into the turnover log?	4.21	5.96	0.11		
0 - Never	4 - 3 times/week			8 - Every Shift	
Rate the amount of information in the general section of the proposed turnover log:	4.09	4.16	0.90		
0 - Not Enough Info.	4 - Right Amt. of Info.			8 - Too Much Info.	
Rate the amount of information in the aircraft section of the proposed turnover log:	4.29	4.14	0.79		
0 - Not Enough Info.	4 - Right Amt. of Info.			8 - Too Much Info.	
Rate the type of information in the general section of the proposed turnover log:	3.81	4.77	0.081		
0 - Of No Use	4 - Useful			8 - Extremely Useful	
Rate the type of information in the aircraft section of the proposed turnover log:	3.83	4.83	0.081		
0 - Of No Use	4 - Useful			8 - Extremely Useful	
How does the proposed turnover log compare to the current turnover log?	5.38	5.48	0.85		
0 - Less Useful	4 - As Useful			8 - More Useful	
How often would you use the proposed log, as compared to your use of the current log?	4.85	5.20	0.51		
0 - Sig. Less	4 - About the Same			8 - Sig. More	
How do you like the format of the general section of the proposed turnover log?	3.91	4.86	0.038		
0 - Not Easy To Use	4 - Easy To Use			8 - Very Easy To Use	
How do you like the format of the aircraft section of the proposed turnover log?	3.64	4.93	0.011		
0 - Not Easy To Use	4 - Easy To Use			8 - Very Easy To Use	
How useful is the current shift turnover log?	4.35	4.12	0.68		
0 - Of No Use	4 - Useful			8 - Extremely Useful	
How useful is the proposed shift turnover log?	4.64	5.26	0.19		
0 - Of No Use	4 - Useful			8 - Extremely Useful	

Management will also schedule meetings with inspectors, and inspectors will determine the frequency of these meetings. These meetings will help management better understand each inspector's needs and concerns. Inspectors issues and concerns will be recorded on a form that includes to whom the issue is assigned and an expected resolution date. The form will be posted on the bulletin board so that everyone is aware of progress made toward resolving the issues.

Other possible solutions inspectors suggested include the following.

1. Allow each inspector to carry a small tape recorder throughout the day so that an inspector can record information, notes, and messages as events happen. The tapes can be passed to the inspector taking over on the next shift. This second inspector can listen to the previous inspector's notes as often as necessary. The tapes can be transcribed into the written log of daily activities for permanent record keeping.
2. Develop a shift turnover log in the form of a simple checklist, allowing inspectors quickly to

complete the log with minimal writing. Eventually, a bar code system could allow even simpler completion.

3. Use one-on-one shift turnovers in which incoming inspectors walk around the hangar with outgoing inspectors to ensure that all necessary information is relayed.

4. Use a blackboard/whiteboard temporarily to record information that may be useful for all inspectors. Information often passes to inspectors through informal, impromptu meetings, often over a particular problem one inspector encountered. When absent, a particular inspector may never know that he or she missed hearing important information. When this problem is again encountered, it may be completely new to some inspectors, although others previously discussed and resolved it. Inspectors would find it helpful for this type of information to be written down so that they all may review it.

## 6.4 Guide to Airlines on Establishing Human Factors Program

One of the outcomes of this study was to be a guide for airlines on how to establish and implement their own human factors/ergonomics programs. The information on task force formation, training, and procedures was written as a guide in [Chapter 2](#) of the FAA's *Human Factors Guide for Aviation Maintenance*.

That chapter presents the following seven-step process:

Establish mission and structure

Form human factors task force

Train task force

Analyze jobs

Design solutions

Reanalyze changes

Transfer technology.

This material was presented and used as the basis for a workshop at the [FAA/AAM](#) Annual Human Factors in Maintenance meeting in Albuquerque, New Mexico, during November 1994. C. G. Drury summarized progress of the current project in a presentation entitled "Integrating Human Factors into Maintenance Program." Project results since that time (Sections 3 and 4 of this report) provide additional feasible structures for human factors implementation. A broader program with limited objectives, but wide involvement, may serve as a viable first project to gain visibility for human factors in a maintenance organization. Lessons learned from the communications/shift log study reported in Sections 3 and 4 are being incorporated into [Chapter 2](#) of the *Guide* and will form the basis of a proposed new *Guide* chapter covering communications processes.

## 6.5 Conclusions

This project demonstrates that a human factors program in an airline maintenance environment succeeds only when it adapts to the maintenance base's specific environment. Our initial methodology of using a workforce/management team to target specific jobs did not produce successful implementations, despite its success in many other industries. Our airline partner's specific needs required a different approach based on involving the maximum number of people, instead of a small task force, and limiting the scope to one issue, i.e., communication, rather than

searching broadly for ergonomic mismatches.

Focusing on communication brought potential solutions under direct control of employees at the site, while still demonstrating potential for improved human error rates. The use of outside data, in this case the [ASRS](#) reports, provided specific instances of human factors needs which could be related to local conditions and suggested practical improvements.

The specific choice of the shift turnover log showed how involvement of both human factors professionals and the inspection workforce can produce a practical refined job aid. The new log meets more communication needs than its predecessor and has good acceptance in the user community.

## 6.6 References

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## Appendix 6-A

### Ergonomic Audits of Inspection Tasks

TO: :John Lane

FROM: :John W. Ditty

Task Description: :Keel Inspection

Date: :4/27/94

Time: :10:00 a.m.

Station: :Atlanta

Hangar Bay: :RED

Aircraft No. :9153

M/E No. :

Q/A No. :

## HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/ DOCUMENTATION

### A. Information Readability

1. 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 = 3.1 mm to 4.2 mm

Maximum Character Height = 4.5 mm

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

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

2. Standards not prescribed. State "TIME" & "QUALITY" standards to ensure consistent print quality.

### B. Information Content

Text

3. 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 & current aircraft under inspection.

### C. Information Organization

4. 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.

5. 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 begin and end on the same page.

6. 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

1. No ongoing program to maintain adequacy of communication channels.

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

1. Fluorescent bulbs: "Fair" to "Good" 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. Flicker exists. Consider:
  - a. appropriate shielding of ends of fluorescent lamps
  - b. regular replacement of fluorescent lamps.
3. Lighting fixtures dirty. Keep lighting fixtures free/clean from dirt/paint.
4. No "Shades/shields" on illumination source. This may cause "direct" or "disability" glare.
5. Illumination sources not working. Consider regular replacement of light sources.

## HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/ ACCESS

### ACCESS-STEP LADDERS

### ACCESS - TALL STEP LADDERS

## HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/DOCUMENTATION-PHYSICAL HANDLING AND ENVIRONMENTAL FACTORS

1. Current light conditions inadequate for quick and easy reading of workcard.
2. The inspector does not sign-off workcard after each subtask. This may lead to errors of omission.

## HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/TASK LIGHTING

1. The average task illumination is 152.50 fc. and the variance is 2318.75. The recommended task illumination should be 200.00 fc. The variance is exceptionally high.
2. Handlamps deliver a max. of 85 fc. of light. This illumination level is inadequate for "Fine Inspection." Handlamps also lack aiming control. Consider using of Standing Lamping (Halogen

500 watts-1200 fc.).

3. Consider headlamp for hands-free illumination: except in explosive environments, e.g., fuel tank inspection.
4. The portable/personal lighting equipment interferes with the inspection task.
5. The operator felt difficulty in handling with respect to the size of the lighting equipment.
6. The operator felt difficulty in handling with respect to the weight of the lighting equipment.
7. The operator experienced glare from the task surface. Consider:
  - a. reducing glossiness of material
  - b. screening of sunlight penetrations
  - c. repositioning the light source
  - d. use diffusing light sources, e.g., fluorescent lamps

#### HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/THERMAL CHARACTERISTICS

1. The current DBT is 0.00 de.g., cent. The recommended temperature is between 20-26 degrees centigrade.
2. The current task has been identified as having HIGH physical workload. The DBT is 0.00 cent. and the clo value for clothing is 0.79 clo. The recommended DBT values for HIGH workload and clo values between 0.75-1.0 are 14-20 de.g., cent. Consider change in clothing.

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

1. The operator found the summer temp. at the workplace to be slightly warm.
2. Operator wanted the summer temp. at the workplace to be cooler than the current temp.
3. Operator is generally not satisfied with the temp. at workplace during summer.
4. The operator found the winter temp. at the workplace to be slightly cool.
5. Operator wanted the winter temp. at the workplace to be warmer than the current temp.
6. Operator is generally not satisfied with the temp. at workplace during winter.

## HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/AUDITORY CHARACTERISTICS

1. The maximum sound level at this task is 105 dbA. Noise levels above 90 dbA indicate the need for management intervention and control.
2. This task involves verbal communication. The average noise level is 95.60 dbA. The distance of communication is 4.00 feet. The noise level for communication at a distance of 3.5-6.0 feet should not exceed 60 dbA.

## HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/NON-DESTRUCTIVE TESTING

1. [NDT](#) equipment was not easily maneuverable during inspection.

### Displays, Controls, and Knobs

2. The inspector experiences division of attention. Consider using two inspectors for the [NDT](#) inspection.
3. Visual checks are not highlighted by aural signals. Auditory signals help by providing redundancy gain.

## HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/ACCESS-ACTIVITY

1. Inspection affected by parallel work, e.g., opening or closing of panels, cleaning other inspections, or repair. Also check for obstruction due to equipment, e.g., tool boxes, lighting equipment, access equipment, etc.
2. The operator felt that access was difficult.
3. The operator felt that access was dangerous.
4. Access equipment was repositioned too frequently. This consumes a lot of operator effort. Consider using multiple access equipment.

## HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/POSTURE

1. The operator felt that the workspace was constrained.

The following extreme postures were observed during the current inspection task: Urgent intervention is requested.

2. Arms in air, back bent, and loading on leg(s).
3. Arms in air, back bent and kneeling, or laying or crawling.
4. Arms in air, back twisted, and loading on leg(s).
5. Arms in air, back twisted, and kneeling or laying or crawling.
6. Back bent and twisted and loading on leg(s).
7. Back bent and twisted and kneeling, laying, or crawling.

#### HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/ SAFETY

1. The inspection area is not adequately cleaned for inspection. Consider appraisal of pre-inspection processes like "open-up" and "cleaning".

#### 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.

## Appendix 6-B

### Ergonomic Risk Factors

#### 1) Workcards

- Card contrast changes
- Ribbon changing-establish preventive maintenance program
- Graphics-confusion using graphics/time to get graphics
- Graphics on cards-could one get too reliant on cards and not use the manual?
- Card content inaccurate?
- Graphics attached to card until buy-off
- Breaks between cards is not good
- Use of if/then statements

## 2) Lighting

- Fixtures are dirty
- Need a preventive maintenance program for lighting
- Lighting at the back of the hangar is inadequate
- Color of hangar bays-to ensure good reflectance, need a light color floor
- Repairs must be performed by facilities department

## 3) Keel Inspection

- Check task lighting-cannot read workcard
- Fuselage stand lighting
- Handling lighting equipment cords and small lights
- Temperature in the summer is too hot
- Task performed in very noisy environment
- Sheet metal work often interferes with task access
- Task performed in a restricted space
- Difficult to get back on to the ladder
- Task requires less-than-optimal posture
- Task must often be re-cleaned-cleaners do not understand necessary level of cleanliness required for this task
- Cleaners' work of is not inspected before task begins
- Time pressure

## 4) PS4 Drain Box Inspection

- [NDT](#) equipment design-probe is difficult to place/equipment is not easy to maneuver
- Scaffolds/ladders can be slippery/task is difficult to access
- Sign-offs/buy-backs on shift change
- Task light cords in the way
- Check lighting levels on task
- Task too hot when the engine is still warm
- Cleaning is often inadequate-not enough time to clean on an overnight inspection

## 5) [E&E](#) Compartment Inspection

- Check task lighting
- Cannot read workcard
- Need fixed task lighting for a number of tasks-need to design an appropriate lighting fixture
- Temperature high, due to equipment, in the summer

- Task requires less-than-optimal postures

#### 6) Forward Accessory Compartment Inspection

- Task requires a high ladder-often difficult to find appropriate ladder
- Requires a different type of ladder than those available
- Check task lighting-use of headlamps
- Task is performed in a restricted space-difficult to access
- Task requires less-than-optimal postures

## Appendix 6-C

### General Communication

#### User Needs Analysis

Your help is needed to assess the quality of internal and external communications in the Hangar Inspection Department. Here is an excellent opportunity for you to help us make improvements in the Inspection Department Communications System which will give you clear information on your work assignments and make the workplace less stressful.

Please complete the questionnaire below and return to the Atlanta Safety Department by October 20, 1994.

Remember, if you do not complete and return a questionnaire, you miss an opportunity to make a difference.

1. How many years experience do you have as an inspector?
2. Where (or from whom) do you get necessary information?
3. Is information given to you verbally or in written form?
4. Whom do you regularly pass information to?
5. How do you pass information (verbally or in written form)?
6. Do you regularly have all necessary information when working on a task, or are you constantly going back for more information?
7. Do you ever read the shift-turnover log? If so, how often do you do so?
8. Do you ever write information in the shift-turnover log? If so, how often, and under what

circumstances?

9. What do you see as the purpose of the turnover log?
10. If you could design a shift-turnover log, what type of information would you include?
11. Should the turnover log be a SEPTRE program similar to Hangar Daily Stat, or book, or both?
12. Do you attend regular crew meetings? If so, who is in attendance at these meetings?
13. Do you feel that regular crew meetings are informative and beneficial, or are they a waste of your time?
14. Have you ever had a problem caused by miscommunication, either between you and another inspector, you and the lead inspector, you and a manager, between you and mechanics, or you and engineering in the work area? If so, please describe.
15. How much turnover time do you have between shifts? Is it sufficient? If not, how much time is needed?

If additional space is needed, please write your response on the back of the page, referencing the question number.

Thank you for your time and input.

John Lane  
Safety Manager

## Appendix 6-D

### Specifications for Proposed Shift Turnover Log

#### A) General Shift Turnover Log

1) The first section of this log records general shift information:

**Date:** Enter the date on which the shift begins.

**To Be Read By:** Circle the shift for which this page has been written: morning (1st shift), afternoon (2nd shift), or night (3rd shift). Each lead inspector should complete this log for the following shift.

**Lead Inspector:** Enter the name of the acting lead inspector on the shift for which this page is intended.

**Manager:** Enter the name of the inspection manager on duty during the shift.

**Filled In By:** Enter the name of the lead inspector who completed this page and circle his or her shift.

*Example:* The day shift lead inspector should begin this log for the afternoon shift. In the first section of the log, the "to be read by" shift is the afternoon shift. The lead inspector is the afternoon lead inspector's name. The manager is the afternoon manager's name. The day shift lead should enter his or her name and circle "morning shift" in the "filled in by" box.

2) The second section of this log records personnel information. Information should be recorded as it is received. The lead inspector should enter information in the log that is to be read by the shift this personnel information affects.

Call-ins should be entered on the log for the shift the inspector was supposed to work.

**Name:** Enter the name of the inspector who called in.

**Reason:** Enter the reason the inspector called in, e.g., sick, family emergency, etc.

**Time:** Enter the time the call was received.

Overtime should be entered on the log for the shift on which the inspector is going to work the overtime hours.

**Name:** Enter the name of the inspector who is working the overtime.

**Reason:** Enter the reason the inspector is working overtime.

**Time:** Enter the number of overtime hours the inspector is expected to work.

Field Trips should be entered on the log for the shift on which the field trip begins.

**Name:** Enter the name of the inspector assigned to a field trip.

**Destination:** Enter the destination of the field trip.

**Departure Time:** Enter the time the inspector departed.

**Return Time:** Enter the time the inspector is expected to return.

*Example:* If Inspector A is supposed to work the midnight shift and calls in sick at 6:00 p.m., the

afternoon shift lead inspector should record this information on the log the night shift lead inspector is to read. Similarly, if day shift Inspector B is asked to work late (overtime), this information should be recorded on the log the afternoon shift lead inspector is to read.

3) The third section of this log records special instructions and general problems. This information, recorded by the lead inspector, is to be read by the lead inspector on the following shift. Information intended for both following shifts should be recorded on both log sheets. The "resolution," "date," and "time" should be completed by the shift resolving the problem or completing the project.

**Problem:** Describe the problem or situation. Each problem on a given day should be numbered sequentially.

### **Needed Action**

**/Alert:** Enter the action the oncoming shift must complete or describe the alert/warning the shift needs to be aware of. Number the actions with numbers of the problem to which they refer.

**Resolution:** Describe the resolution determined or implemented for the problem and include any further developments of a situation. Number the actions with numbers of the problem to which they refer.

**Date:** Enter the date the problem/situation is resolved.

**Time:** Enter the time the problem/situation is resolved.

## **B) Aircraft Log**

1) The first section of this log records general information about the aircraft:

**Aircraft Number:** Enter the number of the aircraft.

**Day:** Enter the number of days the aircraft has been in the hangar.

**Shift:** Circle the shift (morning, afternoon, night) completing this log.

**Inspectors Assigned:** Enter names of all inspectors assigned to this aircraft on this shift.

**Aircraft Status:** Circle the status of this aircraft: Line (not yet in the hangar), Initial Shakedown (initial inspection in the hangar), Inspection (performing scheduled inspections), Buy-back (the buy-back of non-routine workcards).

### **General Information**

**/Notes:** Enter any information about this aircraft important for the next shift to know and/or understand. Some of this information may also be reported to the oncoming lead inspector and

recorded in general shift turnover log.

2) The second section of this log describes ongoing long-term projects:

**Project:** Describe the project being worked on, including the location on the aircraft, if relevant. Number projects sequentially. If more space is needed, continue on the back of the page.

**Status:** Describe the project's status, e.g., project is 30% complete or project is waiting for a specific part, etc.

**Needed Action/Alert:** Describe any actions the next shift must perform or describe any warnings/alerts the next shift should be aware of concerning this project.

**Inspector:** Enter the name of the inspector who entered this project into the log.

3) The third section of this log describes other ongoing projects/problems:

**Inspector:** Enter the name of the inspector who entered this project/problem into the log.

**Project/Problem:** Describe the project, e.g., bag-bin inspection not completed, or the problem, e.g., tail section not clean enough to inspect at 2:30 p.m., that the next shift must be aware of. Number each project/problem consecutively.

**Needed Action/Alert:** Describe actions the oncoming shift should take concerning the projects or problems.

**Resolution:** Describe the resolution to the project/problem that was developed and implemented.

**Date:** Enter the date the project was completed or the problem was resolved.

**Time:** Enter the time the project was completed or the problem was resolved.

# Chapter 7

## Human Factors Audit Program for Maintenance

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### 7.0 Project Objective and Context

This project's objective was to provide a valid, reliable, and usable tool for evaluating human factors in maintenance tasks. The project was part of a broader initiative to apply human factors to reduce human error potential in aircraft inspection and maintenance. As Drury (1994) pointed out, there is a need to move from project-level interventions, such as better lighting, workcards and training, to higher-level process interventions. Two high-level interventions in this phase of the [FAA/AAM](#) project were (a) to provide a tool for assessing the current state of human factors/ergonomics in the hangar (this project) and (b) demonstrating a team approach to ergonomic interventions.

The need for an ergonomics evaluation system has been apparent for some time, and manufacturing audit programs have been developed (e.g., Drury, 1990) to provide a rapid overview of factors likely to impact human/system mismatches at each workplace. In the aircraft inspection context, there is no fixed workplace, so any audit program has to start with the workcard, rather than the workplace, as the basic unit. Such an auditing system was produced in conjunction with two airline partners (Lofgren & Drury, 1994) and tested for both large airliners and helicopters. The system was tested for reliability, and modified where needed, before being validated against human factors expert judgments. Significant agreement was found between the two cases. The system can be used from either a paper data collection form (with later data entry) or directly from a portable computer. The computer is used to compare the data collected against appropriate standards and to print a report suitable for use in an existing airline audit environment. The report allows the airline to direct ergonomic changes to major mismatches.

The scope of this report was to use the Ergonomic Audit for Aircraft Visual Inspection as a starting point for improvement and refinement to produce an Ergonomic Audit for Aircraft Maintenance (EAAM). This report details the differences and similarities between the two programs and the process used to develop the new program/user interface. The EAAM was designed to give an overall, generalized assessment of ergonomic factors applicable to performing a maintenance task. Program input and output were formatted in a way a person unfamiliar with details of the science of ergonomics could understand. This meant the program had to be easy to use, had to help guide the person doing the audit through the steps with relative ease, had to describe less-familiar ergonomic principles, and had to allow the user to access on-line help when questions arose. The results had to be printed in an easily usable form appropriate to the organization's needs and free from unnecessary technical terminology. As with the inspection ergonomics audit, the project's overall aim was to discover human/system mismatches, not to provide prescriptive solutions to problems. Prescriptive solutions still require the depth of ergonomic knowledge, which is best provided by a trained ergonomist.

A task description of a generic maintenance task must be developed and compared to that of an inspection task in order to determine both differences and similarities between the two. Once these differences and similarities have been identified, the inspection audit can be modified to accommodate differences and to provide an accurate tool with which to begin the ergonomic audit and, eventually, the correction process.

From detailed task descriptions and task analyses of inspection activities, Drury, Prabhu and Gramopadhye (1990) developed a generic function description of inspection ([Table 7.1](#)). These descriptions have been used throughout the [FAA/AAM](#) project to structure inspection interventions (Drury, 1994). Now that these descriptions are to be extended to maintenance tasks, a series of tasks

were observed at the airline partner's maintenance facility. From these observations, we developed the equivalent set of generic functions for maintenance shown in [Table 7.2](#).

**Table 7.1** Generic Task Description of Inspection

<b>Function</b>	<b>Visual Example</b>
Initiate	Read and understand workcard. Select equipment. Calibrate equipment.
Access	Locate area on aircraft. Move to worksite. Position self and equipment.
Search	Move eyes (or probe) across area to be searched. Stop if any indication.
Decision	Re-examine area of indication. Evaluate indication against standards. Decide whether indication is defect.
Respond	Mark defect indication. Write up non-routine repair (NRR). Return to search.
Buy-Back	Examine repair against standards. Sign off if repair meets standards.

Tables [7.1](#) and [7.2](#) clearly show the many areas of overlap between the two activities. Initiate (workcards, preparation), parts of Access (getting to the worksite with appropriate equipment), Buy-Back and Respond (final paperwork) have close parallels in these activities. Other major functions are different, but have the same ergonomic concerns. For example, the Search function of inspection depends on good lighting (at least for visual inspection) as do the Diagnosis and Replace/Repair functions of maintenance. Still, other functions are different between inspection and maintenance. For example, Opening/Closing access can require hand or power tools, while Replace/Repair can involve high levels of force exertion or manual lifting: none of these are typically part of inspection.

**Table 7.2** Generic Functions in Aircraft Repair

<b>Function</b>	<b>Tasks</b>
Initiate	Read and understand workcard. Prepare tools, equipment. Collect parts, supplies. Inspect parts, supplies.

Site Access Move to worksite with tools, equipment, parts, supplies.

Part Access Remove items to access parts.  
Inspect/store removed items.

Diagnosis Follow diagnostic procedures.  
Determine parts to replace/repair.  
Collect and inspect more parts and supplies.

Replace/Repair Remove parts to be replaced/repared.  
Repair parts, if needed.  
Replace parts.

Reset Systems Add fluids supplies.  
Adjust systems to specification.  
Inspect adjustments.  
Buy-back, if needed.

Close Access Refit items removed for access.  
Adjust items refitted.  
Remove tools, equipment, parts, unused supplies.

Respond Document repair.

The implication of these differences was that the audit system for aircraft inspection had to be changed, primarily by adding modules to cover maintenance tasks. While this change was being introduced, the opportunity was taken to reconfigure the user interface of the whole data collection and analysis program, using a more modern Windows-based programming language.

## 7.1 Structure of the Audit

An audit program consists of data collection, data analysis, and results presentation. Data collection involves a series of structured job observations and recording these observations. Data analysis has a data input step, and a step where data are compared with human factors standards and good practice. Finally, results presentation takes conclusions drawn from the data analysis and provides them to the user in a useful format. Each step can be either a pencil-and-paper activity or a computer-based activity. The audit program previously developed for aircraft inspection and the one developed here for maintenance tasks have only specified computer-allocation for the analysis and results presentation steps. Data collection can either use hard-copy forms or a portable computer, whichever best fits with the organization's needs. In practice, many organizations prefer to use a form for initial data collection so as to have a permanent record in a highly reliable medium. Data entry then consists of transferring data from the paper form to its mimic on the computer's data input module.

The audit program for maintenance inspection was developed for an IBM personal computer as an integrated program called [EAAM](#). As with the inspection audit program (ERGO), a number of features were required to ensure that the system gave maximum benefit to the user population, typically, maintenance supervisors or quality auditors. Any audit program (Koli & Drury, 1995) must:

- be modular, so as to include maximum coverage without unnecessary length; inserting new

modules to modify the checklist and program for a particular industry is straightforward

- be self-explanatory, so as to minimize training time for auditors
- be based on standards from ergonomics/human factors
- have standards built into the analysis program, rather than into the checklist, to reduce any tendency to "bend" data in borderline cases
- rely on measurements and easily observable conditions to reduce judgment errors
- be usable in different aviation environments, e.g., large fixed-wing aircraft, general aviation aircraft, or rotary wing aircraft, and in different maintenance situations, whether line maintenance or hangar maintenance.

In addition, a structure was required to group audit modules by the human factors principle involved, rather than by generic function. The functions listed in [Table 7.2](#) ensure that coverage is achieved, i.e., all issues which should be raised are indeed part of the audit system. *Structure* in the program should group together the relevant issues. For example, the visual environment is important in a number of functions of [Table 7.2](#), e.g., Part Access, Diagnosis, Replace/Repair, Close Access, but the issues are constant, i.e., the amount and quality of lighting. However, the visual environment is only one type of environment; there are thermal and auditory environments, as well. Thus modules are grouped in a classification scheme using the following four major groupings, following Prabhu and Drury (1992) and Latorella and Drury (1992):

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

This classification formed the basis of the ERGO program and was retained for [EAAM](#).

A second classification scheme was used to reflect the audit program's actual employment. Some factors do not change during the job and can be conveniently evaluated before the job begins, e.g., workcards' quality. Other factors need the job to be in progress before they can be measured, e.g., forces, noise levels, or task lighting. The only module which has to wait for job completion is the evaluation of feedback to the mechanic. Thus, the audit is divided for convenience into three phases:

Pre-Maintenance

Maintenance

Post-Maintenance.

[Table 7.3](#) shows how various modules are classified by ergonomics grouping and phase of audit. Clearly, there are far more physical activity modules in this system than were necessary in the inspection audit program.

### 7.1.1 The Audit Program

**Table 7.3** Classifications of Modules in EAAM

PHASE			
Human Factors Grouping	Pre-Maintenance	Post-Maintenance	Maintenance
Information Requirements	1. Documentation 2. Communication	6. Documentation 7. Communication	23. Buy-Back
Environment Characteristics	3. Visual 10. Thermal Perception	8. Task Lighting 9. Thermal Characteristics	

## 11. Auditory Characteristics

Equipment/ 4. Equipment Design 12. Equipment Availability

Job Aids 5. Access Equipment 13. Access Availability

Physical Activity 14. Hand Tools

Workspace 15. Force Exertion

16. Manual Materials

Handling

17. Vibration

18. Repetitive Motion

19. Physical Access

20. Posture

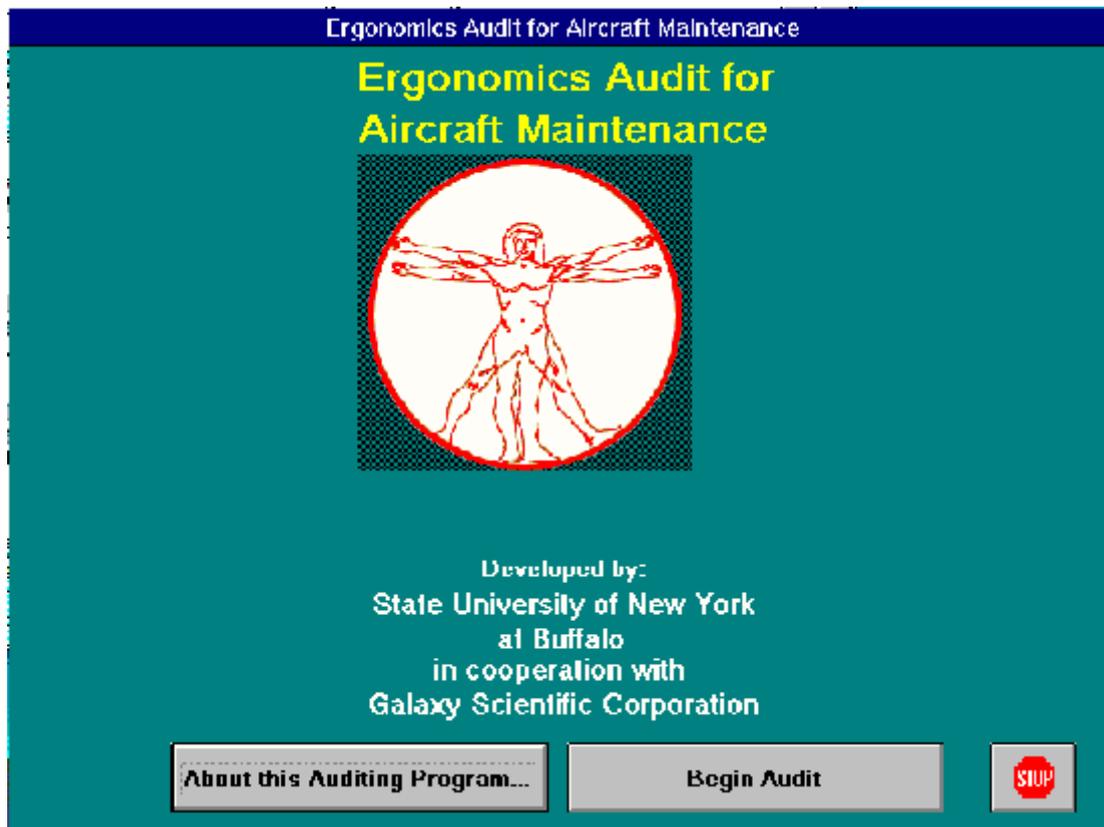
21. Safety

22. Hazardous Materials

The [audit program for maintenance](#) (MAINAUD) will produce a printed form for data entry, referred to as an Audit Checklist (see [Chapter 7 - Appendix](#)). The data entry/data analysis/results presentation program (EAAM) reused some of the inspection audit's background data and calculations, e.g., in the environment modules. However, we took the opportunity to reprogram the whole audit system in Visual Basic 3.0, instead of Turbo Pascal 6.0. Turbo Pascal is a structured, high-level language with multiple overlapping windows, mouse support, a multi-file editor, and an enhanced debugging facility. Visual Basic includes these factors and has greater mouse support abilities, is more user-friendly, and can more easily be expanded to incorporate the changes that may occur in the future. The advantage of Visual Basic is that it allows a programmer to create a program that a person with very little computer experience can use with relative ease. Visual Basic also allows the flexibility of having the final program run on a conventional computer with keyboard and mouse as input or on a pen-based computer system with stylus input. Visual Basic objects, once defined and coded, can be reused in other programs, saving coding effort and reducing coding errors. We chose Visual Basic because of the similarity of its user interface to other Windows-based programs. It uses many of the same symbols for execution as the popular Microsoft programs such as Word, Excel, or Office. A person familiar with any of these programs should have no problem recognizing similarities in Visual Basic and adapting to the Maintenance Audit program, EAAM.

The Title Screen ([Figure 7.1](#)) has an attached HELP system to provide assistance in using the program. At this level, the HELP screen offers a program overview and explanation. Next, heading information is required, e.g., the name of the job, the date, the analyst's name, etc. ([Figure 7.2](#)). The files for input and report document are specified here.

The main program screen lists the modules available and asks the analyst to choose those relevant to the current job audit. Once the analyst chooses a set of modules, each module is presented ([Figure 7.3](#)), in turn, from the Pre-Maintenance phase through the Post-Maintenance Phase. Each module (e.g., [Figure 7.4](#)) requires a series of measurements or classifications. A context-sensitive HELP screen is available for each module; it gives detailed explanations of terms used and of measurement procedures ([Figure 7.5](#)). This practice follows the recommendations of Patel, Drury and Lofgren (1994) for workcards in that it supports different kinds of users, from novice to expert. Each module also provides a comment screen ([Figure 7.6](#)) to allow the analyst to record comments or notes.



**Figure 7.1 Title Screen**

As each module is run, its data are stored in the file the user specified in the heading information screen. When all modules have been run, the final report document is produced, with instructions on how to obtain a hard copy through Windows software ([Figure 7.7](#)).

**Figure 7.2 Heading Information Screen**

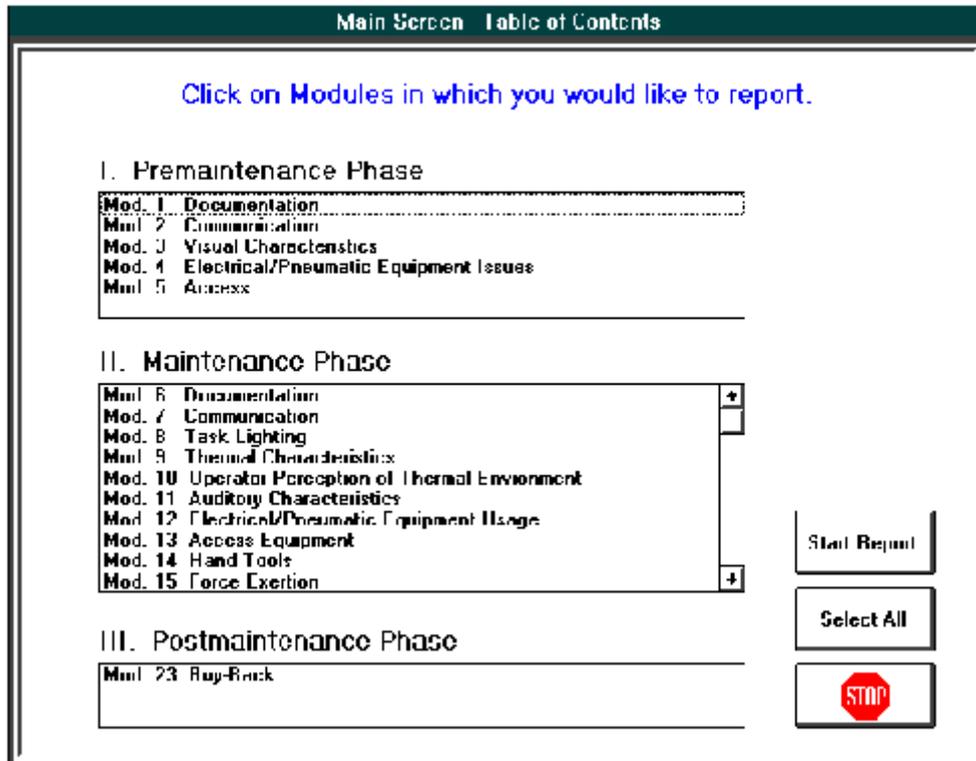


Figure 7.3 Main Program Screen

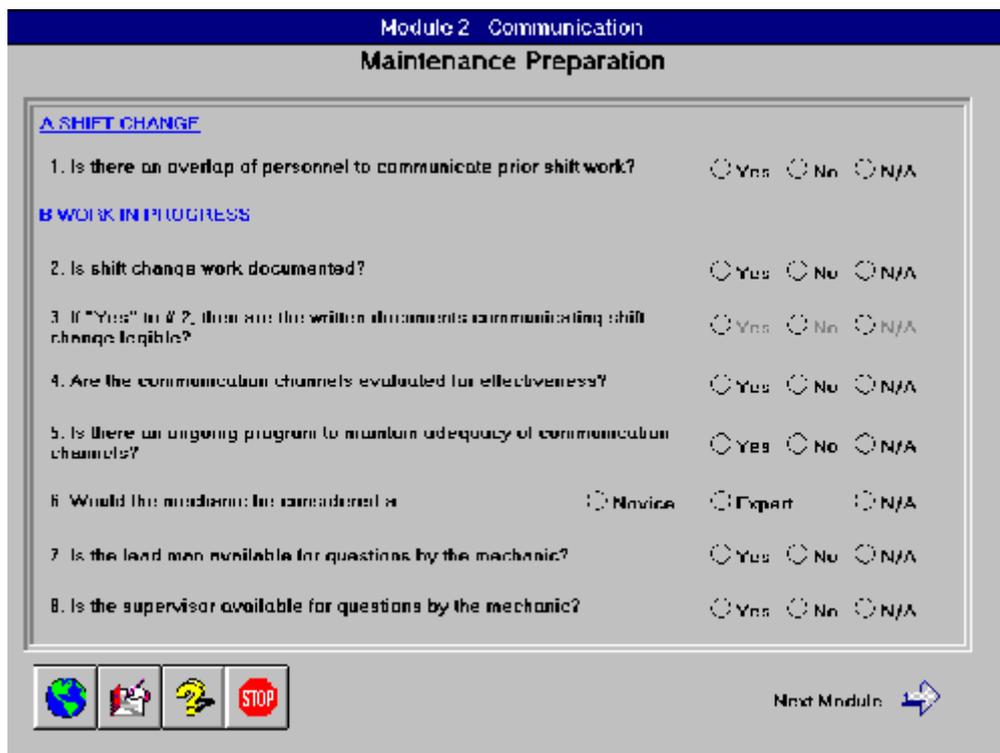


Figure 7.4 Maintenance Preparation Screen

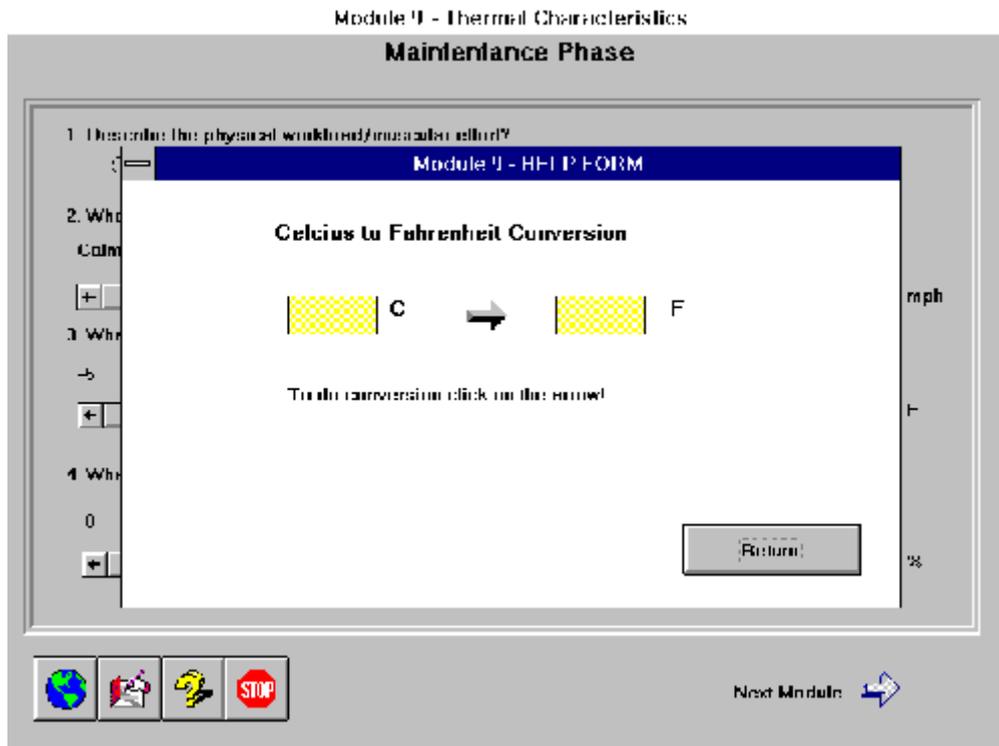


Figure 7.5 Help Screen

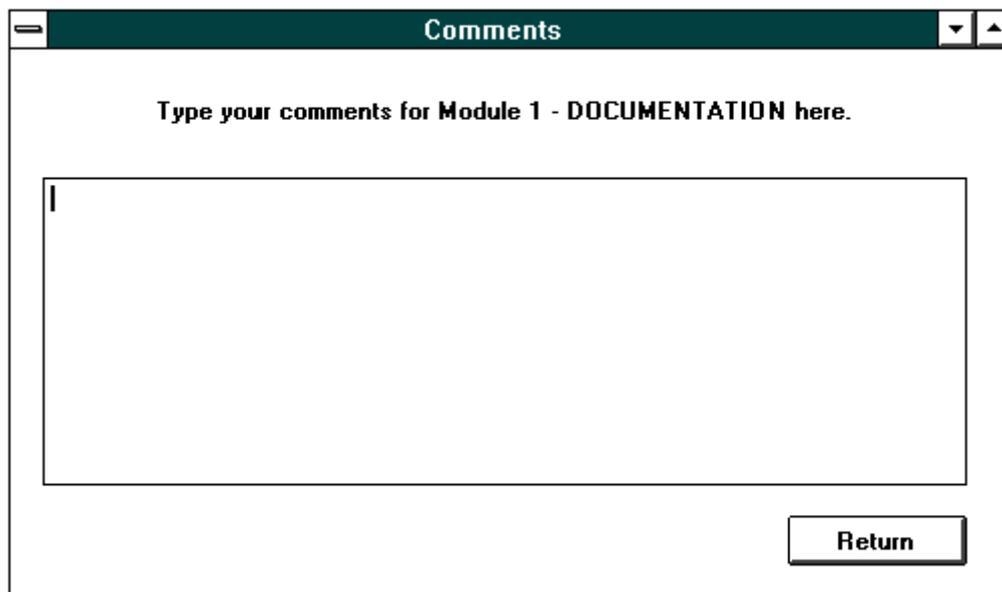
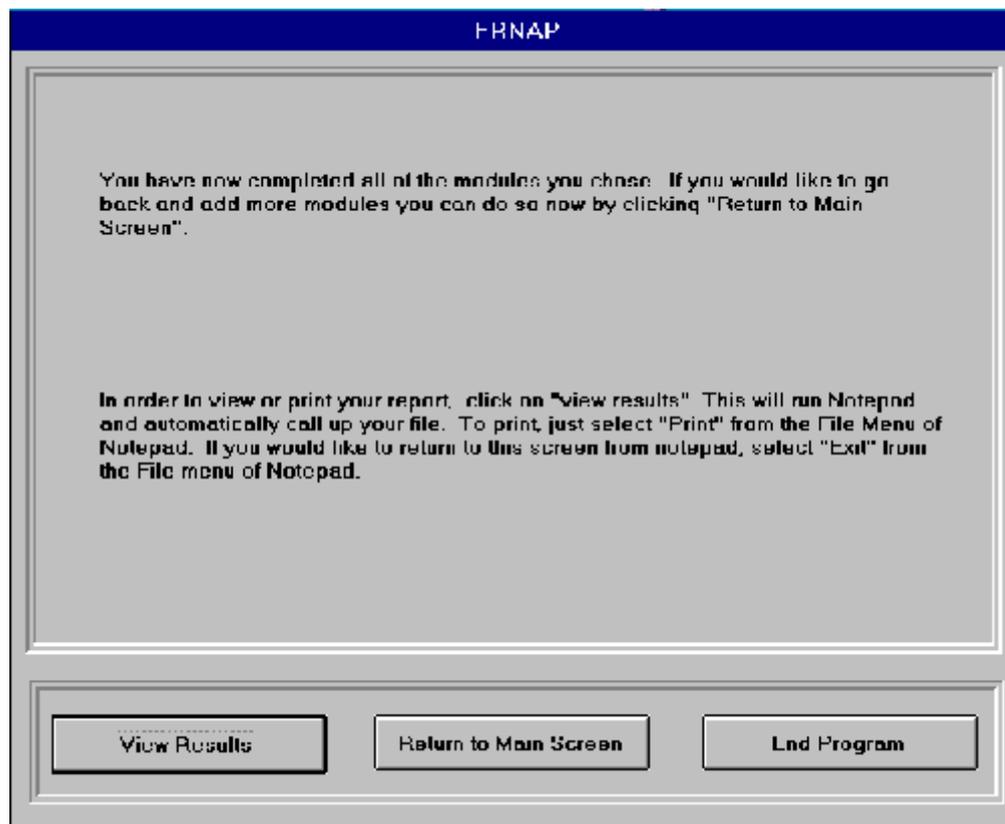


Figure 7.6 Comment Screen



**Figure 7.7 EAAM Screen**

This program is designed to be run on any IBM Personal Computer with at least an INTEL 386 processor, 4 MB of RAM, DOS 5.0, and WINDOWS 3.1. The program itself occupies 2 MB of hard disk space in its stand-alone form. If a user desires to input data directly from the job into the program, a portable computer is necessary; otherwise, a desktop machine is fine. The program can also be run on pen-based computers with WINDOWS compatibility. [Incidentally, the inspection audit ERGO can also run on pen-based systems.]

The modules available in [EAAM](#) are as follows:

#### Pre-Maintenance Phase

##### **MODULE 1-**

###### *DOCUMENTATION*

Information Readability; Information Content, i.e., Text & Graphics, and Information Organization.

##### **MODULE 2-**

###### *COMMUNICATION*

Between-shift communication, availability of lead mechanics and supervisor for mechanics' questions and concerns.

##### **MODULE 3-**

###### *VISUAL CHARACTERISTICS*

Overall lighting characteristics of the hanger, i.e., overhead lighting, condition of overhead lighting, and glare from daylight.

##### **MODULE 4-**

*ELECTRIC/PNEUMATIC**EQUIPMENT DESIGN ISSUES*

Evaluation of the equipment which uses controls, i.e., ease of control, intuitiveness of controls, labeling of controls for consistency and readability.

**MODULE 5-***ACCESS EQUIPMENT*

Evaluation of ladders and scaffold for safety, availability, and reliability.

Maintenance Phase**MODULE 6-***DOCUMENTATION*

Physical handling of documents and the environmental conditions effecting the documents' readability, i.e., weather and light.

**MODULE 7-***COMMUNICATION*

Communication issues between co-workers and supervisors, and whether or not suggestions are considered.

**MODULE 8-***TASK LIGHTING*

The overall lighting available to the mechanic for completing the task. Evaluates points such as light levels, whether personal or portable lighting is used, and whether lighting equipment causes interference with the work task.

**MODULE 9-***THERMAL CHARACTERISTICS*

The current thermal conditions the task is being performed in.

**MODULE 10-***OPERATOR PERCEPTION OF**THERMAL ENVIRONMENT*

Operator perceptions of the work environment at present, during the summer, and during the winter.

**MODULE 11-***AUDITORY CHARACTERISTICS*

Determine if sound levels in the current work environment will cause hearing loss or interfere with tasks or speech.

**MODULE 12-***ELECTRICAL/PNEUMATIC EQUIPMENT*

Availability of any electrical/pneumatic equipment, whether the equipment is working or not, and ease of using the equipment in the work environment.

**MODULE 13-**

### *ACCESS EQUIPMENT*

Availability of ladders and scaffolds, whether the equipment is working or not, and ease of using the equipment in the work environment.

### **MODULE 14-**

#### *HAND TOOLS*

Evaluates the use of hand tools, whether hand tools designed properly to prevent fatigue and injury, and usability by both left- and right-handed people.

### **MODULE 15-**

#### *FORCE EXERTION*

Forces exerted by the mechanic while completing a maintenance task. Posture, hand positioning, and time duration are all accounted for.

### **MODULE 16-**

#### *MANUAL MATERIAL HANDLING*

Uses [NIOSH](#) 1991 equation to determine if the mechanic is handling loads over the recommended lifting weight.

### **MODULE 17-**

#### *VIBRATION*

Amount of vibration a mechanic encounters for the duration of the task. Determines if there are possible detrimental effects to the mechanic because of the exposure.

### **MODULE 18-**

#### *REPETITIVE MOTION*

The number and frequency limb angles deviating from neutral while performing the task. Takes into consideration arm, wrist, shoulder, neck, and back positioning.

### **MODULE 19-**

#### *ACCESS*

Access to the work environment. Whether it is difficult or dangerous, if there is conflict with other work being performed at the same time.

### **MODULE 20-**

#### *POSTURE*

Evaluates different whole-body postures the mechanic must assume in order to perform the given task.

### **MODULE 21-**

#### *SAFETY*

Examines safety of the work environment and what the mechanic is doing to make it safer, e.g., personal protective devices.

### **MODULE 22-**

#### *HAZARDOUS MATERIAL*

Lists types of chemicals involved in the maintenance process, whether they are being used

properly, if workers are following disposal guidelines, if the company is following current [EPA](#) requirements for hazardous material safety equipment.

### Post-Maintenance Phase

#### **MODULE 23-**

#### *BUY-BACK*

Usefulness of feedback information to the mechanic and whether buy-back is from the same individual who assigned the work.

### **7.1.2 Audit Program Evaluation**

The [EAAM](#) program is only part of an audit system. Suitable jobs must still be chosen for auditing, using some sampling plan. The output from the audit must be incorporated into a management structure which will use it effectively to improve job design. None of these issues are essentially different from the equivalent issues for inspection, so they will not be repeated here. Koli and Drury (1995) give details of these procedures. More detail and a discussion of their relationship to the broader field of human factors can be found in Koli (1994).

Any tool designed for human use should be evaluated for its fit to human capabilities and limitations; this is a basic principle of ergonomics. The audit program for maintenance tasks is such a tool, and, like its predecessor for inspection, had to be evaluated. Koli and Drury (1995) tested the inspection audit program ERGO for reliability, i.e., whether different analysts auditing the same job obtain the same results. That reliability study used three jobs, two on a DC-9 inspection and one on a Sikorski S-58T inspection. There were significant differences between the two auditors tested. On further analysis, these differences were shown to be due mainly to inputs requiring auditor judgment. These inputs were modified to reduce the need for judgment. The program was retested on another DC-9 task, showing no significant differences this time between auditors.

Validity of a tool measures whether the tool gives the same output as another trusted tool. Koli (1994) tested the validity of ERGO by comparing its outputs to those of six ergonomics experts viewing a video tape of a DC-8 power plant inspection. The audit program always found at least as many ergonomic issues as any expert, and no issues found by the experts were missed by ERGO.

**Table 7.4** Reliability Data on Maintenance Audit for Four Tasks

#	#					
Task	Questions	Diff.	Reliab.	X <sup>2</sup>	Prob.	
1. Replace overhead passenger service unit.	118	12	90%	12.6	<.001	
2. Close keel box.	163	22	87%	23.6	<.001	
3. Close forward cargo compartment access.	159	27	84%	24.5	<.001	
4. Replace escape window.	134	24	83%	26.4	<.001	

The current program was tested for both reliability and validity in the same way. In addition, its interface was tested for usability, using standard human factors usability testing techniques (McClelland, 1990). Initially, a single user was observed and questioned while using the audit program, partly to assess its usability and partly to develop more detailed measures of interaction between the user and the program. The particular user was a member of the quality assurance

department who regularly performed safety audits and occasional ergonomics audits. Following this analysis, a more detailed observation protocol was developed for usability testing on four other members of the user population.

## 7.2 Reliability Evaluation

Two analysts observed four different maintenance tasks on DC-9 aircraft at the airline partner's maintenance base. The tasks were the following:

1. Replace overhead passenger service unit
2. Close keel box
3. Close forward cargo compartment access
4. Replace escape window

**Table 7.5** Results of Q Test on Maintenance Audit Results

Task	# of Different Outcomes	Cochran's Q	Probability
1. Replace overhead passenger service unit.	10	1.60	>0.25 (ns)
2. Close keel box.	14	7.14	<0.01
3. Close forward cargo compartment access.	10	0.40	>0.25 (ns)
4. Replace escape window.	12	0.33	>0.25 (ns)

For each task, analysts used the paper data collection form as a more severe test of the audit. Direct computer entry of data would have given access to HELP screens. However, since at least some users will want to use paper data entry, this form was used as a worst case. Each analyst recorded answers for each question in each module independently for later comparison. The number of questions differed between the four tasks, as different modules applied for each task. Note that any difference in results between the analysts was counted, whether it affected the audit outcome, or not.

The total number of differences between the two analysts' data sheets were tallied; the results are shown in [Table 7.4](#). Also shown in [Table 7.4](#) is a  $X^2$  test of the hypothesis that the number of errors is equal to zero. This is a very stringent test: for 125 questions only four differences would be needed to conclude that the number of errors was significantly different from zero.

As with the initial reliability study of the Inspection Audit, the audit for maintenance was not reliable enough, averaging 85%. The Cochran Q test, a robust and strong test of the differences between auditors used to evaluate the reliability of the Inspection Audit, was performed on each task to determine the agreement between auditors in terms of output results. For example, if the percent of time the mechanic spent in a particular posture is estimated as 10% by one analyst and 20% by the other, but both results lead to the same outcome, a difference was not scored. [Table 7.5](#) shows the results of this test.

The statistic values show significant differences between the two analysts for one of the tasks, with a magnitude similar to those reported for the same test of the Inspection Audit. However, the non-significant findings on three of the four tasks showed that even the first version of this maintenance audit had been based on lessons learned in the inspection audit. Note that the number of outcome differences was considerably smaller than the number of recording differences. Defined on outcomes, reliability was in fact 92%.

**Table 7.6** Classification of Differences by Error Type

		Number of Differences						
Module	Title	J	D	H	N	O	Total	
1	Documentation	-	2	-	-	1	3	
2	Communication	-	-	-	-	3	3	
3	Visual Characteristics	4	4	-	-	2	10	
4	Electric/Pneumatic Equipment Design	-	-	-	-	0		
5	Issues	6	-	-	6			
6	Access	3	-	2	-	5		
7	Equipment	-	-	-	-	0		
8	Documentation	2	2	-	-	-	4	
9	Communication	3	-	-	-	-	3	
10	Task Lighting	-	-	-	-	0		
11	Thermal Characteristics	2	3	-	-	-	5	
12	Operator Perception of Thermal Environment	1	-	-	-	1	6	
13	Environment	1	-	-	-	1		
14	Auditory Characteristics	4	5	-	-	1	10	
15	Electrical/Pneumatic Equipment	1	-	2	-	-	3	
16	Access Equipment	-	-	-	-	0		
17	Hand Tools	-	-	-	1	1		
18	Force Exertion	-	-	7	-	-	7	
19	Manual Material Handling	2	-	-	1	-	3	
20	Vibration	3	-	-	-	3		
21	Repetitive	1	-	1	-	2		
22	Motion	-	-	-	-	0		
Access								
Posture								
Safety								
Hazardous Material								
<b>Totals</b>		29	24	9	4	9	75	

These reliability results can be analyzed in more detail to determine the cause of each difference and, hence, be used directly to modify the [EAAM](#) audit program. Each difference was classified as one of the following:

**Judgment Error (J)**- A magnitude had to be judged by the analyst, e.g., Was handling the workcard difficult?

**Definition Error (D)**- A lack of definition of terms resulting in different assumptions by different analysts, e.g., Does the working day include lunch break (8 hrs) or no lunch break (7 hours)?

**No Help on Form (H)**- Errors where help is available on the program but not on the form, e.g., What is ulnar deviation of the wrist?

**Non-Observation (N)**- Where one analyst observed an activity, but the other did not, e.g., Is shift change work documented?

**Other Errors (O)**- All other errors, e.g., where one analyst states that the hand tool requires

a power grip, while the other analyst records nothing.

**Table 7.7** Reliability Data on Maintenance Audit Version 2.0

<b>Task</b>	<b># of Different Outcomes</b>	<b>Cochran's Q</b>	<b>Probability</b>
5. Replace first class seats	12	1.33	>0.25 (ns)

Table 7.6 shows the number of each type of difference counted for each module of the audit. As can be seen, 70% of all differences were either judgment or definition related. Changes to improve the reliability of these questions are relatively simple, either by replacing judgment with measurement or by adding/refining definitions. A further 12% of the differences were due to no help facility on the data collection form. Specific helpful expansions can be provided on the form to improve reliability here, too. Non-observation errors and other errors perhaps represent a minimum of errors (less than 2% of responses) which are not simple to correct.

Overall reliability was in the same range as the initial version of the Inspection Audit. Specific changes were made to the program and to the data collection form to secure the improvements required.

Version 2.0 of the Audit Program for Maintenance was developed and retested on a single job with the same two analysts. The rewording of questions involved 9 of the 228 questions in [EAAM](#). The retest was performed on the task "Replace first class seats" on a DC-9. Results of the  $X^2$  test and Cochran's Q test are shown in [Tables 7.7](#) and [7.8](#), respectively.

**Table 7.8** Results of Q Test on Maintenance Audit Version 2.0

<b>Task</b>	<b># Questions</b>	<b># Diff.</b>	<b>Reliab.</b>	<b><math>X^2</math></b>	<b>Prob.</b>
5. Replace first class seats	179	13	93%	13.49	<0.01

The reliability is now much higher at 93% when calculated on number of differences and the same at 93% when calculated on number of different outcomes. At this point the reliability was considered to be established.

### 7.3 Validity of Ergonomic Audit for Aircraft Maintenance

The ergonomic audit program was developed as a rapid screening tool to identify ergonomic mismatches in aircraft maintenance tasks. The majority of people using this audit program will have little training and expertise in ergonomics. In order to evaluate the effectiveness of the program in finding ergonomic mismatches, we compared the results of the audit program to those of four practitioners in the field of ergonomics. The task chosen was a Aileron Removal on the left wing of a DC-9 aircraft. This task was audited using the [EAAM](#) program and simultaneously videotaped for later analysis by the ergonomic practitioners.

The [EAAM](#) program found 55 ergonomic issues which needed to be addressed. The issues were classified into 10 different categories listed in [Table 7.9](#).

**Method:** A group of four ergonomic practitioners, all professors actively involved in conducting ergonomic assessments, were provided with the necessary documentation required to complete an aileron removal. They were each asked to view the video tape made of the aileron removal and evaluate all aspects of the task, operator, equipment, documentation, and environment that they would address in evaluating the system for possible human factor mismatch (Koli, 1994).

**Results:** The results of the four subjects and that of the checklist are listed in [Table 7.10](#). Note that in some cases, for example "Communication", the practitioners raised more issues than the checklist. These "extras" were false alarms, where the maintenance task met the standards even though the practitioners thought it did not.

To determine whether the checklist produced more or less overall ergonomic issues than the practitioners, the differences between the checklist and the mean number of issues found by practitioners were analyzed using a t-test. The value of the t-statistic was  $t = 4.57$ , which was significant at  $p < 0.01$ . This indicates that there is considerable difference between the evaluation of the checklist and that of the practitioners, and that the checklist found more issues.

**Table 7.9** Issues Identified by Checklist

<b>Ergonomic Category</b>	<b>Issues</b>
Information	10
Communication	1
Visual Environment	9
Auditory Environment	1
Thermal Environment	4
Access Equipment	14
Hand Tools	9
Posture	4
Force	2
Safety	1
<b>Total</b>	<b>55</b>

The relatively poor performance of the practitioners when compared to that of the checklist arises from various sources. First, there is a trade-off between direct observation and videotape. Doing analyses by direct observation allows the analyst to move around for the best view and to use three dimensional cues. This inflexibility of movement and unconscious editing by the cameraman performing the video taping could have resulted in loss of certain information. One advantage of videotape analysis is the analyst can play a segment over or freeze action in order to analyze a situation more closely, but only one practitioner used this facility. A second reason why the checklist outperformed the practitioners is because it had been evolved by studying the task domain over an extended period of time. All aspects of the maintenance task were thoroughly investigated before the development of the exhaustive checklist. In other words, the checklist was developed specifically for aircraft maintenance tasks. The practitioners, on the other hand, had to rely on memory to identify the issues.

Overall, the checklist fared as well as, indeed better than, ergonomic practitioners at identifying ergonomic mismatches. However, one issue involving safety was brought up by practitioners which was not identified directly by the [EAAM](#) audit: Safety aspects of the mechanics movements.

**Table 7.10** Ergonomic Issues Identified by Experts and Checklist

<b>Ergonomics Issues</b>									
<b>Category</b>	<b>Subject 1</b>		<b>Subject 2</b>		<b>Subject 3</b>		<b>Subject 4</b>		<b>Checklist</b>
Information	7	2	10	6	10				
Communication	2	0	2	0	1				
Visual Environment	5	2	5	2	9				
Auditory Environment	2	2	1	0	1				
Thermal Environment	1	1	4	0	4				
Access Equipment	5	7	1	5	14				
Hand Tools	5	5	1	3	9				
Posture	3	5	4	2	4				
Force	4	5	3	2	2				
Safety	3	5	3	5	1				
<b>Total</b>	<b>37</b>	<b>34</b>	<b>34</b>	<b>25</b>	<b>55</b>				

Several of the auditors made reference to one of the mechanics' "jumping" back and forth between two ladders in order to complete the aileron removal. The ergonomic audit program does not directly address the issues of safety in personnel movement, but does however ask general safety questions of maintenance personnel. For example, "Do you feel access to the work area is dangerous?" or "Do you feel access to the work area is difficult?". This audit was designed so that such general questions would raise awareness of a broader degree of personal safety issues, which could then be further investigated by ergonomic practitioners.

## 7.4 Final Modifications to the Maintenance Audit

On the basis of the high reliability and validity demonstrated by the Maintenance Audit system, no further modifications were made in structure or content. Some interface changes have been made by Galaxy Scientific Personnel, but these changes do not affect reliability or validity. For 1995/96, it is expected that the Inspection Audit (ERGO) and the Maintenance Audit (EAAM) will be combined with earlier audits into a single audit program.

## 7.5 REFERENCES

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## Chapter 7 - Appendix

### Audit Checklist

#### MAINTENANCE PREPARATION

##### A. Information Requirements

###### MODULE 1. DOCUMENTATION (Work Cards)

##### a. Information Readability

1. Is the *text layout of this workcard* consistent with the other workcards? (Y/N)\_\_\_\_\_
2. Is the *text material justified* to the left margin? (Y/N)\_\_\_\_\_
3. Are *typographic cues* used for segregating important text material in the workcard?  
(Y/N)\_\_\_\_\_
4. Has a *simple block font style* been used to print this workcard? (Y/N)\_\_\_\_\_
5. Are *dot-matrix printers* used for printing workcard? (Y/N)\_\_\_\_\_



b. 3

c. more than 3

(a/b/c)\_\_\_\_\_

## MODULE 2. COMMUNICATION

### a. Shift Changes

1. Is there an *overlap of personnel* to communicate prior shift work? (Y/N) \_\_\_\_\_

### b. Work in Progress

2. Is shift change work *documented*? (Y/N) \_\_\_\_\_

3. If yes, are the written documents communicating shift change, *legible*? (Y/N) \_\_\_\_\_

4. Are the communication channels *evaluated for effectiveness*? (Y/N) \_\_\_\_\_

5. Is there an *on-going program* to maintain adequacy of communication channels?  
(Y/N) \_\_\_\_\_

6. Would the mechanic be considered A) Novice or B) Expert (a/b) \_\_\_\_\_

7. Is the Leadman available for questions by the mechanic? (Y/N) \_\_\_\_\_

8. Is the Supervisor available for questions by the mechanic? (Y/N) \_\_\_\_\_

## MAINTENANCE PREPARATION

### MODULE 3. VISUAL CHARACTERISTICS

1. What is the *type of light source* used for general illumination?

a. incandescent

b. fluorescent

c. mercury-vapor

d. high pressure sodium vapor

e. low pressure sodium vapor a/b/c/d/e)\_\_\_\_\_

2. If fluorescent bulbs are used, does *flicker* exist? (Y/N) \_\_\_\_\_

3. If fluorescent bulbs are used, are they *installed in pairs*? (Y/N) \_\_\_\_
4. Are *lighting fixtures free/clean* from dirt/paint? (Y/N) \_\_\_\_
5. Are illumination sources provided with *shades* or *glare shields*? (Y/N) \_\_\_\_
6. Are all the illumination sources *working*? (Y/N) \_\_\_\_
7. Is there indirect glare from the source? (Y/N) \_\_\_\_
8. Is the general lighting source within the line of sight? (Y/N) \_\_\_\_

#### MODULE 4. ELECTRICAL/PNEUMATIC EQUIPMENT DESIGN ISSUES

1. Are controls requiring *precision* performed manually? (Y/N) \_\_\_\_
2. Do *selector switches* have fixed scales and moving pointers? (Y/N) \_\_\_\_
3. Are *toggle switches* used in sequence, mounted in a horizontal array? (Y/N) \_\_\_\_
4. Are controls *labeled with all "words" or "symbols"*? (Y/N) \_\_\_\_
5. Are labels *typographically consistent*? (Y/N) \_\_\_\_
6. Do *push buttons* prevent slipping of fingers (eg., surface texture, shape of knob etc.)?  
(Y/N) \_\_\_\_
7. Do *push buttons* have an audible click or snap feel to indicate control action?(Y/N) \_\_\_\_
8. Are *edges of knobs, dials, switches or instrument* rounded? (Y/N) \_\_\_\_
9. Are labels *readable* in all weather conditions? (Y/N) \_\_\_\_
10. Have *abbreviations* been avoided on labels wherever possible? (Y/N) \_\_\_\_
11. Are *emergency controls* clearly distinguished from normal controls? (Y/N) \_\_\_\_
12. If the control function is *RAISE*, is the movement of the control *UP*? (Y/N) \_\_\_\_

#### MAINTENANCE PREPARATION







3. Indicate the light levels taken from 4 zones during the task. Zone 1 = \_\_\_\_\_fc

Zone 2 = \_\_\_\_\_fc

Zone 3 = \_\_\_\_\_fc

Zone 4 = \_\_\_\_\_fc

4. What *type of light source* is used as *portable* lighting equipment?

a. hand lamp (Y/N) \_\_\_\_\_

b. standing lamp(Y/N) \_\_\_\_\_

5. What *type of light source* is used as *personal* lighting equipment?

a. 2D cell flashlight

b. 3D cell flashlight

c. 4D cell flashlight

d. Headlamp

e. Other (a/b/c/d/e)\_\_\_\_\_

6. Does the portable or personal lighting equipment *interfere* with the maintenance task?

(Y/N) \_\_\_\_\_

7. Do you feel any *difficulty in handling* with respect to the *size* of the lighting equipment?

(Y/N) \_\_\_\_\_

8. Do you feel any *difficulty in handling* with respect to the *weight* of the lighting equipment?

(Y/N) \_\_\_\_\_

9. Do you experience discomfort *glare* from the *task surface* ? (Y/N) \_\_\_\_\_

10. Do you experience discomfort *glare* from *workcard surface*? (Y/N) \_\_\_\_\_

11. Are there excessive contrasts between different colors in the task area? (Y/N) \_\_\_\_\_

## MAINTENANCE PHASE

### MODULE 9. THERMAL CHARACTERISTICS

Measurement tools: Dry and Wet bulb thermometer and an anemometer to measure the wind speed.

1. Describe the *physical workload/muscular effort*? a. low





**MODULE 12. ELECTRICAL/PNEUMATIC EQUIPMENT**Availability

1. Is equipment *available*? (Y/N) \_\_\_\_
2. Is the equipment *working* at all times? (Y/N) \_\_\_\_
3. If no, are there any satisfactory *substitute arrangements*? (Y/N) \_\_\_\_
4. Is electrical/pneumatic equipment easily *maneuverable* during maintenance? (Y/N) \_\_\_\_

**MAINTENANCE PHASE**Displays, Controls, Knobs

5. Can you easily understand all the *labels/display menus*? (Y/N) \_\_\_\_
6. Are control elements easily differentiated by touch? (Y/N) \_\_\_\_
7. Are control movements as *short* as possible? (Y/N) \_\_\_\_
8. Is there *division of attention*? (Y/N) \_\_\_\_

**MODULE 13. ACCESS EQUIPMENT**Availability

1. Is correct access equipment *available*? (Y/N) \_\_\_\_
2. If no, is satisfactory *substitute equipment* available? (Y/N) \_\_\_\_
3. The access equipment is:
  - a. *fixed*
  - b. *movable*
  - c. *both of the above* (a/b/c) \_\_\_\_
4. If movable, is it *easily maneuverable*? (Y/N) \_\_\_\_

**MODULE 14. HAND TOOLS**

1. Is there shoulder adduction during tool operation? (Y/N) \_\_\_\_

2. Is forearm fully extended during tool operation? (Y/N) \_\_\_\_
3. Does tool operation involve noticeable: a) Wrist ulnar deviation? (Y/N) \_\_\_\_  
b) Wrist radial deviation? (Y/N) \_\_\_\_  
c) Wrist flexion? (Y/N) \_\_\_\_  
d) Wrist extension? (Y/N) \_\_\_\_
4. Does the tool vibrate perceptibly? (Y/N) \_\_\_\_
5. Can the tool be used by both left and right handed people? (Y/N) \_\_\_\_
6. Does the tool handle end in the palm? (Y/N) \_\_\_\_
7. For power tool, does the tool handle provide electrical insulation? (Y/N) \_\_\_\_
8. Does the tool handle provide heat insulation? (Y/N) \_\_\_\_
9. Does the tool handle have sharp edges or corners? (Y/N) \_\_\_\_
10. Is the tool handle compressible? (Y/N) \_\_\_\_
11. Is the tool handle hard enough to resist embedding of particles? (Y/N) \_\_\_\_
12. Is the tool grip non-absorbent to sweat, oil, grease, etc.? (Y/N) \_\_\_\_

#### MAINTENANCE PHASE

13. Is a heavy grip needed to avoid slippage? (Y/N) \_\_\_\_
14. Are there any unguarded pinch points on the tools? (Y/N) \_\_\_\_
15. Are there stops to prevent the handles from fully closing? (Y/N) \_\_\_\_
16. The type of activating trigger is : a. single finger? (Y/N) \_\_\_\_  
b. multiple finger strip? (Y/N) \_\_\_\_  
c. thumb? (Y/N) \_\_\_\_
17. If a thumb operated trigger is used, is the thumb hyperextended? (Y/N) \_\_\_\_

18. Is the trigger very frequently used? (Y/N) \_\_\_\_

19. The grip on the tool is:            a. pulp pinch  
    b. lateral pinch  
    c. power grip            (a/b/c) \_\_\_\_

20. If the tool is heavy is it supported or counter balanced? (Y/N) \_\_\_\_

[Picture of Hand Movements]

### **MAINTENANCE PHASE**

#### *MODULE 15. FORCE EXERTION*

1. Does the task involve:            Horizontal pushing?            (Y/N) \_\_\_\_  
    Horizontal pulling?            (Y/N) \_\_\_\_  
    Vertical pushing?            (Y/N) \_\_\_\_  
    Vertical pulling?            (Y/N) \_\_\_\_

2. Does the task involve use of            One arm?            (Y/N) \_\_\_\_  
    Both arms?            (Y/N) \_\_\_\_

3. Is the type of grip:            a. power grip?  
    b. hook grip?  
    c. finger pinch grip?            (a/b/c) \_\_\_\_

4. Vertical level of first force application :    a. Above head height  
    b. Head height  
    c. Shoulder height  
    d. Elbow height            (a/b/c/d) \_\_\_\_

5. Muscle groups involved in the task:            a. whole body  
    b. primarily arm and shoulders            (a/b) \_\_\_\_

6. Is the person's arm moving while the force is being applied? (Y/N) \_\_\_\_

7. What is the force being applied?            \_\_\_\_ (Kg.)

[Picture of Man Pointing]**MAINTENANCE PHASE**

*MODULE 16. MANUAL MATERIAL HANDLING*

1. Do loads have proper handles? (Y/N) \_\_\_\_\_
2. Can these handles be used by the whole hand? (Y/N) \_\_\_\_\_
3. If protective clothing is indicated, is it provided? (Y/N) \_\_\_\_\_
4. Is the task area clear of obstructions? (Y/N) \_\_\_\_\_
5. Is the floor clean, dry and non-slip? (Y/N) \_\_\_\_\_
6. Is the area for setting down the load clear? (Y/N) \_\_\_\_\_

NIOSH EQUATION

1. What is the objects weight? (kg) \_\_\_\_\_
2. Frequency of Task? (Lift/Min) \_\_\_\_\_
3. Hand distance away from body at start? (cm) \_\_\_\_\_
4. Hand height at start? (cm) \_\_\_\_\_
5. Hand distance away from body at conclusion? (cm) \_\_\_\_\_
6. Hand height at conclusion? (cm) \_\_\_\_\_
7. Width of Object? (cm) \_\_\_\_\_
8. Back Rotation angle? (Deg.) \_\_\_\_\_
9. Task Duration? (Hrs.) \_\_\_\_\_
5. Is the floor clean, dry and non-slip? (Y/N) \_\_\_\_\_
6. Is the area for setting down the load clear? (Y/N) \_\_\_\_\_

*MODULE 17. VIBRATION*

1. Is hand-arm vibration present? (Y/N) \_\_\_\_
2. Are anti-vibration tools being used? (Y/N) \_\_\_\_
3. Are anti-vibration gloves being used? (Y/N) \_\_\_\_
4. Are workbreaks provided to avoid constant vibration exposure? (Y/N) \_\_\_\_
5. Do hands remain warm while working? (Y/N) \_\_\_\_
6. Can the tool be supported or rested while working? (Y/N) \_\_\_\_

### MAINTENANCE PHASE

7. Does worker experience:
  - a. tingling of the digits (finger) ? (Y/N) \_\_\_\_
  - b. numbness of the digits? (Y/N) \_\_\_\_
  - c. blanching of digits? (Y/N) \_\_\_\_
8. What is the vibration frequency? (HZ) \_\_\_\_
9. What is the duration of maximum continuous vibration exposure? (Min) \_\_\_\_
10. What is the total duration of vibration exposure on this shift? (Min) \_\_\_\_
11. What is the vibration acceleration? (m/s<sup>2</sup>) \_\_\_\_

### *MODULE 18. REPETITIVE MOTION*

1. Does the task require the following to be performed?
  - a. Reach with arms above shoulder level (Y/N) \_\_\_\_
  - b. Work with arms above shoulder level (Y/N) \_\_\_\_
  - c. Reach behind the body (Y/N) \_\_\_\_
  - d. Inward rotation of forearm with bent wrist (Y/N) \_\_\_\_
  - e. Outward rotation of forearm with bent wrist (Y/N) \_\_\_\_
  - f. Ulnar deviation of wrist combined with supination (Y/N) \_\_\_\_
  - g. Radial deviation of wrist combined with pronation (Y/N) \_\_\_\_
  - h. Flexion of wrist (Y/N) \_\_\_\_
  - i. Extension of wrist (Y/N) \_\_\_\_
  - j. "Clothes wringing" motion with hands (Y/N) \_\_\_\_

- k. Hand/wrist contacting sharp edges (Y/N) \_\_\_\_
- l. Flexion of the back (Y/N) \_\_\_\_
- m. Extension of the back (Y/N) \_\_\_\_
- n. Flexion of the shoulders (Y/N) \_\_\_\_
- o. Extension of shoulders (Y/N) \_\_\_\_
- p. Flexion of neck (Y/N) \_\_\_\_
- q. Extension of neck (Y/N) \_\_\_\_

[Picture of Neck Movements]

2. If a tool is being used:
- a. Can the location of the tool be adjusted? (Y/N) \_\_\_\_
- b. Is the tool suspended? (Y/N) \_\_\_\_
- c. Is the tool handle made of non-metallic material? (Y/N) \_\_\_\_

### MAINTENANCE PHASE

#### MODULE 19. ACCESS

1. Is there any *conflict due to parallel work*? (Y/N) \_\_\_\_
2. Do you think access is: a. *difficult*? (Y/N) \_\_\_\_  
b. *dangerous*? (Y/N) \_\_\_\_
3. How often was access equipment *repositioned*? a. 1 or 2 times in the entire task  
b. 3 or more times (A/B) \_\_\_\_

#### MODULE 20. POSTURE

1. Do you feel that the workspace is *constrained*? (Y/N) \_\_\_\_
2. How often were the following postures adopted by Mechanic during the task?

#	body part positions			percentage of total task time			
	UPPER LIMBS	BACK	LOWER LIMBS	0%	0%	10%	above
				10%	25%	25%	
1	<i>arm(s) in air</i>	<i>back bent</i>	<i>leg(s) bent</i>				
2	<i>arm(s) in air</i>	<i>back bent</i>	<i>kneeling/crawling/laying</i>				

- 3 *arm(s) in air back twisted leg(s) bent*
- 4 *arm(s) in air back twisted kneeling/crawling/laying*
- 5 *arm(s) in air back bent and leg(s) bent  
twisted*
- 6 *arm(s) in air back bent and kneeling/crawling/laying  
twisted*

*0% - never observed 10%-25% - occasionally observed*

*0% - 10% - seldomly observed above 25% - frequently observed*

### **MODULE 21. SAFETY**

1. Is the work area free of clutter, dirt, oils, etc? (Y/N) \_\_\_\_
2. Are *safety attachments* used when the mechanic performs maintenance at heights?  
(Y/N) \_\_\_\_
3. Is the maintenance person wearing safety shoes? (Y/N) \_\_\_\_
4. If task requires, is the maintenance person wearing eye protection? (Y/N) \_\_\_\_

### **MAINTENANCE PHASE**

### **MODULE 22. HAZARDOUS MATERIAL**

1. Is training provided for proper handling and clean up of hazardous materials? (Y/N) \_\_\_\_
2. Are all hazardous materials properly labeled with type and caution information?(Y/N) \_\_\_\_
3. Are eyewash stations available for emergency use? (Y/N) \_\_\_\_
4. Are shower stations provided for emergency use? (Y/N) \_\_\_\_
5. Are all hazardous materials properly labeled with type and cautions? (Y/N) \_\_\_\_
6. Were hazardous material signed out and weighed? (Y/N) \_\_\_\_
7. Were hazardous material signed in and weighed? (Y/N) \_\_\_\_
8. If unused material was discarded, was it done properly? (Y/N) \_\_\_\_

9. Does Work Card give proper Hazardous material Identification #? (Y/N) \_\_\_\_\_

10. Hazardous Material being used is in the form of: a) Paint

b) Epoxy

c) Cleaning Agent

d) Lubricant

e) More than one

f) Others (a/b/c/d/e/f) \_\_\_\_\_

11. Is safety equipment (corresponding to the type of hazardous material) being used?  
(Y/N) \_\_\_\_\_

12. Is the recommended safety equipment readily available? (Y/N) \_\_\_\_\_

13. Does the safety equipment cause restriction in movement? (Y/N) \_\_\_\_\_

14. Is the General Maintenance Manual available for review of Hazardous Material use  
(Y/N) \_\_\_\_\_

15. What % of total task time are the hazardous materials being used? a) 10% - 24%

b) 25% - 49%

c) 50% - 74%

d) 75% - 99%

e) 100%

(a/b/c/d/e) \_\_\_\_\_

16. Does the use of a hazardous material intrude on other workers? (i.e., fumes, aerosol)  
(Y/N) \_\_\_\_\_

## **POST MAINTENANCE**

### *MODULE 23. BUY-BACK FOR ROUTINE MAINTENANCE*

1. Was the maintenance task required to be bought back by:

a) the initial inspector?

b) any Inspector (besides initial inspector)?

c) maintenance foreman?

d) maintenance person himself? (a/b/c/d) \_\_\_\_\_

2. Did the task pass buy - back on the first try? (Y/N) \_\_\_\_\_
3. If No to question 2, was the same inspector used for the latter attempts at buy-back?  
(Y/N) \_\_\_\_\_
4. Was the maintenance person present when the buy back was done? (Y/N) \_\_\_\_\_
5. If "Yes" to #4, was feedback information given to the maintenance person? (Y/N) \_\_\_\_\_
6. If "No" to #4, was maintenance person informed of discrepancies by written notice?  
(Y/N) \_\_\_\_\_
7. Does the maintenance person feel feedback information is informative and useful?  
(Y/N) \_\_\_\_\_
8. Is the supervisor available for questions by the maintenance person? (Y/N) \_\_\_\_\_

# Chapter 8

## Improving the Reliability of Maintenance Checklists

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### 8.1 Introduction

Patel, Prabhu, and Drury (1993) describe a workcard as "the prime source of on-line directive and feedforward information in aircraft inspection. It is the primary document that starts the inspection and serves as a major influencing factor on inspection performance" (p.1). The workcard can also be viewed as a checklist that aids the mechanic in recalling all the numerous tasks to be performed in a check. Once a task or group of tasks is finished, the mechanic or inspector is required to sign it as being satisfactorily completed. As the workers perform these tasks repeatedly, there is a tendency to perform them at least partially from memory, with a block of sign-offs made at a convenient time. This is not how workcards are intended to be used, and such use can result in errors. Since the safety of civil aircraft is highly dependent on reliable inspection, we undertook an analysis of how workcards are presently used and how workcards design affects their use and the subsequent potential for error.

#### 8.1.1 Checklist Objectives

Workcards and other forms of checklists are common throughout the aviation industry. In addition to workcards being used for all inspection and maintenance tasks, flight crews use checklists to prepare the aircraft for each new stage of a flight. Degani and Wiener (1990; 1993) reviewed the role of checklists in the cockpit, the potential effects of their design, and sociotechnical factors affecting their use. Although the content of flight deck checklists differs substantially from those for maintenance and inspection, the checklists' objectives (as Degani and Wiener describe them), as well as many of their design concepts and performance factors, are similar.

Degani and Wiener defined checklist objectives that are pertinent to aircraft maintenance: to assist the user in recalling procedures, to outline a convenient sequence for motor movements and eye fixations, to allow mutual supervision within crews, to distribute tasks among crew members, and to act as a quality control tool for management and government regulators (Degani and Wiener, 1990, p.7). The first objective of a workcard is to remind mechanics or inspectors of items to be checked; any type of job aid shares this goal. By providing information externally, a job aid reduces the information a person must store and process (Swezey, 1987). Listing tasks in an order providing a convenient sequence of motor movements should reduce the time spent accessing the task areas. Workcards also provide written records of tasks to be performed and ease the supervision and distribution of tasks. Finally, sign-offs of tasks on a workcard verify that the work is complete, as dictated by the airline and by [FAA](#) regulations. Workcards used in aircraft maintenance and inspection tasks **should** meet these checklist objectives. For this project, we analyzed methods maintenance technicians use to perform different levels of checks to determine if their workcards met these goals. More-detailed B-, C- and D-checks have fewer, larger tasks on each workcard. Lower-level checks (A-checks and below) were the main focus of this study because they typically consist of larger lists (20-100 items) of relatively short tasks. These are what is called "checklists." Although people performing these checks are classified as mechanics, these tasks' functions are associated with inspection, i.e., checking whether specific aircraft features meet pre-defined criteria for safe flight. Our earlier work on inspection is directly relevant to the present study: Patel, et al. (1993) investigated specific design issues relevant to inspection using workcards.

#### 8.1.2 Workcard Design Issues

Patel, et al. (1993) found that usable documentation must embrace the following factors: information readability, information content, information organization, and physical handling and environmental factors. Information readability issues are concerned with the documentation's typographic layout, as well as conventions concerning sentences, words, and letters. Information content involves what information to give, how to give it, and in what order. Documentation must be appropriate, accurate, complete, and easily comprehensible. Information organization deals with the classification and differentiation of directive information and other information such as notes and warnings. The structure of directive information should be broken down into the command verb, the action qualifier, and the object of the action (Inaba, 1991). Patel, et al. (1993), in their study of A- and C-checks, pointed out that tasks should be listed in the natural sequence most inspectors use during a check. Finally, the workcard must be physically suitable for the tasks and the environment. Inspectors should be able to carry workcards with them while they perform tasks, without the workcards hindering task performance. Workcards should be resilient to all types of weather and to dirt and oil because inspections are performed under a variety of adverse conditions.

Patel, et al. (1993, p. 13-16) developed a set of guidelines for designing documentation for aircraft inspection tasks. Using these guidelines to redesign workcards, they found significant improvements in inspectors' and mechanics' ratings of redesigned workcards when compared with old workcards. These researchers also observed that, for A-check workcards, the sequence of tasks did not match the sequence mechanics typically follow to perform checks. There is some variability in the ways mechanics and inspectors sequence their tasks throughout a check, and the number of sign-offs varies across tasks. These findings demonstrate the need for investigation of issues related to workcard task sequence and the optimal number of sign-offs.

### 8.1.3 Purpose of Project

This project's original aim was to undertake an experimental evaluation of checklist reliability. The factors of interest were the grouping of tasks and the number of sign-offs required. Different workcard formats were to be designed for less-detailed, frequently performed checks such as low-level and A-checks. Possible formats would have included workcards with sign-offs after each step, with sign-offs only after the most salient items, and two-level checklists providing more-detailed information for less-experienced mechanics. The methodology of this project changed from an off-line experiment to a field study at the request of our airline partner and after our observation of mechanics performing these checks.

The task analysis described in the next section shows that present workcards do not provide mechanics and inspectors with the most useful information. Although mechanics and inspectors do read workcards for changes, they do not continually use workcards as they perform the checks. They are highly practiced in their tasks, and the fact that checks are repetitive makes it difficult to ensure that all tasks are performed to the same level each time. Job aids or redesign of workcards may help achieve the reliability required in aircraft inspection. This is why we changed the project's aims to determining how mechanics use workcards, why mechanics do not use workcards continually during some checks, the possible effects of mechanics not using workcards, and how to make workcards meet checklist objectives Degani and Wiener (1990; 1993) defined.

## 8.2 Study of Workcard Usage

The project's first objective was to determine how mechanics actually use workcards during frequently performed checks. We needed to study workcard usage on the hangar floor to establish the degree that workcards meet Degani and Wiener's checklist objectives. A task analysis of a system is the foundation of any human factors investigation (Drury, Prabhu, and Gramopadhye, 1990).

## 8.2.1 Task Analysis

Our study of mechanics' current use of workcards during checks consisted of videotaping and observing mechanics performing three levels of checks, as well as interviews and workcard evaluations. We made no videotape without the mechanics' permission. Videotaping is an unintrusive way to gain accurate information on how a mechanic normally performs a check. The specific checks we studied were A-checks and two less-detailed checks: lower-level check 1 (least comprehensive) and lower-level check 2 (more comprehensive, but less than an A-check). Our activity during our first two trips to a hangar consisted of following mechanics as they performed the check. An observer asked questions to gain a basic understanding of each check for various types of equipment. The primary data we gathered from videotapes were the sequence of tasks a mechanic performed, the number of times a mechanic referred to the workcard, and the approximate number of times a mechanic was interrupted. After mechanics finished a check, we interviewed them, often while they viewed the videotape of their inspection activity. We also questioned supervisors and lead mechanics about the workcards' usefulness and asked for their suggestions for change. In order to gain opinions from an adequate number of mechanics, we distributed evaluations on both the workcards and the subsequently developed job aids at one maintenance base. We present results of videotaping, interviews, and workcard evaluations so that readers may develop an understanding of workcards' usefulness for frequently performed, repetitive checks.

### *8.2.1.1 Mechanics' Attitudes Towards the Workcards*

Responses to interviews and workcard evaluations we distributed to mechanics provided many interesting insights. Perhaps the most important finding is that mechanics use individual methods and skills to complete checks. Lock and Strutt (1985), in their study of the reliability of inspections in British aviation, had similar findings. The implication of this finding is that it is difficult to establish reliability of checks because mechanics do not value the standard workcard.

Workcard evaluation results are presented in [Appendix 8-A. Question 5 in Section II](#) showed that some mechanics do not usually refer to a workcard during a check. About half responded that they perform a particular check in the same sequence each time they perform the check. Most indicated that they sequence tasks based on locations on the airplane; they start with the nose and work around the aircraft to check for discrepancies. If a check is assigned to two people, tasks are typically divided logically, e.g., into exterior and interior tasks. The exterior is usually checked before the interior. Some mechanics sequence tasks by difficulty and/or the probability of finding a discrepancy that must be fixed. If they need assistance, they request a "floater" to help them. [Appendix 8-B](#) shows mechanics' ratings of task difficulty and the probability of finding a discrepancy for B-737 lower-level 2 checks. Tires and brakes generate the most concern because of the time required to change them when a discrepancy is identified.

Although workcard evaluation results indicate that mechanics find workcards useful, interviews with and observations of mechanics performing checks indicate that workcards are not always used as intended. Many mechanics view workcards as guides only for inexperienced workers who may refer to it during a check: checks become routine and easily memorized. Also, mechanics typically check more items than the workcard requires because of their conscientious natures. Most mechanics feel that they only need to refer to a workcard for interim changes before performing a check. When mechanics find a discrepancy during a check, most state that they make a note to fix the discrepancy after they finish the check. However, the observer rarely saw notetaking, with the exception of one mechanic. This could be because some mechanics do not carry workcards continuously while performing a check. After completing a check, mechanics return to the workcard to sign-off the tasks. The question remaining is, if mechanics do not use the workcard to sequence tasks for a check, what are the reasons for this and how do they sequence the required tasks?

### *8.2.1.2 Content of the Check*

One reason mechanics rarely use the workcard while performing these checks is that the lower-level and A-checks are repetitive and frequent. Most of these mechanics perform fifteen lower-level 2 checks and five A-checks every month. They have done these checks at this maintenance base for an average of 9 years (this result came from the workcard evaluations shown as [Appendix 8-F](#)). Furthermore, checks for various kinds of equipment are similar, with only a few, possibly important, differences. Mechanics easily memorize the checks and believe they do not need workcards as portable job aids.

### *8.2.1.3 Task and Environmental Factors*

Lower-level and A-checks are mobile: their tasks are located throughout an airplane's exterior and interior. Mechanics walk around a plane to check for defects, bending, kneeling, or reaching into an access panel. These movements are not conducive for carrying an 8.5 X 11 inch workcard that a mechanic can refer to, make notes on, and sign-off tasks. In addition, many line checks are performed outside in a variety of weather conditions such as wind, cold, rain, and/or snow. Carrying a paper workcard and writing on it is even less practical in these circumstances.

### *8.2.1.4 Sequence of Tasks*

Patel, et al. (1993) found that mechanics' ordering of tasks for an A-check did not match the workcard's order. In the current study, mechanics also rarely performed tasks in the order listed on the workcard. In a second workcard evaluation, mechanics were asked to order tasks of a B-737 lower-level 2 check in the sequence they normally complete the check. [Appendix 8-C](#) presents results of this workcard evaluation. No mechanic provided the sequence given in the workcard. Subjects 1 and 2 have an additional column in their tables since they were videotaped. In addition to sequence data from workcard evaluations, transcript analyses from videotapes of subjects performing checks show that mechanics do not use workcards to sequence their tasks. Tasks that are difficult to observe directly are indicated by asterisks in [Appendix 8-C](#). This does not indicate that tasks were not performed, only that the observer could not see them on the videotape.

Workcard evaluations and videotapes indicate that mechanics tend to sequence tasks by spatial cues on the airplane, associating a specific area on the aircraft with all checks for that area. For example, at the right main landing gear, a mechanic checks tires for serviceability, checks the tire pressure, checks the tie bolts, cleans the strut piston, cleans the downlock viewer and indicator, and checks the brakes. All these tasks are performed at the right main landing gear before the mechanic moves to another area. The workcard's functional organization, however, asks a mechanic to check all tires for serviceability before moving to another sign-off task. This would require a mechanic to walk around the nose landing gear, the right main landing gear, and the left main landing gear and then to revisit the same locations to check the tire pressures. The workcard sequence does not reflect the way most people work. Tasks such as "Check fuselage, empennage, and wings for obvious damage or irregularities as viewed from the ground" demonstrate this point even more dramatically. A mechanic does not check the entire fuselage for discrepancies at once; instead, he or she checks the fuselage while working around the aircraft performing other checks. This is demonstrated by the numerous times mechanics being videotaped checked the fuselage; they often cover the same area more than once and re-visit the same task numerous times (see [Appendix 8-C](#)).

Mechanics organize tasks by spatial cues, not by workcards' functional order, because areas to be inspected are very large. Humans optimize their use of time by minimizing the distance to be travelled. By checking everything in a particular aircraft area before moving to an adjacent area, a mechanic saves significant time and energy compared with that necessary to walk around the airplane as many times as would be necessary to check everything by functions. Using spatial cues, instead of functional locations, reduces the number of things a mechanic must remember, hence reducing his or her mental workload.

There is a mismatch between the tool provided for the job (workcard) and mechanics' natural way of working. Such a mismatch can be addressed either by altering the tool or by altering the way of working. The alteration chosen depends ultimately upon what system reliability is obtainable.

### 8.2.2 Non-Compliance in Using Workcards

Our observations from other airlines during previous projects confirm this project's findings. For rarely performed tasks, such as most C- and D-checks, inspectors use workcards to perform the check. Mechanics do not use workcards for frequently performed checks, i.e., A-checks and below. They have memorized these checks, "gaining a feel for items to check" through frequent repetition. One of the problems with this is that mechanics may not receive feedback on the accuracy of their judgments since problems rarely occur. Also, since workcards are not physically compatible with the environment and the tasks, even inexperienced mechanics who want to use workcards have difficulty doing so. Finally, the functional sequence of tasks on workcards does not match the way people sequence tasks distributed over large areas. Tasks with only one sign-off for a particular function are often distributed over large areas of an aircraft, e.g., check the tire pressure of the main landing gear tires, and are performed as a mechanic reaches the area. Since mechanics tend to sign-off all tasks when the entire check is complete, tasks that are not completed sequentially should have separate sign-offs. We conclude that present workcards do not provide useful information for mechanics and, consequently, do not meet the checklist objectives Degani and Wiener (1990; 1993) defined.

### 8.2.3 Relationship Between Workcard and Checklist Objectives

To review, the objectives of a checklist are to aid the user in recalling procedures, to outline a convenient sequence for motor movements and eye fixations, to allow mutual supervision within a crew, to distribute tasks among crew members, and to function as a quality control tool for management and government regulators (Degani and Wiener, 1990;1993). Since present workcards do not provide a convenient sequence for motor movements and eye fixations, they are not used continuously during checks. The workcards do not aid the user to recall procedures. The present workcards cannot be used conveniently to distribute tasks among mechanics because many sign-offs are not separated. The practice of signing off tasks at the end of the checks diminishes the workcards' ability to serve as a quality control tool. A job aid needs to be designed that meets checklist objectives listed above and that accommodates mechanics' different work methods. Mechanics working for many different airlines would use such a job aid.

## 8.3 National Data on the Effects of not Meeting Workcard Goals

That the present system appears to be working is demonstrated by high reliability, i.e., accidents are extremely rare. However, mechanics' workcard use is reduced because the job aids do not match their needs and individual work methods. The danger of not using workcards during a check is that a mechanic must then rely solely on his or her memory. If a mechanic were to become distracted, he or she could forget to perform a check, yet automatically sign it off because he or she has performed the check so many times correctly. A mechanic's confusion with similar checks and other aircraft may result in him or her substituting a required task with a task appropriate for another check or aircraft.

Our observations from other airlines indicate that similar patterns in workcard usage exist throughout the industry. It is worthwhile to place our findings in a broader context by analyzing similar errors reported elsewhere. The following examples of errors relating to these issues are taken from [NASA's](#) Aviation Safety Reporting System (ASRS). These voluntary reports are subject to reporting biases, and no airline is named in these reports.

The following excerpts from [ASRS'](#) reports illustrate the importance of workcards meeting checklist

goals. They also illustrate other problems, such as the speed-accuracy tradeoff and poor training, but all have a common contributing cause of mechanics' not following procedures specified on the workcard.

\* I had just completed an outside service inspection...when an [FAA](#) inspector pointed out that I had failed to check for water in the fuel tanks and had missed a couple of unreadable placards but had signed off blocks saying I had checked these items. Both were inadvertent oversights, were not deliberate, and did not cause any significant unsafe conditions. The problem arose because I was in a hurry to get the job done. Also, in the 2 years that I have worked on these aircraft, I have never heard of any mechanics finding water in the fuel tanks. I have corrected the situation by slowing down and paying attention to the checklist and my actions.

\* While performing an A check,...one of my coworkers, Y, pencil-whipped the aircraft landing gear and flap lube. I had been working the engines all night and know that the flaps had not been extended for lubing.

\* I did not perform a pitot static leak check on the altimeter system after altimeter replacement....I was at fault because I was unaware that the maintenance manual had been revised to reflect this change.

\* Due to an oversight, not having the sign-off document immediately available, I did not document the company form that I had complied with XXXX, a visual inspection of the cargo door prior to takeoff.

\* I feel my actions may well be the cause of the gear failure due to improper reassembly of the uplock activator, and failure to follow proper procedures. In addition, I made several mistakes in following the proper procedures, as called for by company maintenance manuals. I failed to enter a discrepancy on a mechanic's discrepancy list. I did not use proper maintenance manual reviews. I did not perform a gear retraction following reassembly of the activator.

These reports all illustrate errors that could be attributed to not using or not complying with workcards or maintenance manuals. The first two reports provide examples of workers signing-off tasks they did not perform. The example of a mechanic not performing a fuel tank sump check demonstrates one of the effects of experience. Since the mechanic does not expect to find a problem, the check is not taken seriously. The report of an inspector or mechanic being unaware of a maintenance manual revision is an example of a failure to read interim changes. The fourth account states that the reporter did not have the workcard immediately available, probably because the workcard was incompatible with the task and environment. The last report provides another example of a mechanic not complying with proper procedures. This could be attributed to numerous factors such as training, the mechanic's attitudes, time constraints, and environmental factors that make using the maintenance manual either difficult or inconvenient.

\* After servicing #1 engine and while servicing #3 I was distracted by another crew member standing below my servicing buggy. He wanted me to check something else on the aircraft and after doing so I returned to my servicing buggy, still thinking that I had finished #3 engine. I moved on to another aircraft. This aircraft took off and during the first part of the flight the crew noted the #3 engine oil level falling and then stabilizing at an acceptable level. Upon landing the crew called maintenance, who found the #3 engine oil service door missing, along with the oil cap.

\* During the reassembly procedure the screws were not installed in the panel. I was called away by a co-worker and foreman to help on another problem on the aircraft. Then a push to get the aircraft on line occurred...The aircraft was stopped at its next destination; the panel was found missing.

\* On the aircraft's right wing tail light assembly, I removed the light assembly to change the top bulb. Note: On removal of the unit, I had laid the 8 securing screws on top of the wing. Before I secured the unit into the wing tip, I wanted to be sure it worked. I went into the cockpit and activated the lights. I went out to the wing tip to find them working properly and returned to cockpit to shut them off, as the lights would be blinding while securing the unit. After shutting lights off

from cockpit, I stopped for 3-4 minutes to talk to a mechanic who was doing aircraft interior work. After leaving the interior of the aircraft, I was thinking I wanted to finish all exterior work quickly, as it was 18 degrees F with the wind chill factor. A ladder I had out on the left engine caught my eye as I was coming down the stairs. I was running through my mind items I had to complete to get inside out of the weather. With the wing tip light fixed, all I had to do was put the ladder away [without securing the screws].

These errors demonstrate potential negative effects of inattention and distractions. Although the mechanics we interviewed all strongly stated that if they were distracted they would not need to make a note to remember which tasks to complete, most research in human error suggests otherwise. Reason (1990) developed a human error model that particularly considers the effects of inattention.

### 8.3.1 Applicable Human Error Research

Rasmussen (1982) models human performance and its interactions with a possibly unaccommodating environment, categorizing it on the basis of human information processing. At the skill-based (SB) performance level, people perform familiar, routine tasks requiring little attention. Rule-based (RB) activities involve using established rules to make familiar decisions or to solve common problems. Knowledge-based (KB) performance is employed when no known rules are available for the situation and a person must resort to reasoning, to mental models, and to high-order cognitive processes to appraise the available information, to assign goals, and to develop methods for achieving them.

Reason (1990) describes two cognitive modes for differentiating between the sequential reasoning used for **KB** tasks and the automatic control used for **SB** and **RB** tasks. The attentional mode for knowledge-based activities requires high cognitive effort and is characteristic of the decision-maker's low level of experience with the problem or situation. During SB and RB performance, the schematic mode involves semi-automatic actions with few or no attentional checks. A person's intentions or matching conditions in the environment activate strongly associated groups of actions called "schemata."

Reason writes, "When cognitive operations are underspecified, they tend to default to contextually appropriate, high-frequency responses, or, the more often a cognitive routine achieves a successful outcome in relation to a particular context, the more likely it is to reappear in conditions of incomplete specification" (1990, p. 97). In other words, when a person cannot define all aspects of a situation, he or she resorts to habitual actions. Incomplete specification of a situation can be attributed to a combination of situational factors and/or a person's lack of attention. Errors result from activation of the wrong schemata or from activating the right schemata either in the wrong order or at the wrong time. As a person becomes practiced with a habitual task, the chances of activating a common, yet inappropriate, schemata increase.

Errors often occur in "strong-but-wrong" form, i.e., behavior is appropriate to past circumstances because of lack of attention to changed circumstances. Skill-based performance errors occur because actions at this level are directed by schemata most active when an attentional check is omitted or mistimed. Rule-based performance errors are usually attributed to inappropriate associations between contextual cues and previously applicable rules. Knowledge-based performance errors are unpredictable since the person does not have the knowledge to deal with the unfamiliar situation. These errors are due to "bounded rationality" and incomplete or inaccurate mental models (Reason, 1990).

The potential skill-based errors is particularly important for repetitive lower-level and A-checks. Experienced mechanics quite familiar with the tasks operate at the skill-based level when they move between tasks within a check. When an attentional check is omitted, the mechanic does not specifically note where he or she is in the task sequence. The mechanic then can easily be "captured" by a schema or another task that he or she frequently would perform in that situation, even if the mechanic's intentions call for a different action. For example, an attentional check can be omitted because of an external interruption such as another crew member asking the mechanic to check

something. The distraction could be internal, e.g., the mechanic worrying about other tasks, the weather, even time pressure.

Mechanics may use rules to determine if an indication is a discrepancy. One objective of workcards and maintenance manuals is to externalize rules so the mechanic does not need to remember them. For example, the workcard gives the acceptable range of tire pressure. If the mechanic does not use the workcard, the potential for rule-based errors rises since the mechanic is forced to rely on memory. Rules often differ among tasks which are otherwise similar, e.g., different tire pressures are acceptable for different aircraft.

Knowledge-based errors are not relevant to the checks under study in this project. As mentioned, lower-level and A-checks are repetitive and familiar for these mechanics. Knowledge-based reasoning rarely occurs; when it does, a workcard is likely to be of little assistance. In knowledge-based situations, maintenance manuals and a mechanic's experience and knowledge are the best resources. The goals of checklists are to assist skill-based and rule-based performance and to compel mechanics to make more attentional checks while they work in the schematic mode. The errors listed in the next section are associated with workcards' failure to meet objectives for checklists.

### 8.3.2 Potential Errors Related to Workcards

We derived the following potential errors after considering Reason's theories of human error and from our study of workcard usage. We made our predictions of potential types of errors related to workcards knowing that mechanics rarely use workcards, that they sign-off all tasks at the end of the check, and that the potential for distractions and interruptions is high as they perform these checks. The first three kinds of errors are omissions related to skill-based performance. The last category is related to rule-based errors. There are other kinds of potential errors, but the following are most relevant to findings of our study of workcard usage.

#### 8.3.2.1 Omissions Related to Interruptions

Reason's (1990) theories predict that distractions and interruptions occurring while workers perform highly skilled, familiar tasks, such as lower-level and A-checks, are particularly critical. When the mechanic directs attention back to the check, he or she may not finish a task or fail to perform a task. Since checks are performed in the schematic mode, task completion within a check is fairly automatic. A mechanic recovers from most interruptions by making a conscious effort to ensure continuity. Unless the mechanic makes an effort to recall what he or she was doing when interrupted or distracted, the mechanic can continue the check after being interrupted as in the most frequently occurring circumstances. Since the mechanic has previously completed the task numerous times, he or she may honestly believe the task to have been completed. As the [ASRS](#)' examples illustrate, the mechanic may never direct attention back to the task, particularly if there is time pressure to complete the check. After an interruption, the mechanic may start on a new set of tasks and never return to his or her original mental task list. Possible remedies for these types of errors include the following:

- a) Workcards should be designed to be easy for workers to make notes on or to sign off complete tasks
- b) Mechanics should be informed of effects of interruptions and distractions, as well as the importance of making notes about incomplete tasks.

We need to consider ways to combat all errors frequent enough to be captured by [ASRS](#).

#### 8.3.2.2 Omissions Related to Workcard Sequence

Workcards sequence tasks by functions. If mechanics actually followed workcards' sequences, the probability of distraction would increase as they constantly moved around the aircraft to complete

functional checks. In turn, this would increase the likelihood of an omission associated with an interruption or distraction. Sign-offs for some tasks are not separated, although the tasks are spatially separated. For example, there is a single sign-off for serviceability of both right and left main landing tires. However, tires are checked separately. This workcard sequence of tasks may increase the probability of a mechanic signing-off the task after checking one side of the main landing tires, but before checking both sides.

### *8.3.2.3 Omissions Related to Workcard Non-Compliance*

Task analysis of mechanics performing checks revealed that workcards' functional sequence of tasks rarely matches the spatial sequence mechanics use. The task analysis also predicted and revealed that mechanics rarely use workcards, partly because they do not match work habits and partly because they are physically incompatible with the tasks and environment. Mechanics disregarding the task sequence on a workcard rely on memory and are thus more likely to omit a task, particularly one they perceive as unlikely to reveal a discrepancy. Since mechanics assigned to frequent checks generally perform them on a number of different aircraft, they may unknowingly confuse checks, e.g., substitute a task from a different check or aircraft. Workcards help them recall tasks to be performed. Most mechanics decrease the chances of this type of error by performing substantially more checks than the workcard requires. For example, a mechanic may treat part of a lower-level check as the equivalent part of an A-check.

A lack of a rigidly performed sequence is likely to induce omission(s) when the task sequence is not habitual and requires more attention. A number of mechanics indicated that they do not follow the same task sequence each time they perform a check. Also, mechanics' practice of signing-off all tasks at a convenient break, even at the end of a check, instead of immediately after completing a task, increases the likelihood of an omission when a mechanic frequently performs the checks. If an omission is possible due to a distraction, time pressure, or some other reason, the mechanic signing-off tasks must pay careful attention to each one he or she signs-off, and must actually recall performing that task at that time. Since sign-offs are highly repetitive and require very little attention, a mechanic could easily assume that a task was completed because it previously was always completed.

### *8.3.2.4 Rule-Based Errors*

One of the objectives of a checklist is to aid users to recall procedures (Degani and Wiener, 1990; 1993). Workcards mainly outline tasks to be performed; they also remind mechanics of some specification limits, such as those for tire pressures. Other specification limits are not given on the workcards, so one recommendation for improvement is to include all limits on the workcard. If a mechanic does not regularly use a workcard throughout a check, he or she may confuse specification limits among airplanes.

More likely causes of rule-based errors relate to the nature of a check and the high experience levels of mechanics performing them. Because mechanics are familiar with the checks, they may not readily recognize unusual circumstances, as Reason predicts. Although experience normally assists mechanics by directing their attention to likely locations of defects, it may hinder them when circumstances substantially differ from their expectations. As Lock and Strutt write, "There is a danger that too much familiarity with a particular item could lead an experienced inspector to miss a significant defect, if it does not conform to the expected pattern (condition) or expected locations which are fixed in the inspector's mental model of the aircraft and its pattern of deterioration" (1985, p. 6.5). Paradoxically, mechanics' high level of experience and expertise is one of the greatest challenges we face in developing a job aid for the checks.

## **8.3.3 The Challenge of Developing a Job Aid**

Task analyses performed with existing workcards revealed potential causes of error as checks are

currently performed. A job aid needs to be designed that reduces the potential for errors associated with workcards incompatible with mechanics' work habits and for errors related to mechanics' failure to use workcards throughout a check. These errors all stem from the fact that the present workcard is frankly not useful for mechanics. The design difficulty is compounded by the fact that highly skilled, well-trained, and experienced mechanics view workcards as guides for inexperienced mechanics and as quality control tools.

This project's challenge was to help increase the reliability of an already reliable system. Mechanics' work is extremely reliable without workcards. Even when mechanics make an error, they rarely receive feedback. Due to the redundancy and frequency of checks, airplanes normally fly without incident. However, there remains a slight possibility that not using workcards during the check, or using workcards that do not match work methods, could result in an error with adverse consequences. Adding to the challenge is the fact that as mechanics' experience increases, the probability they use a workcard as intended decreases. It is worthwhile to explore developing a job aid that reduces the small probability of error because it is compatible with mechanics' work habits and meets Degani and Wiener's checklist objectives. Any increase in reliability is worth the effort in an industry affecting public safety as directly as airlines.

## 8.4 The Job Aid

The proposed job aid must meet individual mechanic's work methods, must be physically compatible with their environment and tasks, and must meet guidelines for workcard design Patel, Prabhu, and Drury (1992) developed. Mechanics are more likely to use a job aid with these characteristics.

### 8.4.1 The Development of the Job Aid

Observations and videotapes of checks revealed that the task sequence differs among mechanics. Even the same mechanic performs tasks for the same check in a different sequence on different nights. These findings suggest that the job aid must be flexible in task sequencing and adaptable to different circumstances.

Most mechanics order tasks by using spatial locations on an airplane. [Appendix 8-D](#) lists grouped tasks of a B-737 lower-level 2 check commonly occurring sequentially within a check. We developed this list after analyzing the videotaped checks. We organized tasks in a FROM/TO chart that showed the number of times two tasks were performed sequentially. We follow each task in [Appendix 8-D](#) with a list of tasks performed sequentially to the first task for a group. Groups largely mirror the spatial layout of tasks on the aircraft. Workcard tasks could be divided into the spatial areas in which mechanics perform a group of checks, as revealed by sequential analysis.

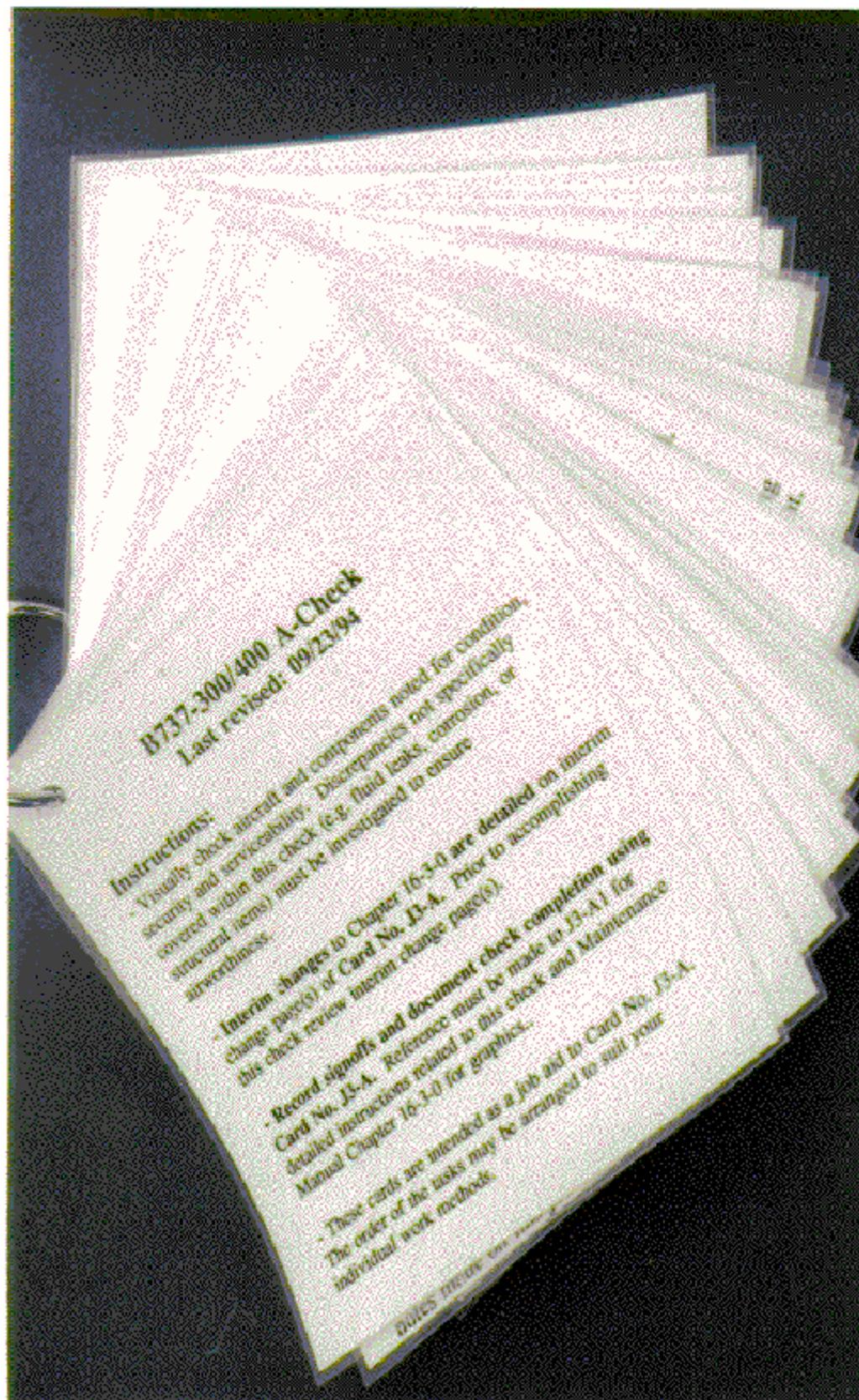
The proposed job aid organizes tasks spatially by listing all tasks for a particular area of the aircraft on one pocket-sized card. The cards are laminated and placed on a ring so that a mechanic easily can change the order of cards. [Figure 8.1](#) shows the front page of the cards. Dividing tasks by area into small cards allows a mechanic to sequence areas according to his or her individual work habits. Tasks are organized with the spatial layout most mechanics prefer. A mechanic can use a grease pencil to note discrepancies, interrupted tasks, or sign-off tasks completed. Notes can then be copied onto reports or wiped off the job aid when the check is complete. The job aid cards are designed to have a bar code on each card so that a future scanning system could check which cards had been completed or to match cards with bar codes located on the aircraft. This feature was removed after initial design and is not used in the current evaluation.

Job aids were designed for both lower-level checks and for A-checks on three fleets of aircraft. The workcards' design follows Patel, et al.'s (1992) guidelines for information readability, information content, information organization, and physical handling and environmental factors. Some guidelines

were particularly important for this job aid.

The guidelines for information content recommend that "information provided should be supportive of the inspector's personal goal to read quickly and also understand the information, to ensure its usage and eliminate personal biases" (Patel, et al., 1992, p.14). We accomplished this in the job aid's design by meeting other guidelines such as the following:

Resort to use of primary typographic spatial cues like vertical spacing, lateral positioning, paragraphing and heading positioning as far as possible; if space usage is premium, then resort to use of secondary cueings, e.g., boldfacing, italics, underlining, color coding and capital cueing in a decreasing order of preference



**Figure 8.1 Top Card of the Job Aid for a B737-300/400 A-Check**

Distinguish between directive information, reference information, warnings, cautions, notes, procedures and methods

Directive information should be broken into the command verb (e.g., check), the objects (e.g., valves, hydraulic lines) and the action qualifiers (e.g., for wear, frays). Use a consistent typographic

layout throughout the document

[The content] should have certain consistent and common elements to foster generalizations across contexts (Patel, et al., 1992, pp. 13-15).

Each workcard's heading refers to a spatial location on the aircraft combined with a functional description, e.g., right main landing tires, right forward fuselage, flight deck, right CSD oil. We capitalized the headings and centered them on the top of each workcard. Each heading's color indicates where the group of tasks listed on the workcard is located on the aircraft, e.g., green indicates radome and forward fuselage. Color-coding makes sorting cards by aircraft areas easier: mechanics can arrange cards in their preferred sequence quickly. Tasks to be performed are left-justified. Cautions are indented and bold. Notes are indented from the cautions and presented in a smaller font (see [Figure 8.2](#)). Each task is numbered on the workcard and separated from other tasks with blank lines. This arrangement makes it easier for mechanics to distinguish among tasks and to mark completed tasks with a grease pencil. The command verb immediately follows the number; it is followed by the object and the action qualifiers, as in the following example:

**1) Check: forward lavatory** for general appearance and condition.

The command verb and the object are bold because mechanics already know the action qualifier and simply need a reminder of the task to be performed. Some mechanics suggested listing only the object to be checked on the workcards. We could not investigate this idea in this project because regulations do not allow workcards' content to be changed. The typographic layout and general content is consistent throughout workcards for all checks, ensuring consistency for mechanics.

The following are the organizational issues and physical handling/environment factors we considered pertinent to the design of the job aid:

Task information should be ordered/sequenced in the natural order most inspectors would perform the tasks

The page should act as a naturally occurring information module

The workcard's pages should be a handy size

If use of a workcard demands exposure to environmental agents like wind, rain, snow or even harsh and oily floor conditions, we should take adequate precautions to avoid excessive degradation" (Patel, et al., 1992, p. 16).

One of the primary goals of our job aid is to meet the guideline concerning the order of task information. Patel, et al. (1992) ordered tasks in an A-check by finding the most common sequence among mechanics they surveyed. For our study, we took an approach based upon groups of tasks that mechanics perform sequentially. We then listed each group of tasks on one card (for an example, see [Figure 8.3](#)) so that workcards act as naturally occurring information modules. Since mechanics can arrange the groups of tasks in any order they choose; our job aid provides a natural sequence to **all** mechanics, not to **most** mechanics.

Further, the pocket-sized cards leave mechanics' hands free, when necessary. The cards are laminated to protect them against environmental agents and to provide a better writing surface than paper (see [Figure 8.4](#)).

Although we encourage mechanics to make notes on the job aids and to check tasks completed, the job aid does not replace workcards' sign-off sheets. The first card of the job aid explains what the job aid is and instructs the mechanic to read interim changes included in the workcard and to sign-off tasks on the workcard. The second card shows the headings' colors and associates colors with areas of the aircraft. These features help meet the checklist objectives and, consequently, reduce the potential for error.

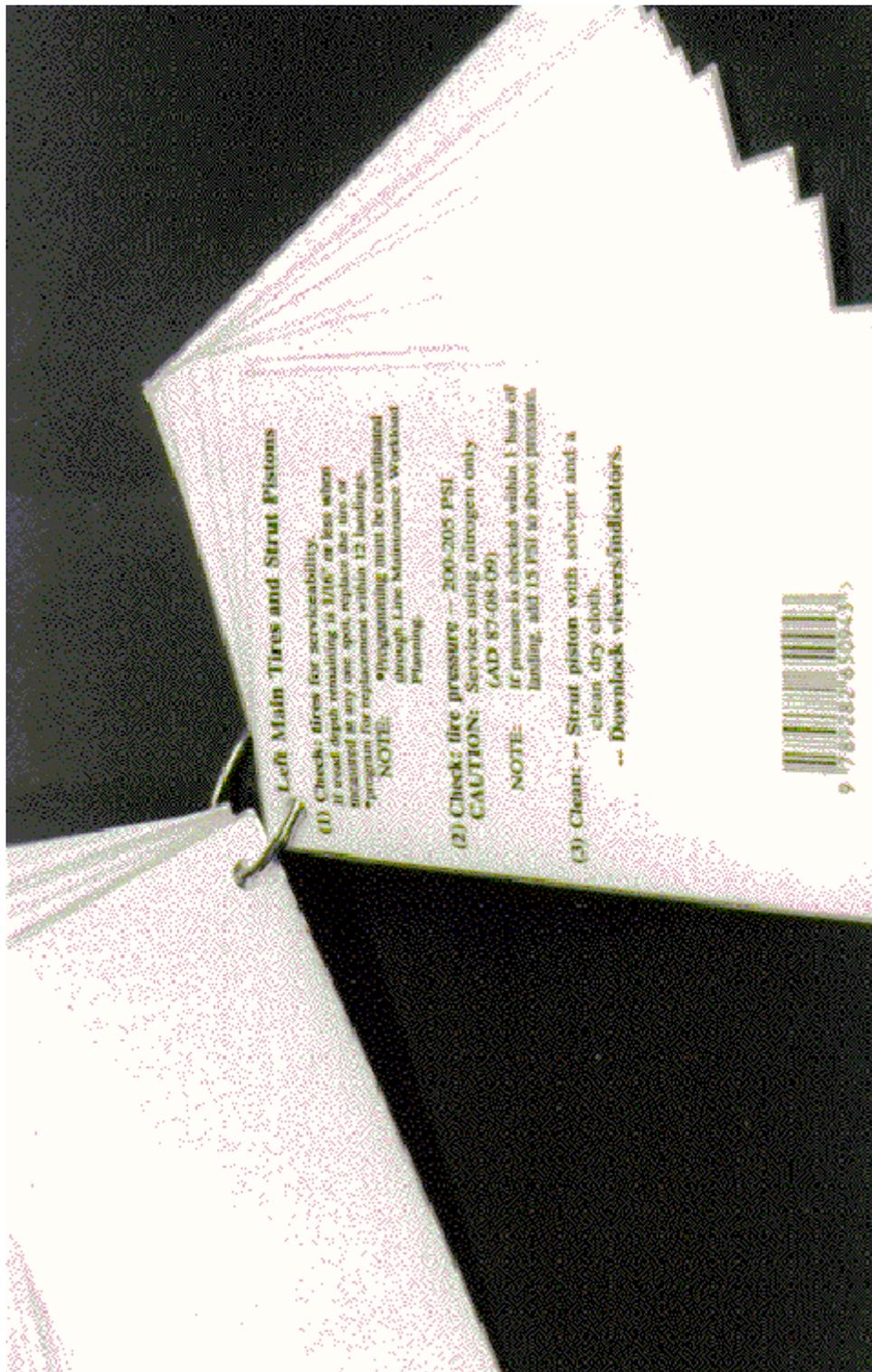
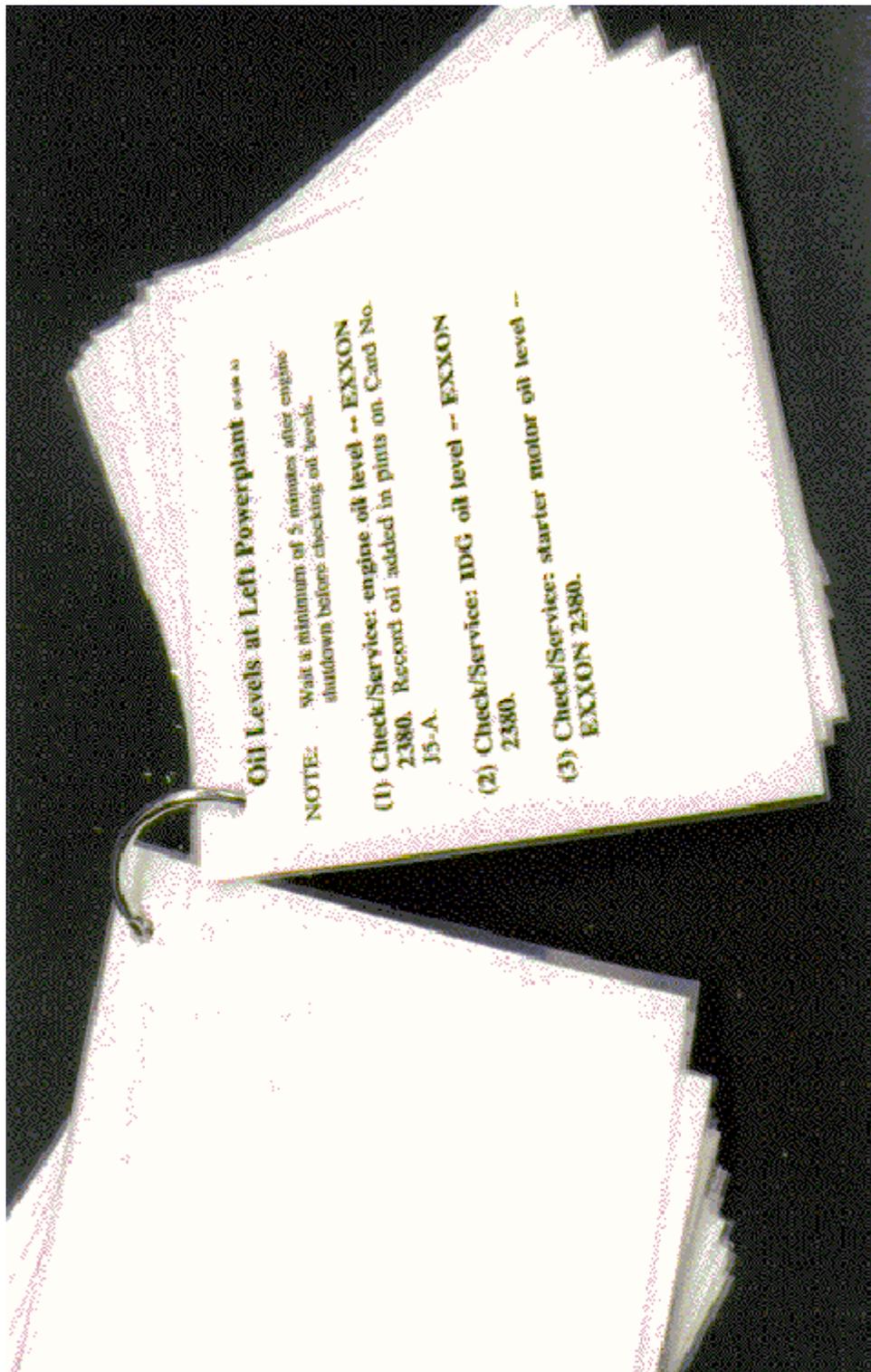


Figure 8.2 Example of Job Aid Layout, with Barcode



Figure 8.3 Spatial Layout Grouping for Work Card Items in Job Aid



**Figure 8.4 Typical Page Layout and Lamination of Job Aid**

### **8.4.2 Does The Job Aid Meet Checklist Objectives?**

To review, the objectives of a checklist are to aid the user in recalling procedures, to outline a convenient sequence for motor movements and eye fixations, to allow mutual supervision in a crew, to distribute tasks among crew members, and to function as a quality control tool for management and government regulators (Degani and Wiener, 1990; 1993). Dividing tasks spatially in small cards affords a mechanic the flexibility to sequence areas according to his or her individual work habits while also organizing the tasks spatially. The job aid provides a convenient sequence for motor

movements **within** an area while allowing a mechanic to determine the most convenient sequence **between** areas. In addition, dividing tasks into cards that can be separated allows for easier task distribution among crew members, allowing mutual supervision in a crew. Features of our job aid such as allowing mechanics to sequence and distribute tasks, the convenient size and surface of the cards, and, possibly, increased ease of reading the workcards (in compliance with the Patel, et al.'s (1992) guidelines) should promote mechanics' use of the job aid, in turn aiding users in recalling procedures. Although our job aid will not replace a sign-off sheet as a quality control tool, it should reduce sign-off errors since mechanics no longer have to rely on memory to know which tasks are complete. Since tasks are separated logically into cards, mechanics can check cards as they complete the tasks.

Since our job aid meets these objectives, it should reduce errors associated with workcards, as the task analysis predicts. Omissions related to workcards not matching mechanics' individual work habits should be reduced since the job aid allows flexibility in the sequence of task areas. Omissions related to interruptions should also decrease. Tasks are separated into small, logical groups so that a mechanic can quickly scan the card he or she was working with before being interrupted. The workcards' easier writing surface should encourage mechanics to take notes about tasks interrupted, tasks completed, and of discrepancies found. Omissions and rule-based errors arising from mechanics not using the workcard should be reduced since the job aid was designed in a way that encourages its use. To determine whether these predictions are valid, we obtained feedback from mechanics and observed them using our job aid while performing checks.

## 8.5 Evaluation of the Job Aid

Our evaluation of the job aid consisted of the same methodology we used for task analysis. We observed mechanics performing the check using the job aid, had interviews with selected mechanics, and distributed workcard evaluations to evaluate and further refine the job aid.

### 8.5.1 Direct Observation

We videotaped a mechanic performing a lower-level 2 check while using the job aid. He rearranged the cards to reflect his preferred sequence for the check and followed the cards almost exactly during the check. The mechanic frequently referred to the cards to ensure he had completed all tasks in sequence. After he thought he had completed the exterior checks and referred to the cards, he found that he did not check the fuel tank sump. In the aircraft's interior, the mechanic noted blown lights on a piece of paper because the job aid he used was a prototype made of cardstock and not laminated. The mechanic's sequencing of tasks demonstrated the expected spatial sequence; he performed tasks while walking clockwise around the aircraft. General observation indicated that this mechanic followed our job aid's task sequence significantly more than the workcard's task sequence.

### 8.5.2 First Workcard Evaluation

Appendix 8-C shows results of a preliminary workcard evaluation we used for feedback after developing our first job aid. The placemaker page received a "useful" rating. This page is a colored instruction card intended be placed on top of the card stack. As a mechanic turned each card over, the placemaker page separated completed cards from those yet to be performed. Our observations and interviews revealed that mechanics were reluctant to move the placemaker page after they completed tasks on a card. We removed the placemaker feature since it might be more confusing than helpful. Mechanics, instead, can use a grease pencil to track completed tasks.

General results from the first workcard evaluation and those from subsequent interviews with mechanics and an inspector suggested that they found the division of tasks into small cards useful, that they would rearrange the cards into their own preferred order, and that they would find a grease pencil useful. In addition to preferring the job aid to the workcard, they indicated that they would be

more likely to perform tasks in the job aid's order they arranged than with the workcard's dictated order. They generally liked the card system and found it useful. Two suggestions we used to design the revised job aid were to make the cards smaller and to color-code cards by spatial areas of the aircraft so that it would be easier to order the cards. Due to time constraints, only three mechanics filled out the preliminary workcard evaluation. After revising job aid, we distributed another workcard evaluation.

### 8.5.3 Second Workcard Evaluation

Seventeen mechanics completed the second workcard evaluation after they viewed a demonstration of the job aid. The results, presented in [Appendix 8-F](#), reveal little difference between the present workcard and the proposed job aid. The only factor revealing a difference between the workcard and the job aid was the mechanics' opinion that they would perform the check in the order given. They indicated that they seldom perform tasks in the workcard's order but would-sometimes to usually-perform tasks in the order they arranged while using the job aid. This result is encouraging given that the job aid's main goal is to provide a task order mechanics will follow so they use the workcard and do not rely on memory. Mechanics found color coding of cards (3.65), division of tasks into the smaller cards (3.82), and the grease pencil (3.88) slightly less than useful (which would be a 4.0 rating). These findings are somewhat surprising since many mechanics make notes and a mechanic recommended color-coding. One mechanic suggested that the entire card be color-coded. Our question regarding the usefulness of dividing tasks into smaller cards was probably inappropriate since tasks were divided so that mechanics could arrange the sequence (which received a favorable response).

One potential reason for the "neutral to slightly above" evaluation of the job aid versus the workcard is that many respondents did not use the job aid to perform a check, but only saw a demonstration. Had they used the job aid, many mechanics may have been more convinced about its usability. Also, mechanics who had been trained to use workcards were reluctant to accept a change. They seemed concerned about issues of tracking interim changes and the ease of updating cards for new information. If lamination becomes too costly, there is an alternate possibility of printing cards on card stock, which is more resilient to environmental factors than ordinary paper. Such cards could be used once and be updated as easily as the workcards. The job aids printed on card stock that were used for the DC-9 lower-level 2 check we videotaped and reported in [8.5.1](#) appeared to work well.

Another possible reason for mechanics' neutral responses reflects their belief about the reliability of their work. As we previously discussed, these mechanics are experienced and extremely familiar with tasks performed in a check. They typically receive little, if any, feedback about the danger of interruptions and of failing to use the workcard or to follow its task sequence. Since relationships between human error and using the workcard are not obvious, any possibility of increasing these checks' reliability is worth investigating.

### 8.5.4 Overall Results

Observations we made of mechanics using the job aid while performing a check generally revealed closer compliance with the task sequence the mechanics arranged while using the job aid than observations we made of mechanics using traditional workcards. Interviews and informal discussions revealed that mechanics had generally favorable responses to the job aid. The first workcard evaluation's results reflects this finding. In contrast, the second workcard evaluation's results revealed mostly neutral responses to the job aid. Most mechanics completing the second workcard evaluation were unfamiliar with the goals of this project. Hence, they were skeptical about the project and logistics of implementing the job aid. In contrast, the first workcard evaluation and direct observation involved a small numbers of people who understood the project's goal of increasing workcard compliance. After other mechanics begin using the job aid, we expect initial neutral reactions to be followed by acceptance with increased use.

## 8.6 Conclusion

In this study, we examined issues in developing a job aid for frequently performed, long, sequential tasks to increase reliability of task performance. Our most important recommendation from this project is to design flexible job aids meet individual work methods. To do so, it is important to identify factors influencing individual work methods. Our task analysis found that mechanics performing low-level checks and A-checks use the spatial locations of tasks and, sometimes, perceived task difficulty for sequencing the tasks. Other factors may be more important for sequencing less frequently performed checks.

Separating tasks allows for a natural division of work and, more importantly, makes it easier for mechanics to track completed tasks. The job aid should allow mechanics quickly to see what tasks are completed. Further, sign-offs for tasks located on different aircraft sections should be separated since generally they are not performed sequentially.

Another potential method for helping mechanics to track completed tasks is a bar code reader. A bar code could be printed on each card of a check. After a mechanic completes all tasks on a card, he or she could scan the bar code, using a small, lightweight computer attached to his or her belt. After the check is complete, the computer could identify any tasks mechanics missed. After mechanics are sure that all tasks are completed, they can do their "sign-offs" either manually or with the computer (when computer recognition of signatures becomes common). Either approach would significantly reduce mechanics' current reliance on memory. As bar code readers are relatively inexpensive, airlines should further investigate this option.

The job aid must be resilient to environmental factors and compatible with task factors. Task analysis should identify conditions under which mechanics will use the job aid. The job aid must not physically hinder users performing their tasks.

Mechanics must understand the importance of using workcards, especially the ways interruptions and distractions can lead mechanics to omit tasks. Factors such as weather, absences by co-workers, reassignment, and time pressure all contribute to the potential for distractions.

Finally, workcards, as a form of checklists, must meet objectives of checklists (Degani and Wiener, 1990; 1993). Workcards should aid users to recall procedures by outlining a convenient sequence for motor movements and eye fixations. Workcards should permit mutual supervision within a crew, as well as helping a crew distribute tasks among themselves. Taken together, these factors should increase a workcard's ability to function as a control tool for management and government regulators, thereby increasing the checks' reliability.

## 8.7 References

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## APPENDIX 8-A

### Results of Present Workcard Evaluations

#### I. Summary Statistics

Number of respondents = 8

Age of respondents: Mean=40.38 sd=7.73

Years worked as a mechanic: Mean=17.4 sd=9.80

Average number of lower-level checks performed per month:

Mean=14.25 sd=8.25

#### II. Open-Ended Questions

1. Do you normally perform the tasks on a lower-level 2 check in the same order every time you do the check?

Yes: 3

No: 4

Depending on aircraft type: 1

2. Normally, how do you sequence the tasks you must perform to complete a lower-level 2 check?

Subject 1: Starting at the nose of aircraft, I wrap around wings and empennage finishing at the nose again.

- Subject 2: Nose to left side of aircraft to nose.
- Subject 3: Sometime start on the outside, sometimes start inside.
- Subject 4: Start at nose, work way around.
- Subject 5: Outside, inside, work release items.
- Subject 6: Inside right to left, inside back to front.
- Subject 7: Outside, inside, pilot items.
- Subject 8: Habit.

3. If you are doing the check with another person, how does this change your strategy for performing the check?

Subject 1: Assistant on check would service tires, APU oil, engine oil and CSD oil and hydraulic fluid.

- Subject 2: None.
- Subject 3: One person will do the outside, the other one will do the inside.
- Subject 4: Usually split inside and outside.
- Subject 5: Depends on level of experience.
- Subject 6: None.
- Subject 7: None.
- Subject 8: One man assigned to inside, One man outside.

4. What do you do when you find a discrepancy, e.g., do you make a note to fix it after you are finished with the check, or do you fix it as soon as you find it?

- Subject 1: Make notes.
- Subject 2: Make note of discrepancy.
- Subject 3: Made a note and fix it after the check is done.
- Subject 4: Make a note usually unless able to fix on spot.
- Subject 5: Fix after.
- Subject 6: Make a note.
- Subject 7: Fix after the check.
- Subject 8: Make a note.

5. Could you please comment on the usefulness of the workcard, e.g., do you need to refer to the workcard while performing the check?

- Subject 1: No, unless there is a new revision.
- Subject 2: No.

Subject 3: Sometimes.

Subject 4: Used as guide since things checked are usually more than required.

Subject 5: No.

Subject 6: No.

Subject 7: Sometimes.

Subject 8: The first 4 to 5 times you do the check on any specific a/c after that no.

### III. General Questions on the Usefulness of the Present workcards

1. How useful do you find the workcard?

Mean=4 sd=0.535

[0= of no use 2= not very useful 4= useful 6= considerably useful 8= extremely useful]

2. How often do you refer to the workcard?

Mean=4.125 sd=1.727

[0= always 2= usually 4= sometimes 6= seldom 8= never]

3. Would you prefer a workcard that is:

Mean=4.688 sd=1.945

[0= more concise 4= about the same 8= more detailed]

4. How would you rate the ease of understanding of the workcard?

Mean=5.125 sd=1.959

[0= very difficult 4= moderately easy 8= very easy]

5. Do you have any problems handling the workcard?

Mean=6.625 sd=1.408

[0= always 4= sometimes 8= never]

6. Do you perform the tasks in the order given by the workcard?

Mean=2.750 sd=1.389

[0= never 4= sometimes 8= always]

7. When do you sign off complete items on the workcard?

Five mechanics responded at end of workcard.

One mechanic responded between intermittently and end of workcard.

One responded after every section.

One responded after every task.

## APPENDIX 8-B

### Mechanics' Ratings of Probability of Discrepancy and Difficulty of B-737 Lower-Level 2 Check Tasks

The approximate likelihood of finding a discrepancy was rated:

0= never 4= sometimes 8= always

The difficulty of performing the task was rated:

0= very easy 4= moderately easy 8= very difficult

**Prob. of Discrepancy: mean (sd)**  
**Difficulty of Task: mean (sd)**

Check left engine inlet and reverser area.	1.2 (2.0)	2.2 (2.4)
Check right engine inlet and reverser area.	2.5 (1.3)	1.6 (1.6)
Check brakes for wear with pressure applied.	2.9 (1.7)	4.0 (2.3)
Check main landing tires for serviceability.	3.5 (1.3)	2.6 (1.4)
Check nose landing tires for serviceability.	2.8 (1.5)	1.8 (1.1)
Check nose tire pressure.	4.2 (1.8)	3.3 (2.8)
Check main landing tire pressure.	3.7 (2.0)	1.8 (1.6)
Accomplish a visual check of MLG wheels for broken or missing tie bolts.	2.2 (2.2)	2.9 (2.1)
Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.	3.3 (1.8)	1.6 (1.6)
Clean NLG strut piston with solvent. Clean NLG downlock viewers/indicators.	3.3 (1.2)	2.3 (1.6)
Check fuselage for obvious damage as viewed from the ground.	3.1 (2.0)	1.8 (2.2)
Check empennage for obvious damage as viewed from the ground.	2.6 (1.1)	2.6 (2.4)
Check wings for obvious damage as viewed from the ground.	2.3 (1.1)	1.7 (1.4)
Check tail-skid (737-400 only)	1.8 (2.5)	0.5 (0.6)
Check engine fire bottle pressure.	1.1 (0.9)	0.9 (0.7)
Check APU fire bottle disc and thermal relief	0.6 (0.7)	1.1 (2.4)

indicator.

- Check exterior lights for proper operation. 4.1 (0.9) 1.9 (1.8)
- Check fuel tank sumps. 3.3 (1.2) 2.1 (1.1)
- Service hydraulic fluid for standby system. 3.3 (1.4) 2.5 (1.4)
- Service hydraulic fluid for system B. 2.7 (1.7) 1.9 (1.8)
- Service hydraulic fluid for system A. 2.7 (1.5) 1.7 (1.6)
- Service auxiliary power unit oil to NON RON aircraft. 3.9 (1.8) 2.7 (1.9)
- Service engine oil for engine #1. 4.9 (2.3) 1.1 (1.4)
- Service engine oil for engine #2. 4.4 (2.6) 0.9 (0.6)
- Service constant speed drive engine #1. 3.2 (1.6) 1.6 (1.4)
- Service constant speed drive engine #2. 2.6 (1.4) 0.8 (0.8)
- Service oxygen-crew, portable. 2.4 (1.4) 2.4 (2.0)
- Check attendants' seats for proper operation and condition. 2.3 (1.0) 2.4 (1.9)
- Ensure outboard seat in the emergency exit row has a non-standard thinner seat bottom cushion installed. 2.5 (1.9) 0.6 (0.6)
- Check that a yellow lifevest is installed under each seat. 5.7 (2.3) 1.9 (1.8)
- Check LH overhead stowage bin row (10) for 8 spare yellow passenger life vests. 3.0 (2.1) 1.2 (1.4)
- Check forward LH closet for 2 each yellow demo lifevests. 2.4 (1.8) 0.6 (0.6)
- Check LH emergency equipment bin for 2 demo lifevests. 3.0 (2.3) 1.1 (1.7)
- Check protective breathing equipment for serviceability. 0.8 (1.0) 1.2 (1.4)
- Check lavatory flush pumps/timers. 2.7 (2.3) 1.8 (1.8)
- Check emergency lighting system. 2.7 (1.9) 2.8 (1.9)
- Check and repair the entrance area for appearance and condition. 3.3 (1.2) 2.1 (2.3)
- Check cabin area for appearance and condition. 4.3 (1.8) 2.5 (1.7)
- Check galley area for general appearance and condition. 2.4 (1.8) 2.2 (1.6)
- Check forward lavatories for general appearance and condition. 2.4 (1.5) 2.0 (1.2)
- Check rear lavatories for general appearance and condition. 2.8 (1.3) 1.9 (1.4)

## APPENDIX 8-C

### Sequence of Tasks for Lower Level-Check 2 on B-737

Five mechanics completed this evaluation. The first two respondents were also videotaped performing this check.

In [Table A2](#), the order in which each task was performed is indicated by its task number. Mechanics m1-m5 completed the evaluation and are denoted by m1q-m5q. Mechanics m1 and m2 were also videotaped and are denoted by m1-v and m2-v. Note that mechanic 2 split the check with another mechanic, so many tasks were not observed. For mechanic m1, some tasks could not be seen due to the video camera's position.

**Table A1. Workcard Order for Tasks 1-27**

Task #	Description
1	Check engines inlet and reverser area.
2	Check brakes for wear with pressure applied.
3	Check tires for serviceability.
4	Check tire pressure.
5	Accomplish a visual check of the main landing gear for broken or missing tie bolts.
6	Clean MLG & NLG strut piston with solvent.
7	Clean MLG & NLG downlock viewers/indicators.
8	Check fuselage, empennage, and wings for obvious damage or irregularities as viewed from the ground.
9	Check tail skid.
10	Check engine fire bottle pressure.
11	Check APU fire bottle discharge disc (yellow) and thermal relief disc (red).
12	Check exterior lights for proper operation.
13	Fuel tank sumps.
14	Hydraulic fluid (System A, B, and Standby).
15	Auxiliary Power Unit Oil.
16	Engine oil.
17	Constant speed drive #1, #2.
18	Oxygen-Crew, portable.
19	Attendants' seats for proper operation and condition.
20	Ensure outboard seat in the emergency exit row has a non-standard thinner seat bottom cushion installed.
21	Check passenger life vest, for aircraft that are equipped for over water operation.
22	Protective breathing equipment (PBE) for serviceability.
23	Lavatory flush pumps/timers.
24	Emergency lighting system.
25	Entrance area for appearance and condition.
26	Galley area for general appearance and condition.
27	Cabin area for general appearance and condition. Lavatories for general appearance and condition.

**Table A2: Order of Performing Tasks on B-737 Lower-Level Check 2.**

Order	m-q	m1-v	m2-q	m2-v <sup>1</sup>	m3-q	m4-q	m5-q
1	11	7	3	6	2	7	15

2 4 6 6 7 3 6 16  
3 6 4 7 1 3 6 15  
4 3 6 7 1 5 7 16  
5 6 3 7 16 4 12 2  
6 7 4 1 7 4 13 3  
7 16 6 16 2 1 13 3  
8 4 7 2 3 1 13 3  
9 3 1 3 2 7 15 4  
10 5 16 5 6 7 15 5  
11 2 7 6 8 7 16 1  
12 1 1 9 13 9 1 6  
13 9 7 10 7 9 1 6  
14 7 3 13 2 10 1 6  
15 7 2 13 6 6 3 7  
16 10 5 13 6 6 3 7  
17 8 4 1 2 6 3 8  
18 16 6 11 3 12 4 9  
19 1 13 16 4 14 4 10  
20 12 6 18 6 15 5 11  
21 14 9 20 9 15 6 13  
22 13 10 23 13 16 6 13  
23 13 7 25 2 16 7 13  
24 13 7 26 3 13 8 7  
25 23 14 27 4 13 9 14  
26 20 7 20 6 13 10 17  
27 18 7 21 1 18 14 18  
28 20 7 22 7 17 11 19  
29 21 3 27 1 21 27 20  
30 27 6 23 9 19 23 20  
31 27 2 20 13 20 22 20  
32 19 5 20 7 20 18 20  
33 25 4 19 24 20 21 21  
34 20 6 8 21 20 20 22  
35 22 13 14 20 27 20 23  
36 17 1 17 20 22 24 24

37	24	7	6	22	24	25	25
38	26	1	6	27	25	26	26
39	20	7	4	22	26	27	12
40	15*	17	4	27	27	20	27
41	22	12*	17	23	20	27	
42	27	15*	8*		19		
43	23	10*		17			
44	21	11*					
45	20	12*					
46	19	14*					
47	18	15*					
48	20	18*					
49	24	19					
50	21	23*					
51	20	25*					
52	26	26*					
53	8						
54	11*						
55	12*						
56	15*						
57	25*						

**\* Asterisks represent tasks performed by other mechanics or not observed due to video restrictions.**

## APPENDIX 8-D

### Tasks Occurring Sequentially

Tasks which follow each heading task are listed.

#### **Check left engine inlet and reverser area.**

Check main landing tire pressure.

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Check fuselage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Service constant speed drive engine #1.

Service constant speed drive engine #2.

**Check right engine inlet and reverser area.**

Check main landing tires for serviceability.

Check main landing tire pressure.

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Check fuel tank sumps.

**Check brakes for wear with pressure applied.**

Check main landing tire pressure.

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Check empennage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

**Check main landing tires for serviceability.**

Check main landing tire pressure.

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Service constant speed drive engine #1.

**Check nose landing tires for serviceability.**

Check nose tire pressure.

Clean NLG strut piston with solvent. Clean NLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

**Check nose tire pressure.**

Clean NLG strut piston with solvent. Clean NLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

**Check main landing tire pressure.**

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

**Accomplish a visual check of MLG wheels for broken or missing tie bolts.**

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

**Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.**

Check empennage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Service constant speed drive engine #2.

**Clean NLG strut piston with solvent. Clean NLG downlock viewers/indicators.**

Check fuselage for obvious damage as viewed from the ground.

Check exterior lights for proper operation.

**Check fuselage for obvious damage as viewed from the ground.**

Check empennage for obvious damage as viewed from the ground

Check wings for obvious damage as viewed from the ground.

Check exterior lights for proper operation.

Check fuel tank sumps.

Service APU unit oil to NON RON aircraft.

Service constant speed drive engine #1.

Check and repair the entrance area for appearance and condition.

**Check empennage for obvious damage as viewed from the ground.**

Service APU unit oil to NON RON aircraft.

**Check wings for obvious damage as viewed from the ground.**

Check fuel tank sumps.

Service hydraulic fluid for standby system.

Service constant speed drive engine #1.

Service constant speed drive engine # 2.

Service oxygen-crew, portable.

**Service hydraulic fluid for standby system.**

Service hydraulic fluid for system B.

**Service hydraulic fluid for system B.**

Service hydraulic fluid for system A.

**Service oxygen-crew portable.**

- Check LH emergency equipment bin for 2 demo lifevests.
- Check protective breathing equipment for serviceability.
- Check lavatory flush pumps/timers.
- Check forward lavatories for general appearance and condition.

**Check attendants' seats for proper operation and condition.**

- Check that a yellow lifevest is installed under each seat.
- Check LH emergency equipment bin for 2 demo lifevests.
- Check lavatory flush pumps/timers.
- Check emergency lighting system.
- Check and repair the entrance area for appearance and condition.
- Check forward lavatories for general appearance and condition.

**Ensure outboard seat in the emergency exit row has a non-standard thinner seat bottom cushion installed.**

- Check that a yellow lifevest is installed under each seat.
- Check emergency lighting system.
- Check cabin area for appearance and condition.
- Check that a yellow lifevest is installed under each seat.
- Check LH overhead stowage bin row (10) for 8 spare yellow passenger life vests.
- Check LH emergency equipment bin for 2 demo lifevests.
- Check protective breathing equipment for serviceability.
- Check lavatory flush pumps/timers.
- Check cabin area for appearance and condition.
- Check LH overhead stowage bin row (10) for 8 spare yellow passenger life vests.
- Check cabin area for appearance and condition.

**Check forward LH closet for 2 each yellow demo lifevests.**

- Check and repair the entrance area for appearance and condition.
- Check cabin area for appearance and condition.

**Check LH emergency equipment bin for 2 demo lifevests.**

- Check and repair the entrance area for appearance and condition.
- Check cabin area for appearance and condition.

**Check protective breathing equipment for serviceability.**

Check emergency lighting system.

Check and repair the entrance area for appearance and condition.

Check cabin area for appearance and condition.

**Check lavatory flush pumps/timers.**

Check rear lavatories for general appearance and condition.

**Check emergency lighting system.**

Check forward lavatories for general appearance and condition.

**Check and repair the entrance area for appearance and condition.**

Check forward lavatories for general appearance and condition.

**Check cabin area for appearance and condition.**

Check rear lavatories for general appearance and condition.

**APPENDIX 8-E****First Evaluation Feedback on the Proposed Job Aid****I. Mechanics' Ratings of Job Aid**

Three mechanics (M1-M3) responded.

<b>Question</b>	<b>M1</b>	<b>M2</b>	<b>M3</b>	<b>Mean</b>
How useful would you find the placemaker page? 0=of no use 4=useful 8=extremely useful	5	3	4	
How useful do you think the division of tasks into small cards would be? 0=of no use 4=useful 8=extremely useful	5	6	5	5.3
Would you rearrange the cards to suit your individual work habits? 0=never 4=sometimes 8=always	7	8	5	6.7
Would you read the interim page at the end of the "official" w/c before starting the check? 0=never 4=sometimes 8=always	4	3	3.5	
Would you use the grease pencil to make notes while completing the check? 0=never 4=sometimes 8=always	7	8	1	5.3
How would you rate the size of the cards? 0=too small 4=about right 8=too big	5	6	1	4

How useful do you find the present w/c system? 4 1 5 3.3  
0=of no use 4=useful 8=extremely useful

How useful do you think the proposed job aid would be? 6 6 5 5.7  
0=of no use 4=useful 8=extremely useful

Do you perform the tasks in the order given by the present w/c? 0 0  
0=never 4=sometimes 8=always

Would you perform the tasks in the order you arranged using the job aid? 6 8 5 6.3  
0=never 4=sometimes 8=always

How often do you refer to the present workcard as you perform a lower-level 2 check? 4 0 5 3  
0=never 4=sometimes 8=always

How often would you refer to the job aid as you perform a lower-level 2 check? 6 6 3 5  
0=never 4=sometimes 8=always

How often do you refer to the present workcard as you perform an A-check? 5 5 7 5.7  
0=never 4=sometimes 8=always

How often would you refer to the job aid as you perform an A-check? 6 6 7 6.3  
0=never 4=sometimes 8=always

## II. Open-Ended Questions

### 1. Comments and suggestions on the design of the cards:

#### a. Size of the cards

Subject 1: Could be a little smaller to stow in pockets when both hands are needed.

Subject 2: Shirt pocket with a grommet to allow the cards to fan open, or some firm type of clip.

Subject 3: Good size for information that is on each card.

#### b. Groupings of the tasks

Subject 1: OK-after rearranging to preference.

Subject 2: From aircraft access (fwd med) toward nose and around to right buy areas (normal course).

Subject 3: Good idea. I think it's easier to start at the nose gear and continue around the aircraft in one complete circle.

#### c. Placemaker/instructions page

Subject 1: OK.

Subject 2: Instructions on front as a cover. Check boxes at item number with back page having colored stripes-"Check off area" to recall page with check.

Subject 3: Once I got used to doing a check on an aircraft, I don't think I would use the placemaker/instruction card and just use the sign-off sheet.

d. Wording of the cards/instructions

Subject 1: Wouldn't hurt to go into more detail.

Subject 2: Revision date in large print to match sign-off sheet date. Common abbreviation naming component only. Include limits. Leave out procedure (manuals dictate procedure).

Subject 3: Simplified and easy to understand.

e. Ease of understanding the instructions

Subject 1: Good.

Subject 2: Very brief-reference changes only-new or limited experience personnel should consult M/M until they are confident in their procedure.

Subject 3: The cards are very easy to understand.

f. Ease of rearranging the order of the cards

Subject 1: OK.

Subject 2: Not necessary if color-code by geographic areas of aircraft.

Subject 3: Rearrange the cards in order of doing the check.

2. How well do you think this idea can be extended to other checks?

Subject 1: The more involved the check, the more useful the cards.

Subject 2: Very well.

Subject 3: Very easily.

3. General comments

Subject 1: I like the card system better.

Subject 2: Its nice to see that people are interested in approaching these tasks in a real-world manner.

## APPENDIX 8-F

### Evaluation Feedback on Revised Job Aid

#### Statistical Data on Respondents

N = 17

Age = 36.47(8.15) years

Number of years in civil aviation = 14.35(7.58)

Number of years as a mechanic = 12.94(6.95)

Number of years as an inspector = 0.29(0.99)

Number of years performing lower-level 2 checks = 9.59(6.76)

Approximate number of lower level 2 checks performed in a month = 15.85(9.07)

Number of years performing A-checks = 9.59(6.76)

Approximate number of A-checks performed in a month = 4.65(4.00)

<b>Present Job</b>		
<b>Question Workcard Aid</b>		
<b>Mean (sd) Mean (sd)</b>		

How would you rate the ease of readability of the text?	5.47(1.42)	6.12(1.27)
0=terrible 2=poor 4=fair 6=good 8=excellent		

In general, how easy is the information to understand?	6.06(2.19)	6.12(1.65)
0=very difficult 4=moderately easy 8=very easy		

How would you rate the effort required in locating a particular task?	5.35(2.42)	5.59(1.77)
0=very difficult 4=moderately easy 8=very easy		

What would be the chance of you missing a sign-off or a task?	5.94(1.84)	6.35(1.27)
0=always 2=usually 4=sometimes 6=seldom 8=never		

How would you rate the ease of physically using the workcard/job aid?	5.47(2.10)	6.06(1.92)
0=very difficult 4=moderately easy 8=very easy		

Would you perform the tasks in the order given by the workcard/job aid?	2.47(2.40)	5.18(2.40)
0=never 2=seldom 4=sometimes 6=usually		

8=always

How often do/would you refer to the workcard/job aid as you perform a lower-level 2 check? 5.12(2.42) 5.41(2.09)  
0=never 2=seldom 4=sometimes 6=usually  
8=always

How often do/would you refer to the workcard/job aid as you perform an A-check? 6.18(1.85) 6.47(1.59)  
0=never 2=seldom 4=sometimes 6=usually  
8=always

How useful do you find the workcard/job aid? 4.06(2.19) 5.12(2.12)  
0=of no use 4=useful 8=extremely useful

How useful would you find the color-coding of the tasks into areas? 3.65(1.90)  
0=of no use 4=useful 8=extremely useful

How useful do you think the division of tasks into small cards would be? 3.82(1.98)  
0=of no use 4=useful 8=extremely useful

Would you rearrange the cards to suit your individual work habits? 5.76(2.44)  
0=never 2=seldom 4=sometimes 6=usually  
8=always

Would you read the interim page at the end of the workcard before starting the check? 6.00(2.21)  
0=never 2=seldom 4=sometimes 6=usually  
8=always

Would you use the grease pencil to make notes while completing the check? 3.88(2.34)  
0=never 2=seldom 4=sometimes 6=usually  
8=always

# Chapter 9

## Support of the FAA/AANC Visual Inspection Research Program (VIRP)

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### 9.0 Objective

This project's objective is to provide human factors inspection expertise to support the Visual Inspection Research Program (VIRP). Note: The material in this chapter is the result of a collaborative effort among many organizations and is not solely the work of C. G. Drury, [SUNY](#) at Buffalo, or of Galaxy Scientific Corporation.

### 9.1 Background and Need

Over the past two decades there have been several studies of human reliability in aircraft structural inspection (Rummel, Hardy, & Cooper, 1989; Spencer & Schurman, 1994; and Murgatroyd, Worrall, & Waites, 1994). All of these studies to date have examined the reliability of Non-Destructive Inspection (NDI) techniques, such as eddy-current or ultrasonic technologies. However, over 80% of civil aircraft inspection does not use NDI and is classified as Visual Inspection (Goranson & Rogers, 1983). Both the [FAA](#) (*National Aging Aircraft Research Program Plan*, 1993, p. 26, p. 35) and the [ATA](#) have recognized the need for equivalent studies of the reliability of visual inspection as a research priority.

Flight safety is dependent upon airframe integrity; for the civil airline fleet, this includes the detection and repair of structural defects as they appear. Data on airframe structural forces, material characteristics, and models of crack growth are used in the Maintenance Steering Group-3 (MSG-3) process to determine safe inspection schedules. This assumes that there are multiple inspection opportunities between the time a crack becomes detectable and the time it compromises safety. This process is, thus, very sensitive to assumptions about crack detectability. For example, overestimation of inspection reliability would lead to longer inspection intervals, compromising safety. Conversely, underestimation of inspection reliability would lead to shorter intervals, increasing costs because of unnecessary inspection.

While there is a need to obtain accurate measures of in-service visual inspection reliability, there is also a parallel need to understand the process of aircraft visual inspection to improve it. There is a large body of literature on visual inspection in the manufacturing industry (e.g., Drury, 1992), and an increasing number of papers applying this to aircraft inspection (e.g., Drury, 1995). However, there are still no on-aircraft studies which quantify the effects of the many variables affecting human factors in visual inspection. Thus, a second major goal of the VIRP is to provide quantitative evaluations of the effectiveness of visual inspection enhancements.

### 9.2 Definitions

Quantifying visual inspection is inherently more complex than quantifying NDI. Visual inspection uses many senses and is expected to detect many indications beyond cracks. It may be applied to many different structures and surface treatments.

Bobo and Puckett (1994), in the FAA's latest Advisory Circular on Visual Inspection for Aircraft, use the following definition:

*Visual Inspection is the process of using the eye, alone or in conjunction with various aids, as the sensing mechanism from which judgments may be made about the condition of a unit to be inspected.*

Visual inspection involves using the "eye, alone or with various aids," and also shaking, listening, feeling, and sometimes smelling, the aircraft and its components. Additionally, the process of any inspection can be analyzed as a combination of various functions, the two most important functions are search and decision-making (e.g., Latorella & Drury, 1992).

In visual inspection, a search process uses most of the human body's senses to detect and locate an indication. There is then a secondary process of combining relevant knowledge, sensory input, and pertinent logic to determine if the indication represents a flaw. The inspector must then make a decision whether or not this flaw is sufficiently sensitive to pose a risk to the continued safe operation of the aircraft or aircraft part.

The Visual Inspection Research Program uses the following definition of "Visual Inspection":

*Visual inspection is the process of examination and evaluation of systems and components by use of human sensory systems, aided only by mechanical enhancements to sensory input, such as magnifiers, dental picks, stethoscopes, and the like. The visual input to the inspection process may be accompanied by such behaviors as listening, feeling, smelling, shaking, twisting, etc.*

**Table 9.1** Classification of Indication & Defect Type

CODE	DESCRIPTOR
20	Wear and Tear
30 21	Loose
40 22	Pulled
23	Bent
24	Dent
25	Scratch
26	Frayed
27	Leaking
28	Lighting Hole
31	Corrosion
32	Pillowing
33	Exfoliation
34	Intergranular
41	Material Missing
42	Broken
43	Crack
44	Disbond
	Delamination
	Part Missing

In addition to defining the process of visual inspection, definitions of both the types of indications, i.e., potential defects detectable with visual inspection and the structure on which this inspection is practiced, need to be addressed.

The types of indication possible in aircraft structures were derived from findings at The Aging Aircraft Non-Destructive Inspection Center (AANC) and on other documents relating to inspection. A two-level classification scheme was developed; each major heading was given a two-digit number ending in zero. Below this level, individual indication types shared the same first digit with the appropriate major heading. [Table 9.1](#) shows the current version of this scheme, which can be expanded or modified as needed.

To fully characterize an indication on an aircraft, it is necessary to know the type of indication ([Table 9.1](#)) and the structure on which it is found. As results of the baseline inspection of the fuselage area of the AANC's Boeing-737 test bed became available, the findings were classified into the two-level scheme shown in [Table 9.2](#). This table only includes structural items needed in the current research; there are obviously many more structural elements on an aircraft. As with [Table 9.1](#), this classification scheme gives sufficient detail for the test bed used in VIRP, but should be expanded and modified as necessary to better characterize visual inspection tasks.

From the definitions given in this section, the VIRP was able to design representative experimental evaluations.

### 9.3 Design of the VIRP Experiments

The research team responsible for designing, conducting, and analyzing the VIRP experiments includes personnel from Sandia National Laboratories/AANC, SAIC, [AEA](#) (U.K.) as well as State University of New York (SUNY) at Buffalo. To design the experiments, we held working sessions which included airline inspection representatives (through the [ATA](#)) and [FAA](#) Technical Center representatives. This group met formally on two occasions during 1994 at AANC facility in Albuquerque; the research team performed its detailed design work outside these meetings.

**Table 9.2** Classification of Structure for Fuselage Inspection (Only includes items with indications in Baseline)

CODE	DESCRIPTOR
10	Skin
20	11 Doubler
30	12 Extension Skin
40	13 Interior Skin
50	14 Bulkhead
	15 Panel
	21 Fasteners
	22 Rivet
	23 Screw
	31 Bolt
	32 Support Structure
	33 Frame
	34 Stringer
	35 Track
	36 Bracket
	37 Web
	41 Mount
	42 Clip
	51 Other Structure
	52 Rod
	Strap
	Other Material
	Seal
	Paint

Reliability of NDI for crack detection is typically reported as one or more Probability of Detection (POD) curves, plotted against crack length. As the design progressed, it became obvious to the research team that visual inspection was a multifaceted activity; unlike NDI of cracks, it could not be characterized by a series of performance curves plotted against a single characteristic. While an

equivalent curve can be generated for visual inspection for the single defect type of crack, as [Table 9.1](#) shows, it would only give a partial description of inspection performance. Thus the goals of VIRP were defined as follows:

- A. *To establish probabilities of detection for a range of different types of visual inspection (cracks, corrosion, wear and tear, and mechanical) for a "typical" aircraft visual inspection.*
- B. *To provide quantified "best practice" guidance on improving visual inspection reliability.*

A research program was developed based on these goals. This process has been described fully in the research team's 1994 White Paper on VIRP and is only summarized here.

The VIRP experiments are designed to achieve Goals A and B (above) in a series of experiments. Because of the large number of factors potentially affecting performance, a single experiment cannot economically provide a measure of overall performance and simultaneously quantify the effects of important parameters. Thus, the program was developed as a Benchmark Experiment (Goal A), followed by a series of Follow-On Studies giving parametric measures of various factors of interest (Goal B).

The detailed protocols for the Benchmark Experiment were partly based upon AANC's 1992-94 study of human reliability in eddy current inspection (Spencer, et al., 1994). Because the main vehicle for testing was AANC's high-cycle Boeing-737, that aircraft had to be subjected to a thorough inspection to determine potential indications/defects. This was performed in a Baseline study during 1994, using qualified commercial inspection personnel to perform a D-check package on the fuselage structure. This study's findings were placed into a database that could be accessed either by the job card (workcard) on which the defect was found or by the defect type. This database was used to develop a new set of job cards specific to VIRP, each containing known defects. These job cards were often designed as subsets of the original job cards so as to include specific areas and specific defects of most interest.

To determine the factors to be included in the experimental program's design, the working group (ATA, FAA, and research team) listed factors known or suspected to affect inspection performance under four headings (see Czaja, Drury, & Shealy, 1981):

- **Task:** The actions the inspector performs, for example: which defects are inspected for, the level of inspection, the time constraints, etc.
- **Operator:** Individual characteristics of the inspector, such as visual ability, training, motivation, familiarity with the task.
- **Machine:** Details of the structure inspected and of the tools used, from mirrors and flashlights to layout of the job card.
- **Environment:** The surroundings of the inspection task. This obviously includes visual, thermal, and auditory environments, but can also include restrictiveness of access and even managerial climate.

Based on these considerations, the working group decided that the Benchmark experiment would be concerned primarily with using the factors to ensure that results would be representative of industry practice. The Follow-On experiments would then examine specific factors one or two at a time. In this way, any data obtained in the Follow-On experiments, e.g., new flashlight designs or better training, could be compared directly against the Benchmark study to measure the effectiveness of any changes in inspection "best practice."

### 9.3.1 Benchmark Study

During the benchmark study, a group of inspectors, who have not seen the test aircraft previously, will be asked to make a visual inspection of specific areas defined by the VIRP jobcards. The benchmark will be set up as a "typical" scenario by controlling key variables. Each inspector will

inspect a number of areas of the aircraft in order to assess that inter-inspector reliability. Videotapes of inspectors performing inspection tasks will be made. Following the actual aircraft inspection, each inspector will be interviewed using a structured interview schedule to elicit his or her expert judgments about the factors influencing successful performance. Analysis of the results will include consideration of the types of errors inspectors may make. The outputs of the benchmark study will be as follows:

#### Quantitative Results

1. probabilities of detection for different flaw/defect types and sizes
2. inter-inspector reliability
3. estimate of the effects of inspector characteristics included in the design (see below)

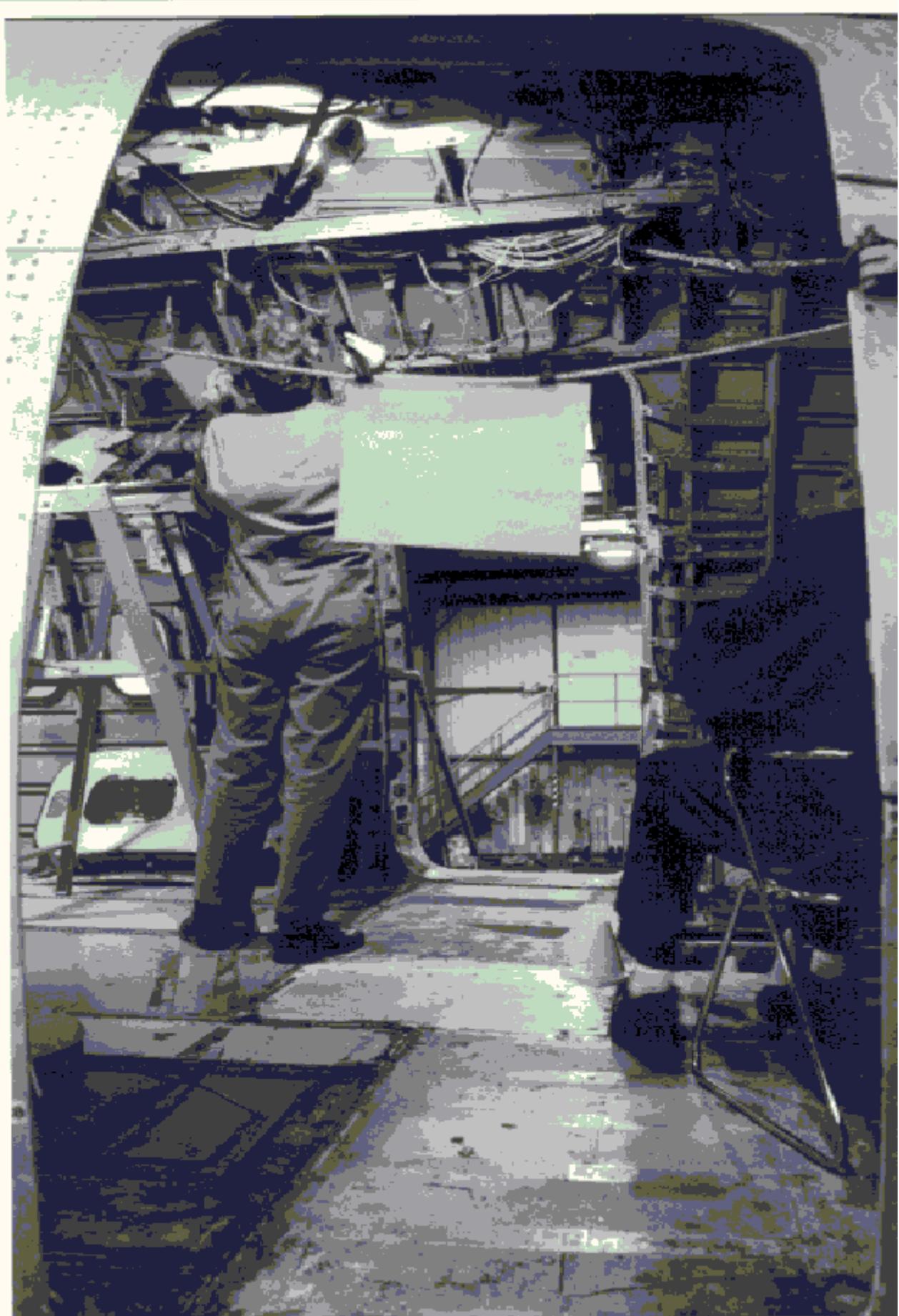
Use of videotape as a recording medium will allow a classification of whether an unreported defect was due to an inspector not reacting to the defect (search failure), or reacting, but deciding not to report it (decision failure). After this experiment, it will be possible to measure the reliabilities of the search process and of the decision process so that detailed guidance can be given on suitable improvement interventions.

Both factors to be varied in this experiment concern difficulty of the task. Job cards were developed to provide inspection tasks with either high or low physical access difficulty and with high or low visual complexity. Twelve experienced airline inspectors, recruited through the ATA members, will inspect each area of the B-737 test bed over a two-and-a-half-day period ([Figure 9.1](#)). They will also inspect a sample of the crack test panels developed for the NDI eddy-current reliability experiment ([Figure 9.2](#)) to determine how reliable inspectors are on a highly-controlled, but realistic, task of the aircraft.

Factors to be fixed were chosen so that they would be at the "best practice" level. Thus, only experienced inspectors will be used. Each will use a good standard tool kit (mirror, flashlight, etc.), and the jobcards will be well-designed (Patel, Drury & Lofgren, 1994). The hangar environment is low-noise with minimum distractions, and the support stands are sturdy and of the correct height.

In addition to the primary data of whether or not each inspector detected each defect, secondary data will be available from a video debriefing procedure. This procedure prompts inspectors to describe what they were doing, and why they were doing it, during various inspection procedures. The procedure we will use is called a Retrospective Verbal Protocol (e.g., Ohnemus & Biers, 1993). It provides valuable insight into the cognitive mechanisms of inspection (e.g., Kleiner, Drury, Sharit, & Czaja, 1989). To improve the precision of the experiment and to obtain a greater understanding of individual factors in aircraft visual inspection, a small battery of tests will be given to each subject. These tests, which provide co-variates for later analysis, include visual performance, mechanical comprehension, and field dependence (e.g., Thackray, 1992; Drury, & Wang, 1986).

As of March 1995, a pilot subject has been tested, and the lessons learned were incorporated into the Benchmark Study. Ten test subjects have now been run.



**Figure 9.1 Subject Inspecting B-737 Structure**



**Figure 9.2 Inspector Inspecting Test Panels for Cracks**

### 9.3.2 Follow-On Studies

While a large variety of studies are possible following the benchmark study, only those of most direct benefit to the user community, e.g., to FAA and ATA, will be performed as part of the VIRP. The developed protocols and the characterized B-737 test bed could be used as the basis for specific commercial studies in a manner similar to AANC's continuing work in NDI. No follow-on studies will be finalized until the results of the benchmark study are available; indeed, the design of the follow-on studies is likely to be an ongoing activity of the group as industry and FAA needs are better defined.

In the White Paper produced before the Benchmark Study began, we identified four potential follow-up studies:

1. Effects of fatigue and rest pauses on the detection of flaws

*Objective:* To assist in providing guidance on the effective use of rest pauses or other work changes to enhance inspection and to combat the effects of fatigue.

*Background:* Studies of human reliability in other domains have shown that, with fatigue/time on shift, the performance of experts tends to deteriorate; in extreme instances performance reverts to that of relatively untrained personnel. Studies have also clearly related the ability to detect signals to levels of attentiveness. The negative effects of both of these factors may be controlled with rest pauses. Data from this study could be compared with that from the benchmark study.

2. Perceptual factors

*Objective:* To form a basis for guidance on suitable lighting levels, color enhancements, etc., needed to design an appropriate physical environment for visual inspection tasks.

*Background:* Visual detection will be influenced by pertinent factors in the physical environment such as contrast, color enhancement, light levels, etc. Job aids such as flashlights, mirrors, etc., will interact with such factors. Aspects such as the color of the

inspection surface may affect ease of detection.

### 3. Search criteria

*Objective:* To study the effects of search criteria on the probability of detecting flaws and to assist in the development of guidance on suitable search criteria.

*Background:* The ability to detect signals has been shown to be dependent on the search criteria provided, e.g., general versus detailed inspection. Factors such as the number of type of flaws to be searched for may influence the probability of detection of both these and other types of flaws.

### 4. Decision criteria

*Objective:* To study the effects of decision criteria on the probability of detection of flaws and to provide guidance on suitable decision criteria.

*Background:* The criteria provided to or assumed by inspectors will influence both the hit/miss and false alarm rates. Criteria may also be affected by the actual or perceived consequences of calling or failing to call a flaw.

## 9.4 Conclusions

The VIRP is designed to respond directly to industry needs, as expressed through the ATA, and to FAA concerns. Over the first year a test bed has been characterized, protocols developed, and job cards produced so that subsequent studies will benefit in terms of reduced design time and effort. As the Benchmark study is completed and analyzed (Spring, 1995), benefits in data handling and analysis for subsequent studies will also be available. The whole VIRP effort has been unique in the way it has combined knowledge of human inspection behavior, experience of aircraft inspection, and statistical design of experiments. Future experiments will extend the VIRP effort to investigate the effects of inspector fatigue, the visual environment, and for the criteria used by the inspector.

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# Chapter 10

## Correlates of Individual Differences in Nondestructive Inspection Performance: *A Follow-up Study*

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### 10.0 INTRODUCTION

In an earlier review of studies and programs dealing with nondestructive inspection (NDI) reliability, a repeated finding was the existence of large individual differences among inspectors in their inspection proficiency (FAA/AAM & GSC, 1993). The few studies cited in this review that attempted to determine possible reasons for these differences in NDI proficiency were generally unsuccessful.

While the above review was confined largely to NDI reliability in the Air Force and the nuclear power industry, a recent study of commercial aviation inspection/repair facilities confirmed that inspector-to-inspector differences were a major source of variation in the commercial field as well (Spencer & Schurman, 1994). While differences among facilities in the procedures used (or in the training inspectors received) undoubtedly accounted for some of the differences found in this study, it seems unlikely that these factors accounted for all of the variation among inspectors.

In the review report noted above, research studies of individual differences in inspection and vigilance, interviews with NDI training supervisors and inspectors, and opinions of experts in the NDI field suggested a number of skills, aptitudes, and traits, measures of which might be relevant to NDI selection and/or proficiency. To explore these possibilities, a study was conducted to examine relationships among many of these aptitudes, traits and performance on a simulated eddy-current inspection task. More specifically, the study sought (a) to determine the relationships of various predictor measures derived from these skills, aptitudes and NDI performance and (b) to examine evidence of fatigue changes, if any, over a simulated day-shift period (Shepherd & GSC, in press).<sup>1</sup> In addition to these primary purposes of the study, a number of other relationships were also examined. A summary of the major findings follows:

- Accuracy of inspection (low numbers of missed faults and false alarms) was found to be positively related to test measures of mechanical ability and attention-concentration.
- Speed of inspection was positively related to test measures of such traits as extroversion, impulsivity, and lack of meticulousness.
- Accuracy and speed of inspection were found to be unrelated.
- There were increases in the percentage of faults missed and in the percentage of good rivets called "faulty" (false alarms) both within and between performance sessions over the simulated day-shift period. Although statistically significant, these percentage increases were relatively small, ranging from 0.8 to 4.5 percent.
- Expressed 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.

The present study was conducted to follow-up on the findings of this previous study.<sup>2</sup> Of particular

concern was the question of whether the relationships between NDI task performance and psychometric measures of mechanical ability and attention-concentration would hold for a different group of subjects drawn from a somewhat different population. A secondary purpose of this follow-up study was to re-examine a number of the relationships noted above.

The task employed in this study was a slightly modified version of the computer-simulated NDI eddy-current task used in the previous study. This task was developed by Drury and his colleagues at the State University of New York (SUNY) at Buffalo and was described in detail in the previous study and in studies by Drury, Prabhu, Gramopadhye, and Latorella (1991), and Latorella, Gramopadhye, Prabhu, Drury, Smith, and Shanahan (1992). It utilized a SUN SPARC workstation and incorporated a standard keyboard and optical three-button mouse as input devices. As Latorella et al. (1992) have emphasized, this task was not developed to devise a simulator that could be used for training on actual NDI tasks, nor was the aim to develop a task that could be used to measure absolute values of the probability of detecting particular types and sizes of faults. The aim was to devise a task that closely approximated the characteristics and requirements of eddy-current inspection tasks to enable laboratory investigation of factors that may influence NDI performance.

The task modification referred to above involved necessary software changes that did not change the essential nature of the NDI simulation but did change some of its response characteristics. A software problem during the previous study would cause the system to malfunction at times, with resulting loss of data. Correcting this problem resulted in a simulation with somewhat faster response characteristics. The effects of these changed characteristics on task performance will be described in subsequent sections.

## 10.1 Methodology

### 10.1.1 Subjects

A total of 37 subjects, 18 males and 19 females, participated in the study. Subjects ranged in age from 18 to 29 years, had normal visual acuity (as determined from an Orthorater screening test), and were paid \$10.00 an hour for their participation through an existing Federal Aviation Administration (FAA) contract. Most subjects were currently employed and attending a junior college, a vocational institute, a military training program, or a local university on a part-time basis. Educational levels ranged from high school graduate to college graduate. Approximately one-third of the subjects were Air Force enlisted personnel assigned to Tinker Air Force Base.

None of the subjects was an aircraft mechanic or inspector and none had prior training or experience in aircraft maintenance or inspection. As in the previous study, this ensured a more heterogeneous sample, thereby maximizing differences among individuals. The inclusion of college students appeared justifiable on the basis of several recent studies of inspection performance that used both students and inspectors (Gallway, 1982; Gallway & 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 in the comparisons made. Finally, educational levels in the present study were comparable to those of inspectors in the recent field study of NDI reliability conducted by Sandia (Spencer & Schurman, 1994).

### 10.1.2 Apparatus

The basic apparatus consisted of a SUN SPARC Model 4/50GX-16-P43 workstation, a 19-inch color monitor, and a 3-button optical mouse. Although the nature of the task and its physical characteristics have been described in the previous study and elsewhere (Drury et al., 1991; FAA/AAM & GSC, 1994; Latorella et al., 1992), task elements are briefly reviewed here.

The display consisted of four basic task elements (windows). These are shown in Figure 10.1 and

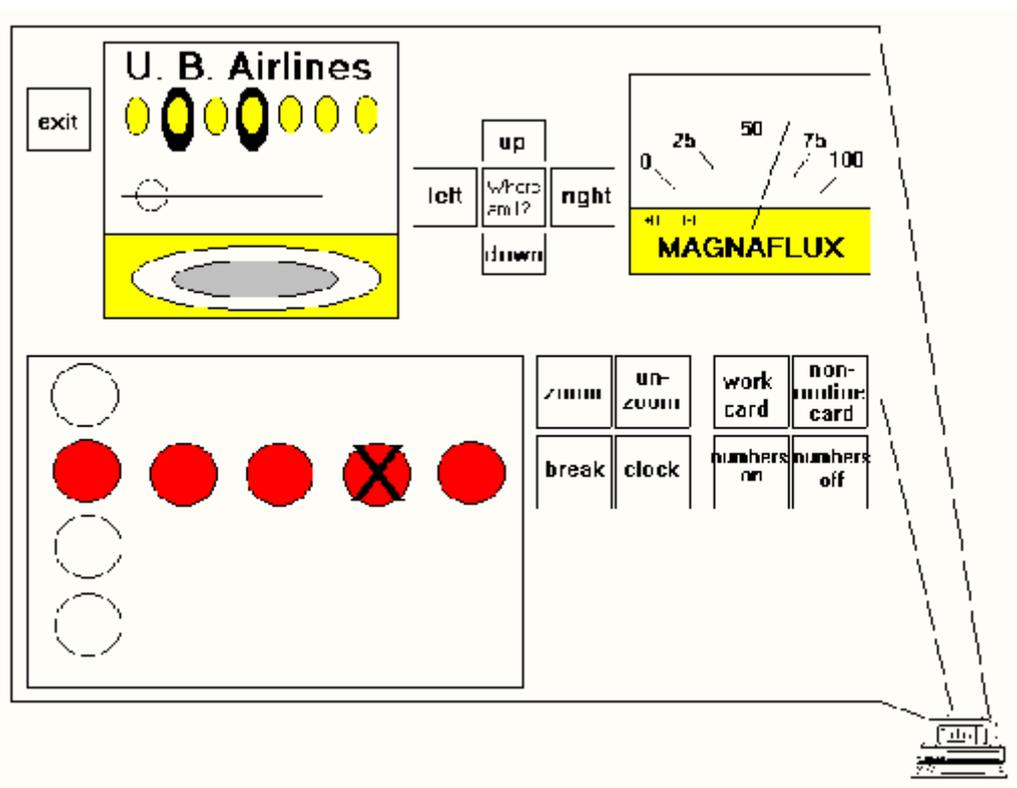
described in the following sections.

### 10.1.2.1 Inspection Window

The lower left portion of the screen displayed the inspection window and contained the actual rivets to be inspected. Although it was possible to present more than one six-rivet row of rivets to the subject, only a single row was used in this study. Each subject used an optical mouse to move the cursor around the circumference of each simulated rivet. The subject was free to examine the rivet until he or she decided whether or not a crack was present. If the subject decided that a rivet was defective, he or she pressed the right mouse button, causing a red cross to appear over the "defective" rivet; the words "rivet marked bad" appeared on the screen. If the subject decided that a rivet was nondefective, he or she pressed the middle button, causing the words "rivet marked good" to appear on the screen. If a subject realized that he or she made an incorrect response, it could be corrected by pressing the appropriate button.

When all of the six rivets had been inspected, the subject clicked the left mouse button on the directional block labeled "right." This caused a black marker ring to circle the last rivet inspected, and the next six rivets in the row appeared in the inspection window.

### 10.1.2.2 Macro-View and Directionals



**Figure 10.1 NDI Task Simulation (Drury et al., 1992)**

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 during the task, the subject could move the cursor over the words "Where am I?" in this area and a momentary circle would appear over the portion of the rivet row currently being examined.

### 10.1.2.3 Eddy-Current Meter

The upper right portion of the display contained a simulated analog meter that served as the eddy-current output indicator. Deflections beyond a set point on the meter produced an audible signal. Meter deflections could be caused by:

- touching a rivet edge with the cursor or moving the cursor over the head of a rivet
- the cursor passing over a crack, all of which were "subsurface" and invisible
- the cursor passing 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.

#### *10.1.2.4 Lower Right Window*

The lower right portion of the display could be used by the subject to exercise a number of options (e.g., to "zoom" to take a closer look at a rivet being inspected, to stop the task in order to take a break, or to display elapsed time). The only feature used in the present study caused a number to appear on each rivet and was used only by the experimenter during training feedback sessions to enable location and rechecking of rivets incorrectly classified.

### **10.1.3 Crack and Meter Characteristics**

As was noted earlier, the developers of this task never intended it to be used as a simulator for NDI training or to measure absolute values of the probability of detecting particular types and sizes of faults. Their aim was to develop a task that, by approximating the characteristics and requirements of eddy-current inspection tasks, could be used in the laboratory to investigate factors that may influence NDI performance. Nevertheless, to provide as much realism as possible, the range (14 to 350 mils) and mean (approximately 100 mils) of fault sizes employed were designed to correspond with those that might be encountered in the field and approximated those derived from data reported in the recent Sandia eddy-current reliability study (Schurman & Spencer, 1994). Meter deflection was proportional to crack size, with the simulated needle showing a similar rapid, abrupt deflection when the cursor passed over or was in close proximity to either cracks or noise elements.

### **10.1.4 Predictors and/or Task Correlates**

The previous study identified a number of variables, measures of which showed significant relationships to performance on the NDI task or appeared to warrant re-examination. A few of the tests and measures used in the earlier study failed to correlate with any of the performance criteria and were discarded. The variables retained included measures of the following:

- Mechanical Aptitude
- Attentiveness/Distractibility
- Extroversion/Impulsivity
- Motivation/Perseverance
- Decision Time/Accuracy

The tests and measures used for each of these were discussed in detail in the previous study. For purposes of review, however, those employed in this study are briefly described in the following sections.

#### *10.1.4.1 Subjective Rating Scale (SRS)*

This is a simple self-rating scale that the author developed and has used in numerous studies (e.g., Thackray, Bailey, & Touchstone, 1977; Thackray & Touchstone, 1991) to assess current feeling levels, with measures generally 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. One additional scale measuring effort required to remain attentive during task performance was also included. Although the previous study failed to show significant relationships of these measures to task performance, this scale was retained so as to allow comparisons of feeling states of subjects used in the two studies.

#### *10.1.4.2 Bennett Mechanical Comprehension Test*

One of the recommendations of the Southwest Research Institute study of ways to improve NDI technician proficiency was to select individuals who scored high on mechanical/electronics aptitude (Schroeder, Dunavant, & Godwin, 1988). This recommendation was also echoed in interviews with NDI instructors; they believe that individuals who are above average in mechanical aptitude make better inspectors (Shepherd & GSC, in press). The previous study found that the Bennett Mechanical Comprehension Test, a measure of the ability to perceive and understand relationships of physical forces and mechanical elements in practical situations, shows a significant relationship to performance; individuals scoring higher on the test were more accurate in their performance on the NDI task. This was the most promising test result found in the previous study, and there was a definite need to re-examine this finding in the follow-up study.

#### *10.1.4.3 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 is a scale developed for use in several previous studies (Pearson & Thackray, 1970; Thackray, Jones, & Touchstone, 1973). It 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 the previous study, the subscale measure of distraction susceptibility showed a significant relationship to attitudes towards inspection, i.e., individuals expressing dislike of inspection tasks scored higher in distraction susceptibility. Because of this finding, it was decided to include this scale in the follow-up study.

#### *10.1.4.4 Arithmetic and Digit Span Tests of the Wechsler Adult Intelligence Scale (WAIS)*

Scores on three subtests of the WAIS (the Arithmetic, Digit Span, and Digit Symbol 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 & Karp, 1961; Karp, 1963). In the previous study, a factor analysis found that the Arithmetic and Digit Span, but not the Digit Symbol, loaded highly on the same factor that included the Bennett Mechanical Comprehension Test. Consequently, the Arithmetic and Digit Span subtests were retained in the present study to verify the earlier findings.

#### *10.1.4.5 Eysenck Personality Inventory (EPI)*

The Eysenck Personality Inventory is a short inventory that measures extroversion and neuroticism. As indicated in the previous study, extroversion has been studied extensively in the context of vigilance research because of the hypothesis, originally formulated by Eysenck (1967), 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 & Kantor, 1984; Wiener, 1975) have lent some support to the belief that extroverts generally do not perform as well on vigilance tasks as 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.

In the factor analysis of the previous study, extroversion failed to load on the factor correlated with

performance *errors*, but did load positively on Factor 1, which was the factor correlating significantly with speed of inspection. These findings led to the decision to include the Eysenck Test in order to re-examine relationship of extroversion to performance.

#### 10.1.4.6 Matching Familiar Figures Test (MFFT)

The MFFT is a test developed by Kagan and his associates (Kagan, Rosman, Day, Albert, & Phillips, 1964) and consists of a series of 12 "stimulus" pictures, each of which is associated with 8 "response" pictures. Except for the one correct picture in each of the response sets, all differ from the stimulus picture in some minute detail. Subjects point to the picture they believe to be the correct one in each set and continue to point until the correct one is identified. Both time to first response and number of errors are scored. According to the authors, the test 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.

The previous study found a significant inverse relationship between MFFT error scores and scores on the WAIS Arithmetic scale, i.e., high scores on the latter scale were associated with few errors on the MFFT. Because the Arithmetic scale loaded on the same factor as the Bennett Mechanical Comprehension Test, it seemed desirable to re-examine these relationships in the follow-up study.

#### 10.1.4.7 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 areas of normal functioning, rather than psychopathology.

The Form E used in this study consists of sixteen scales, of which four were re-examined in the follow-up study. The included scales were (a) Endurance, (b) Cognitive Structure, (c) Change, and (d) Impulsivity. A brief description of each and the reason(s) for its inclusion are as follows:

- *Endurance* A measure of the willingness to work long hours and to be patient and unrelenting in work habits. This was included as a possible measure of intrinsic motivation or perseverance in task performance.
- *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.
- *Change* A 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 so 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.

Three of the above scales (Endurance, Cognitive Structure, and Impulsivity) were retained in the follow-up study because they showed high loadings on the factor (Factor 1) of the previous study that was correlated with speed of inspection. The "Change" scale failed to correlate significantly with any of the criterion measures of the previous study, but was included to re-examine its possible relationship to expressed dislike of inspection tasks.

#### 10.1.4.8 Figure Preference Test

This test is a paired comparison version of the Munsinger and Kessen (1964) test of preference for

complex versus simple perceptual stimuli. Subjects choose which pair, of a set of 66 pairs of figure drawings that differ in complexity, they prefer. 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). Although this test failed to correlate significantly with any of the criterion measures of the previous study, it did show a significant relationship to measures of distraction susceptibility and was retained as a further possible measure of attitude toward inspection.

### 10.1.5 Procedure

Upon arrival, subjects were given a brief description of the purpose of the research and signed an informed consent form. The various tests and measures forming the predictor battery were then administered. Following completion of this phase, subjects received practice sessions in the use of the mouse, were required to read and be tested on a document describing eddy-current testing and the need for it, and then began performance training.

The initial phase of training began with practice in use of the computer mouse. This was accomplished with a display program consisting of a single simulated rivet head with a training circle surrounding it. Subjects practiced using the mouse and cursor to circle the rivet while staying within the circle. After each pre-selected block of training trials, feedback was provided consisting of average times required to circle the rivet, and averages of the 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 10 to 20 minutes of practice.

Training on the inspection task consisted of three separate training sessions, each 60 rivets long. Thirty percent of the rivets in each training session 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. Frequency of "noisy rivets" was also thirty percent. 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 were provided around each rivet to assist the subject in keeping the cursor in the appropriate region while circling the rivets; no training circles were used in the second and third sessions.

Following a noon lunch break, subjects performed two 300-rivet task sessions. These sessions were self-paced, and task duration for each subject varied from a minimum of about 60 minutes to the maximum allowable duration of 90 minutes. There was a scheduled 15 minute rest break between each session, although subjects were told they could take short (10-20 second) "stretch" breaks as needed during any session. No feedback was provided following the task sessions, and the frequency of both faults and noise was held at 30 percent each.

Subjective rating scales were administered at the beginning and end of each task session. At the end of the second session, subjects were debriefed and asked several questions about their performance. These included questions about how well they thought they had performed, and whether they felt that inspection was a type of work that they could see themselves doing or would choose to do on an everyday basis.

## 10.2 Results and Discussion

### 10.2.1 Task Performance

#### 10.2.1.1 Performance Measures: Reliability,

### Intercorrelations, and General Observations

Three performance measures were derived from the NDI inspection task: (a) percentage of faults missed, (b) percentage of good rivets marked faulty (false alarms), and (c) mean time per rivet. Of the two types of error (failing to detect a faulty rivet or calling a good rivet bad), missed faults were more common. On the average, approximately 7.8% of faulty rivets were missed, while only about 1.2% of good rivets were marked faulty. The percentage of false alarms was comparable to the 2% obtained in the previous study and to false alarm rates found in the recent Sandia/FAA study (Schurman, 1993). The percent faulty rivets missed, however, was considerably less than the 23% missed in the previous study. The most reasonable explanation for this difference between the two studies involves the software modifications to the NDI simulation that were mentioned earlier. These changes, by eliminating most of the previous slight lag in meter response, apparently increased the likelihood that faults would be detected. Test trials conducted by the author following the software modifications confirmed that the change in meter characteristics did, indeed, increase the probability of fault detection.

The two measures of performance error (percent missed faults and percent false alarms) were found to be positively correlated ( $r = .50, p < .01$ ), but neither was significantly related to speed of inspection ( $p > .01$ ). The lack of a relationship between speed of inspection and measures of performance error was consistent with findings of the previous study. However, the significant correlation between missed faults and false alarms was not anticipated, since the previous study found them to be unrelated. Examination of the score distributions for these two variables revealed that they appeared generally unrelated, except for three individuals who had exceptionally high false alarm rates and who were also above average in missed faults. Inclusion of these individuals may have biased the relationship, resulting in a correlation that was spuriously high. A nonparametric measure (the Spearman rank order correlation) computed for these two variables failed to reach significance ( $p > .01$ ), suggesting that this measure may better approximate the true relationship between missed faults and false alarms for this particular set of data.

#### 10.2.1.2 Performance Change Across Sessions

One of the purposes of the previous study was to examine the data for any evidence of fatigue changes during the morning and afternoon sessions. While examination of possible fatigue effects was not a principal concern of this follow-up study, the earlier study had shown some evidence of fatigue-related performance changes, and it was decided to compare performance change over the two test sessions. Mean values for each performance variable are shown in [Table 10.1](#).

Analyses of variance revealed a significant increase in percent missed faults ( $F(1/35)=70.7, p < .01$ ) and a significant decrease in mean time per rivet ( $F(1/35)=42.5, p < .01$ ). Percent false alarms showed no significant change ( $F < 1.00$ ).

**Table 10.1** Mean Values for the Performance Variables

Performance Variables	Session		Session Mns
	1	2	
Percent Faults Missed	5.19	10.14	7.80
Percent False Alarms	1.15	1.19	1.17
Mn Time Per Rivet (sec)	12.36	10.86	11.61

**Table 10.2** Mean Pre- and Post-Session Ratings

Variable	Mn Pre-Session Ratings	Mn Post-Session Ratings
----------	------------------------	-------------------------

Attentiveness	7.1	5.7
Tiredness	3.9	5.3
Strain	3.4	3.9
Interest	6.9	5.0
Annoyance	1.2	1.8
Effort	3.1	4.6

The changes, although statistically significant for 2 of the 3 measures, were relatively small and generally in accord with the findings of the previous study. Also consistent with the earlier study was the finding of no gender differences in performance levels or change across sessions. Consequently, gender is not shown as a variable in the table.

## 10.2.2 Rating Scale Variables

### 10.2.2.1 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 two performance sessions. An additional item administered only at the end of the performance sessions required subjects to rate the effort required to maintain alertness when the sessions began and when they ended. Mean pre- and post-task values for each rating variable are shown in [Table 10.2](#). Separate analyses of variance revealed significant pre- to post-task decreases in attentiveness ( $F(1/36)=36.6$ ,  $p<.01$ ) and interest ( $F(1/36)=64.4$ ,  $p<.01$ ), along with significant increases in tiredness ( $F(1/36)=27.2$ ,  $p<.01$ ), annoyance ( $F(1/36)=9.1$ ,  $p<.01$ ), and effort ( $F(1/36)=30.5$ ,  $p<.01$ ). The increase in strain shown in [Table 10.2](#) was not significant ( $F(1/36)=3.8$ ,  $p>.01$ ).

Pre-session ratings indicated that subjects began each session feeling moderately attentive, somewhat above their normal energy level, moderately relaxed, moderately interested, and not annoyed. Since all variables were rated on 9-point scales, with 5 representing the midpoint or average value for each feeling state, it is apparent that post-session levels for all variables were near or below this midpoint value. Thus, subjects could not be characterized as inattentive, tired, strained, bored or annoyed following the performance sessions.

Ratings of perceived effort indicated that slight effort was required to maintain involvement in the task initially, with moderate effort required towards the end of a task session.

Initial levels of all the rating variables, as well as the magnitude and direction of changes, were remarkably similar to those obtained in the previous study. This clearly indicates that the samples used in both studies were comparable in terms of their initial feelings and attitudes, as well as in changes that occurred resulting from task performance.

## 10.2.3 Predictor Variables and Performance

**Table 10.3** Loadings of each predictor variable on the three factors

Factor			
Variable	1	2	3
Typical Experiences Inventory	0.071	-0.281	0.537
Bennett Mech Comp Test	0.649	0.142	0.388

Match Fam Fig Error	-0.736	0.037	0.292
Match Fam Fig Time	0.405	0.087	-0.507
EPI Extroversion	0.221	-0.184	0.676
WAIS Digit Span	0.465	0.194	0.043
WAIS Arithmetic	0.823	0.091	0.131
PRF Change	0.025	0.257	0.672
PRF Cog Structure	0.058	0.710	-0.110
PRF Endurance	0.171	0.780	0.016
PRF Impulsivity	-0.148	-0.824	0.107
Figure Preference	-0.580	-0.092	0.414

A number of exploratory analyses were conducted using factor analysis solved for 3 to 5 factors. The clearest relationships were found using a principal components analysis with varimax rotation and solved for 3 factors. Loadings of each predictor variable on the 3 factors are shown in [Table 10.3](#). A cut-off criterion of .60 was again used to select those variables contributing to factor interpretation. This means that a variable would have to explain at least 36% of a factor's variance in order for it to be included in a factor's interpretation. The factors were identified with labels as follows:

- *Factor 1 - Mechanical Aptitude* This factor appears to stand alone as an ability factor, in contrast to the other factors which represent personality dimensions. Three tests loaded substantially on this factor: The Bennett Mechanical Comprehension Test and the WAIS Arithmetic subtest showed high positive loadings, while the MFFT error score showed a high negative loading. The Bennett Test would seem to define the factor, while the other two suggest important attentional components associated with it.
- *Factor 2 - Tirelessness/Patience* Scales loading positively on this factor (PRF Cognitive Structure and PRF Endurance) suggest a meticulous, unfaltering personality style, while the negative loading on the PRF Impulsivity scale suggests deliberation and patience.
- *Factor 3 - Extroversion/Experience Seeking* This factor is characterized by high loadings on the EPI Extroversion Scale and the PRF Change Scale. Taken together, these two scales would appear to identify an outgoing personality dimension with a dislike and avoidance of routine activities.

Pearson product moment correlations between each factor score and the various performance criterion measures showed only one of the factors to be significantly related to performance. Factor 1, which had substantial positive loadings on both the Bennett Mechanical Comprehension Test and the WAIS Arithmetic subtest, and a negative loading on the Matching Familiar Figures Test error score, was negatively correlated with missed faults ( $r = -.62$ ,  $p < .01$ ) and with false alarms ( $r = -.53$ ,  $p < .01$ ). Unlike the previous study, the present study found speed of inspection (mean time/rivet) to be unrelated to any of the factors.

Both the present and previous studies find a significant relationship between a measure of mechanical comprehension (the Bennett Mechanical Comprehension Test) and performance accuracy. This is interesting for several reasons. One reason is that it is consistent with one of the recommendations of the Southwest Research Institute study of ways to improve NDI technician proficiency. That recommendation, based mostly on speculation, was to select individuals for NDI who scored high on mechanical/electronics aptitude (Schroeder, Dunavant, & Godwin, 1988). NDI instructors also believe that individuals who are above average in mechanical aptitude make better inspectors (FAA/AAM & GSC, 1993). The Bennett Mechanical Comprehension Test, as indicated in the manual for this test, has been validated on various groups of aircraft employees, with validity coefficients ranging from .52 to .62. These groups have included shop trainees and aircraft factory workers in mechanical jobs (Bennett, 1969). The findings of both the present and previous study

suggest that the Bennett test may be a useful predictor of NDI performance, as well. This would support the above-noted recommendation of the Southwest Research Institute, as well as the opinions expressed by NDI instructors, of the relationship between mechanical ability and NDI performance.

**Table 10.4** Number of Males and Females Expressing a Liking for or Dislike of Inspection

Gender	Like Inspection	Dislike Inspection
Males	11	7
Females	7	12

The other two tests loading on Factor 1 were the Arithmetic subtest of the WAIS and the error score of the Matching Familiar Figures Test. With regard to the first of these, several factor analytic studies have shown the WAIS Arithmetic and Digit Span subtests and, less frequently, the WAIS Digit Symbol subtest to load on a factor that has been variously named "Freedom from Distractibility" or "Attention-Concentration" (Goodenough & Karp, 1961; Karp, 1963). In the previous study, the Digit Span subtest loaded on the factor containing the Bennett, while in the present study the Arithmetic subtest showed the highest loadings on this factor. Both studies, then, found evidence of an additional dimension (attention-concentration) that was related to NDI task performance. As mentioned in an earlier section of this paper, studies by Gallwey (1982) and Wang and Drury (1989) have also found a relationship of these attention-concentration subtests to inspection performance. Wang and Drury, however, noted that while a measure such as the WAIS Digit Span correlated with performance errors in some of the inspection tasks studied, it failed to correlate in others. The authors concluded that the relationships of WAIS subtest measures of attention-concentration to inspection performance may have to be empirically determined for different inspection tasks.

The other variable with a high loading on Factor 1 was the MFFT error score, which loaded negatively on this factor. The Matching Familiar Figures Test is, according to its developers, a measure of the cognitive style known as reflection-impulsivity (Kagan et al., 1964); those making quick, inaccurate decisions on this test are said to have an impulsive cognitive style, while those who are more deliberate and accurate are said to have a reflective style. The high negative loading of the MFFT error measure shown in [Table 10.3](#), taken in conjunction with the lower, but positive loading on the MFFT time measure, suggests that individuals who were slow and accurate in their performance on the MFFT also tended to be more accurate in their performance on the simulated NDI task. However, since the MFFT did not show significant loadings on the mechanical comprehension factor in the previous study, the validity of this apparent relationship to NDI task performance is questionable.

#### 10.2.4 Gender, Liking for Inspection, and Self Estimates of Task Performance

During the debriefing period, subjects were asked whether they thought they might like inspection work or could visualize themselves as an inspector. They were told that the NDI task they just completed represented only one type of inspection activity and that they should try to base their answer on inspection jobs in general. The answers were coded "1" if inspection appealed to them and "2" if it did not. This variable was then correlated with the predictor measures and with performance. Like the findings of the previous study, the variable "liking" was not significantly related to any of the factor scores or with any measure of performance ( $p > .01$ ). The lack of a relationship between liking for inspection and actual task performance is consistent with findings of Summers (1984) in his follow-up study of the early Air Force "Have Cracks, Will Travel" study (Lewis et al., 1978). Summers found no relationship between expressed liking for (or dislike of) inspection among Air Force technicians and actual NDI performance.

As with the previous study, there was an apparent gender difference in attitudes toward inspection, with males showing a greater liking for inspection and females a greater dislike. These data are shown in [Table 10.4](#). A chi-square test, however, revealed the obtained gender differences to be nonsignificant ( $p > .01$ ). Although not related to liking for inspection and, as noted above, not related to any performance measures, gender was significantly correlated ( $r = -.62$ ,  $p < .01$ ) with scores on the Bennett Mechanical Comprehension Test. As with the previous study, males tended to score higher than females. This finding is entirely consistent with normative data published for the test (Bennett, 1969) and was expected. However, because of the substantial loadings of this test on the factor (Factor 1) which was significantly correlated with performance accuracy, an indirect relationship of gender to performance is suggested.

During debriefing, subjects were also asked to evaluate how well they thought they performed relative to others performing the same inspection task. Twenty-seven of the 37 subjects felt their performance was about the same as most, nine felt that it was better, and only one subject believed his performance to be worse than most. Separate  $t$ -tests were conducted to compare the performance (missed faults and false alarms) of subjects believing their performance was better than most with those who thought it was about the same. None of the comparisons yielded significant ( $p > .01$ )  $t$  values, showing that perceptions of performance were unrelated to actual performance. The lack of a relationship between self-ratings of inspection performance and actual NDI performance is in accord with similar findings of the earlier Air Force NDI study (Summers, 1984) noted above.

### 10.3 Summary and Conclusions

A previous study examined the relationships among a number of predictor tests and measures and performance on a simulated eddy-current inspection task (Shepherd & GSC, in press). The tests and measures employed were intended to tap various skills, aptitudes, and traits that research studies of inspection, interviews with NDI training supervisors and inspectors, and opinions of experts in the NDI field had suggested might be relevant to NDI proficiency (Shepherd & GSC, in press). While the obtained relationships between a number of the predictor measures and task performance were encouraging, findings were considered to be tentative until validated in a subsequent study using a different group of subjects.

The study reported here was conducted to follow-up the earlier results. The basic approaches of the two studies, including the procedures followed and task employed, were essentially the same. Except for the fact that a different group of subjects was used, the major differences between this study and the previous one were that (a) fewer predictor measures were employed, since those showing no promise in the previous study were eliminated and (b) the task sessions were shorter, as examination of possible fatigue effects was not a principal concern of the follow-up study. A summary and comparison of the principal common findings of the two studies follows:

- Both studies were consistent in finding a significant relationship between scores on the Bennett Mechanical Comprehension Test and performance accuracy on the simulated NDI task, i.e., higher scores on the Bennett Test were associated with more accurate NDI task performance. This finding was the single most important of the two studies and supports the beliefs and opinions of NDI experts that mechanical aptitude may be a good predictor of NDI proficiency.
- Both studies were consistent in finding a significant relationship between NDI task performance accuracy and scores on WAIS measures of attention-concentration. In the previous study, the WAIS Digit Span subtest showed the greater relationship, while in the follow-up study it was the WAIS Arithmetic subtest.
- The follow-up study, but not the earlier one, found an apparent relationship between MFFT error scores and performance accuracy. Because of this lack of consistency between studies, the validity of this relationship is uncertain.
- There were statistically significant increases in the percentage of faults missed during the

task sessions in both studies. This increase occurred over the simulated day shift of the earlier study and during the shorter afternoon sessions of the follow-up study. The increase in percentage of faults missed, however, was relatively small in both studies and may not be of practical significance.

- The two studies agreed in finding no relationship between gender and either liking for inspection or performance on the simulated NDI task.
- Liking for inspection was found to be unrelated to task performance in both studies.
- No relationship existed between speed of inspection and performance in either study.

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# Chapter 11

## Teams and Teamwork: Implications for Team Training within the Aircraft Inspection and Maintenance Environment

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### 11.0 INTRODUCTION

This report is divided into four sections. In the first section, Background and Literature Review, we review state-of-the-art literature on team training. In the next section, we outline a general framework for considering/evaluating tasks' potential for team training, also identifying team training strategies for improving different team competencies. In the section on Team Training for Aircraft Inspection Maintenance, we outline implications of team training for aircraft/inspection tasks and report results of a study evaluating effectiveness of team training for an aircraft maintenance task. In the final section, Team Training for A & P Schools, we describe how team training could be incorporated in an A & P school curriculum and provide a functional description of a computer-based team training tool. We performed this project in close cooperation with a major maintenance repair facility and an A & P school so that results address the aviation community's concerns.

### 11.1 BACKGROUND AND LITERATURE REVIEW

#### 11.1.1 Introduction

Previous FAA reports on human factors in aviation maintenance (Shepherd, 1991; FAA, 1993) have recognized the importance of training. To this point, training for aircraft maintenance and inspection systems, essentially, has aimed at improving individual skills (Shepherd and Parker, 1990), ranging from improving diagnostic skills through aircraft maintenance training (Johnson, 1990(a)) to acquiring and enhancing visual inspection skills to improve airframe structural inspection (Shepherd, 1993; Gramopadhye et al., 1992). Researchers have tended to concentrate on improving the overall training program either with training methodology (e.g., Drury and Gramopadhye, 1990; Desormiere, 1990) or with the training delivery system's technology for on-the-job training, classroom training, tutoring, and computer-based training (Gordon, 1994; Johnson et al., 1992; Drury et al., In Press). While there has been much study of individual skills, there has been little on developing team skills.

Task analysis of aircraft inspection and maintenance activities (Shepherd, 1990) reveals that the aircraft maintenance/inspection system is complex, requiring above-average coordination, communication, and cooperation among inspectors, maintenance personnel, supervisors, and members of other subsystems—planning, stores, and shops—to be effective and efficient. Many maintenance activities technicians or inspectors undertake can be performed more effectively and efficiently with a team. Though the airline industry widely recognizes advantages of teamwork (Hackman, 1990), individual AMTs, not the teams they work with, are held responsible for faulty work. The individual AMT licensing process and concerns about personal liability often result in AMTs and supervisors being unwilling to share knowledge and responsibility across shifts or with less-experienced, less-skilled colleagues. This problem is exacerbated by the fact that experienced inspectors and mechanics are retiring and are being replaced with a younger, less-experienced

workforce. The newer AMTs lack the knowledge and skills of the experienced AMTs they replace and also are not trained to work as a team member.

The FAA continually addresses the problem of individual development of initial AMT skills. The newly established Part 66 of the FAR specifically addresses significant technological advancements in the aviation industry, as well as the past decade's advancements in training and instructional methodologies. The FAA, through its Office of Aviation Medicine, has funded efforts to develop advanced training tools for future AMTs. New training technologies under development, e.g., intelligent tutoring systems and embedded training, will be available to A & P training schools. Application of new training technologies should help reduce the gap between AMTs' current skills and those skills necessary to maintain advanced systems.

The effort invested in developing individual skills has led to a revised FAR, to new training tools (e.g., Johnson, 1990(b); Johnson 1992) applying advanced technology, and to development of advanced training delivery systems (Gramopadhye, Drury and Prabhu, In Press). The area now needing attention is development of team skills. In addition to fundamental skills, today's employers require creativity, an ability to communicate, and an ability to work in a team. Team skills are often not well-developed or part of the background of AMTs now joining the workforce. The problem is made more urgent since the aviation maintenance workforce is much younger and less-experienced, usually without experience working on military aircraft. The younger workforce does not carry the passion for airplanes older workers expect. An FAA report (FAA, 1991) stated, "People today join airlines for many reasons beyond the love of planes. This clear shift plus other changes in labor work force confound the long-service employee. Older employees are somewhat dismayed with the newer mechanics' acquired skills, their *laissez-faire* attitude, and their high turnover."

Inspectors and maintenance technicians are challenged to work autonomously while being part of a team. In a typical maintenance environment, an inspector looks for and reports defects. A maintenance person repairs the reported defect and works with the original inspector or the buy-back inspector to ensure that work meets standards. During the repair process, inspectors and maintenance technicians work as a team with colleagues from the same and the next shift, as well as with personnel from areas like planning or stores, to ensure that the task is completed (FAA, 1991). In any typical maintenance environment, a technician must learn to be a team member, to communicate, and to coordinate activities with other technicians and inspectors. However, AMTs joining the workforce lack team skills. The current A & P curriculum often encourages students to compete, so that new AMTs often are not prepared to work cooperatively. To prepare student AMTs for workplace realities, we need to find new ways to build students' technological, interpersonal, and sociotechnical competence while incorporating team training and communication skills into the curriculum.

The present study's general objective was to present the importance of teamwork and team training in the aircraft inspection environment by focusing on teams and strategies to improve team performance. We expected results to help prepare new AMTs for teamwork in the aircraft inspection environment. The study's specific objectives were the following:

- To understand the role of teamwork and team training in the aircraft inspection/maintenance environment
- To evaluate the effectiveness of a team training activity with AMTs from an A & P school
- To develop guidelines and suggestions for incorporating team training in the A & P school curriculum
- To use results obtained from earlier activities to develop functional specifications for a computer-based tool for team training.

To ensure that our project addressed the aviation community's needs, we conducted the project in cooperation with a major aircraft repair and overhauling facility and with an FAA-licensed A & P school.

### 11.1.2 Literature on Teams

Teams have received a great deal of attention in recent research literature (Salas, et al., 1992; Driksell and Salas, 1992; Glickman, et al., 1987). There is consensus among those who study industrial and organizational behavior that teams/work groups will be the cornerstone of future American industry (Cannon-Bowers et al., 1992; Cummings, 1981; Shea and Guzzo, 1987). Teamwork will be essential because tomorrow's task demands are likely to exceed individual capabilities; hence, individuals will need to work together more. Teamwork will assume a critical role for achieve desired performance. Due to inherent complexities of studying teams in organizations, the abundant literature is fragmented, incomplete, and often contradictory. However, it is important to glean from past work any findings that can help us understand teamwork, team performance, and strategies for improving team skills.

The review of the team literature that follows is limited to the objectives of this study and to a greater extent restricted to teams who perform in a complex and dynamic environment similar to the environment of aircraft inspection/maintenance, which takes place at sites ranging from those of large international carriers, through startup and regional airlines, to the fixed based operators associated with general aviation (Drury et al., 1990). Previous FAA reports detail the complexity of the aircraft inspection/maintenance environment, clearly indicating above average coordination, cooperation and communication necessary to accomplish tasks. Additionally, the importance of teams has been emphasized in the National Plan for Aviation in Human Factors (FAA, 1991), where both the industry and government groups agreed that additional research needs to be conducted to evaluate teamwork in the aircraft maintenance/inspection environment.

### 11.1.3 Team and Teamwork Defined

A definition of what constitutes a team facilitates our discussion on teams in the aircraft inspection and maintenance environment. Throughout the literature, *team* and *teamwork* are defined differently. The following definition of *team* is consistent with the nature of the effort required for aircraft inspection/maintenance tasks (Morgan et al., 1986 p6): "a team is a distinguishable set of two or more individuals who interact interdependently and adaptively to achieve specified, shared and valued objectives." A number of principles have been proposed to ensure that teams work effectively in any situation. Scholtes (1992) suggests that effective teamwork depends on the following ten essential ingredients:

1. Clarity in team goals
2. An improvement plan
3. Clearly defined roles of team members
4. Clear communication
5. Beneficial team behavior
6. Well-defined decision procedures
7. Balanced participation
8. Established ground rules
9. Awareness of the group process
10. Use of scientific approach.

For teams to be effective, its members must work collectively to achieve the overall task objective. To accomplish an objective, some sort of task dependency must exist among team members. According to Salas et al. (1992), the completion of a task objective necessitates the following:

- a) exchange: dynamic exchange of information and resources among team members

- b) coordination: coordination of different task activities and adjustments to changes in task structure
- c) organizational structure: some sort of organizational structure of members.

Research in team and teamwork has shown that training facilitates the entire team process (Glickman et al., 1987; Salas et al., 1992; Swezey and Salas, 1992).

Most literature on teams in the aviation industry has focused on the CRM (Crew Resources Management) training program, which focuses on cockpit training for air crews (FAA, 1993; Helmreich, et al., 1989; Helmreich and Wilhelm, 1991; Foushee and Manos, 1981). CRM typically encompasses several team concepts, including team communication skills, interaction, situational awareness, assertiveness, and leadership skills. Although CRM programs have existed for more than a decade, there has been only limited use of the programs for maintenance and inspection crews. To date, little research has evaluated teams working in the aircraft maintenance environment. However, since they realize the importance of teams, several aircraft carriers and repair facilities have developed in-house training programs. These programs often are part of larger management training programs, focusing on teaching management and non-management personnel to improve safety and efficiency (e.g., Robertson et al, 1994; Taggart, 1990). They are not specifically developed for maintenance and inspection personnel.

#### 11.1.4 Team Evolution

To understand how training can provide measurable changes in team behavior that enhance the efficiency and effectiveness of teamwork in aircraft maintenance, we must examine the evolution of teams. Then we can develop effective intervention strategies that can impact teamwork. In recent years, several conceptual frameworks and theories have been proposed to explain the team-evolution process. In this section, we review salient frameworks and theories, drawing upon previous researchers' work to develop a new framework for understanding the team process in the aircraft maintenance environment. The theories described below are only representative; our aim in including them is to explain team performance and training.

Hackman's (1983) normative model offers a comprehensive conceptualization of group process in the organizational environment. Though the model is not developed for a highly structured team, it emphasizes organizational input and the effort, skills, and strategies of team members bring to accomplish team goals. Gersick (1988) described a time and transition model for teams, focusing on the dynamic, evolving nature of team performance. The model shows how exchange of information and resources among team members can result in effective team performance. In Gladstein's (1984) Group Effectiveness Model, group effectiveness is a function of different group processes, such as communication and strategy discussions, moderated by group task demands, such as task complexity and environmental uncertainty. This is one of the few models tested with a large sample of teams in the work environment. Morgan et al.'s (1986) Team Evolution and Maturation Model (TEAM) hypothesizes that teamwork develops through several phases, beginning with loosely organized groups of individuals and proceeding to become a highly effective team over time. This model conceptualizes a team as going through developmental phases and proceeding from ineptness and exploratory interactions to the final level of effective, efficient team performance. The model considers two distinguishable types of team activities through the steps of team evolution: task-related activities and team-related generic activities. Task-related activities are associated with developing operational skills to perform technical tasks; team-related activities are involved in developing team interaction, e.g., relationships, coordination, and interaction.

Other models of team performance emphasize a task analytic approach to team training, e.g., Naylor and Dickinson, 1969; Shiflett et al., 1982. These models consider team performance as a function of the sub-task the team has to perform. They imply that the organization and task complexity establish optimal work and communication and interact to determine individual and team training requirements for enhanced team performance. Tannenbaum et al. (1992) integrate previously described models in a framework for team performance and team training. Canon-Bowers et al. (In

Press) state that, since teams operate in diverse work environment performing a wide variety of tasks, constructs such as teamwork and team training can only be understood in the context within which they occur. Tannenbaum et al. (1992) proposed framework explains this context.

## 11.2 FRAMEWORK FOR TEAMWORK IN THE AIRCRAFT MAINTENANCE ENVIRONMENT

Having reviewed various frameworks and theories, we now propose our framework for considering the team process in the aircraft maintenance environment. Drawing from task analysis of aircraft inspection and maintenance operations (Drury et al., 1990; FAA, 1991), from site visits to repair facilities, from observations made with training personnel and A & P school instructors, and from a detailed review of the team models, we developed the framework shown as [Figure 11.1](#) (Chapter 11 - Appendix). This framework serves as a first step for understanding teamwork in aircraft inspection and maintenance operations; it could be seen as an extension of Tannenbaum et al.'s (1992) team effectiveness model.

The framework illustrates the interaction among internal factors, external factors, the team process, training strategies, and outcome measures. External and internal factors effect the team process. External factors are categorized as follows:

**Organizational factors:** organization's size , type (e.g., airline, general aviation, repair facility), reward structure, management structure, communication norms, and organizational climate.

**Environmental factors:** level of environmental stress (work conduct in hangars or flight-line) and environmental uncertainty.

**Equipment factors:** automation, complexity, specialization, equipment availability, and safety.

**Task factors:** task organization (type of aircraft check: A-, B-, C-, or Heavy-check), task type (e.g., avionics, power plant, hydraulics, sheet metal, frame), task complexity, and task structure.

The internal factors, composed of individual and team skills, can be categorized as follows:

**Individual skills factor:** This represents individual team members' skills and is best represented by AMTs' knowledge, skills, and abilities. In an aircraft inspection/maintenance environment, the individual skills factor is determined by AMTs' experience working on different aircraft types and with different aircraft systems.

**Team skills factor:** The team members' ability to work together productively is dependent on their interpersonal skills, on the team's composition, on the number of people in the team, and on how long members have worked together. We identified team skills relevant to aircraft maintenance tasks and present them in [Table 11.1](#) (Chapter 11 - Appendix). The name for each team skill is based on suggestions by Salas et al (1992); they were established after a comprehensive review of the literature on teams. According to Morgan et al. (1986), team skills that are isolated and identified can provide a framework for team performance assessments. Although attitude is not considered a team skill dimension *per se*, it is a "cognitive" entity that can be acquired through training (Gagne, 1988); hence, it is shown separately in [Table 11.1](#) (Chapter 11 - Appendix). Previous studies have shown that attitude is important for teamwork and team performance.

External and internal factors impact team interaction, as well as the team process. However, team development is evolutionary: a team matures over time (Morgan et al., 1986). When viewed in light of Morgan et al.'s (1986) TEAM model, individual skills reflect task behavior and represent team members' abilities to perform assigned technical tasks; team skills reflect team members ability for successful interaction and coordination. Both skill acquisition and team evolution can be enhanced through training (Morgan et al., 1987). Specific ways for imparting individual training to AMTs has been widely covered in the literature; hence, our effort focuses only on team training.

AMTs are members of not only one team, but of several teams working on different, yet similar tasks. At an aircraft repair facility, an AMT may work on different subsystems of various aircraft and with different team members over a scheduled maintenance period. For such situations, it is critical to identify generic skills (Cannon-Bowers, et al., In Press) and to train team members accordingly. Cannon-Bowers et al. refer to these as "transportable team skills." At the same time, training AMTs on transportable skills, in itself, may not be sufficient to ensure successful team performance. For such performance, AMTs need training on task-specific team skills, focusing on aircraft inspection and maintenance tasks. Methodology for this type of team training is outlined in the section on Team Training.

The entire team's output can be determined by examining the changes in measures of individual and team process and of task performance.

Individual process measures: These measures identify changes in an individual's task knowledge, skills and ability after he or she takes part in a team activity, also reflecting changes in an individual's mental model and understanding of an entire task.

Team process measures: These measures identify evolution of new team processes by changes in members' specific team skills, i.e., coordination, communication, leadership, and interpersonal skills.

Task performance measures: Performance of an aircraft inspection or maintenance task is measured on the dimensions of accuracy, speed, and safety. Accuracy measures the quality of a job the team completed. Speed measures time required to accomplish a task. Safety refers to the team members ability to adhere to safety procedures by not endangering themselves or other team members. Measurement procedures used to evaluate teams must be sensitive to typical speed/accuracy tradeoffs.

We used our understanding of teamwork to identify specific strategies for training AMTs in A & P schools. In the following section, we outline these strategies. Later in the report, we identify specific team projects which could be incorporated into A & P school curricula and report results of the study we conducted to evaluate how team training improves team skills for an aircraft maintenance task.

## 11.3 Team Training

Team performance is a function of the average skills of its members. Individual skills appear to be a necessary, but not sufficient, condition for effective team performance; and the correlation between average skill level and average team performance is typically small (Bass and Barrett, 1981; Teborg et al., 1976). According to Steiner (1972), team performance is dependent on team members' ability to perform assigned tasks and on their ability to coordinate work flow and to communicate effectively. This process can be facilitated by team training.

Development of a team training program follows classic training program development methodology. It begins with a thorough analysis of the training program's requirements and needs (goals). The next step is establishing knowledge, skills and abilities necessary for the job; these are used to specify the training program's behavioral objectives forming the basis for evaluating the training program. The knowledge, skills, and abilities currently required for aircraft maintenance does not include team skills. Team training is instruction team members receive as a unit to enhance team performance (Nieva et al., 1978). It includes training strategies to enhance team skills. When team training must be combined with individual training in a single program, research shows team training to be most efficient and effective when team members first develop individual skills. Swezey and Salas' (1992) taxonomy identifies characteristics of team training to incorporate in every training program as communication, task organization, team decision-making, team organization, and information transmission. Specific strategies to enhance AMT team skills are outlined below.

### 11.3.1 Lecture

Lecture is most appropriate for transportable team skills and can be used to introduce basics of teams, teamwork, and the role of teams in enhancing performance. Lectures are most beneficial for team organization/collaboration in identifying the nature of interdependencies for team members and developing an understanding of the team's structure. AMTs can be taught how other members influence their performance, what contributions other AMTs make, the roles of inspectors, and cleanup crews, and for what conditions they must adapt their performance. For example, members should know what to do when particular equipment is unavailable, when a specific inspector is not available or when a member is assigned to a new task. Lecture can also be used to train AMTs in proper communication by giving examples of good and poor communication. AMTs can be taught what type of communication-written and oral-they should have with other members; to whom they must pass information, e.g., writing up a non-routine workcard or passing work to the next shift; and from whom they must receive instructions. Communication includes both technical and non-technical information. Team members should be trained on how to provide and receive performance feedback on individual and team performance so that individual members and the team as a whole use it to enhance performance.

### 11.3.2 Team Meetings

Team meetings, i.e., group interaction methods, are another popular technique (Goldstein, 1986). This consists of bringing AMTs together to interact in a relatively unstructured environment. Team meetings can be effective for analyzing interpersonal problems and for developing effective understanding and coordination among team members.

### 11.3.3 Role-Playing

Role-playing can be used for training generic team skills. Members become aware of each other's roles (Cannon-Bowers, et al., In Press) by interacting with each other in role-playing situations. They can learn the knowledge, skills, and abilities each task requires. For example, a mechanic can become aware of skills an [NDT](#) inspector has and constraints under which he or she works. Role-playing helps each member develop a better understanding, e.g., mental model, of each task and of interdependencies between and among tasks. With role-playing, trainees have the opportunity to experience on-the-job problems and to explore specific solutions to them (Gordon, 1994).

### 11.3.4 Task Demonstration

Task demonstration has been successfully used for team training. A task demonstration assists trainees by showing where and how individual team members make inputs and can be most helpful for context-specific skills (Cannon-Bowers, et al., In Press). A passive demonstration could be a computer simulation of a task or an illustration consisting of flow diagrams. A passive demonstration helps trainees identify critical task elements; determine how each team member contributes; understand the sequence of subtasks; establish step-by-step procedures; and identify requirements for coordination, equipment and tooling. For aircraft maintenance, when computer simulation of all tasks is not feasible, cross-training is possible with simulations of representative tasks sharing the same critical elements.

### 11.3.5 Feedforward Training

Feedforward training, proven effective for individuals (Drury and Gramopadhye, 1990), improves performance when applied to teams (Fredericksen and White, 1989). Feedforward training can take the forms of physical guidance, demonstrations, or verbal advice. It advises team members about upcoming situations so that they are prepared. For example, trainees learn how a team should resolve conflicts arising due to equipment being unavailable, or how to respond when instruction procedures, e.g., on workcard, are not clear and are ambiguous, or when a member is assigned a

different task.

### 11.3.6 Team Decision-Making

Team decision-making requires educating the team on how to utilize various pieces of information to reach an optimal decision (Hogan, et al., 1991). The method involves training members on decision-making techniques, ranging from decision by consensus to brainstorming, to using nominal group techniques. Not all these techniques apply to or are relevant for training AMT teams. The team decision-making dimension is similar to communication because teams need to know what, why, where and how information can be accessed for optimal decisions (Swezey and Salas, 1992).

### 11.3.7 Feedback Training

Feedback training, i.e., knowledge of results, is beneficial for individual skills training (Patrick, 1992; Czaja and Drury, 1981), and a similar effect exists for teams (Dyer, 1984; Nieva, et al., 1978). In fact, practice without feedback degrades a team's proficiency. Cannon-Bowers et al (In Press) write, "Feedback improves skill acquisition and subsequent task performance by reinforcing learning, by providing cues for goal setting and adjustment, and by reducing the negative effects of self-serving attributions and social loafing."

The following factors are essential for providing effective feedback:

**Timing:** Feedback should be timely. Team performance is generally superior when feedback is immediate, rather than delayed.

**Focus:** Feedback's focus is important. Providing feedback on only certain aspects of a task results in performance improvements on only that aspect of the task. Team training should not emphasize one aspect of team performance more than others.

**Sequence:** Initial feedback should be provided on one aspect of a task; later feedback, on all aspects of a task. This sequence allows trainees to focus on all aspects of team tasks.

**Feedback Mix:** The ratio of individual to team feedback also effects team performance. Individual feedback should be provided during the initial training session to train individuals to a criterion level of performance. Feedback on later sessions should address team aspects of performance. This strategy ensures that individual skills are suitably developed before team feedback is provided while also preventing individual members from developing misconceptions about their own performance when the team receives feedback.

## 11.4 Team Training Study

To test the effectiveness and usefulness of team training as a strategy for improving team performance for aircraft maintenance, we conducted a study with AMTs from an FAA-licensed A & P school. Current analyses are based on the hypothesis that teams successfully completing team training exhibit specific interaction, communication, and coordination behaviors enhancing their performance. In this study, we addressed the following questions:

- Does team training effectively improve overall team performance?
- Do effective and less-effective teams display different types of team behaviors?
- Can team training enhance interactive/communication behaviors?

We designed the experiment described below to test the hypothesis and to answer the questions. We do not provide complete details below, but eventually will publish them as a sequence of technical papers.

### 11.4.1 Subjects

The participants in this study were 24 male students AMTs between 20 and 30 years old from an FAA-licensed A & P school. All subjects were in the second year of a two-year curriculum.

### 11.4.2 Task

The task consisted of two distinct sessions: the removal and the installation of a turbine engine from a Beechcraft airplane. Major phases in the removal of the engine are external preparation, engine preparation, and engine extraction. Major phases in engine installation are engine installation, engine preparation, and external preparation. Details of each phase are outlined in [Table 11.2](#) (Chapter 11 - Appendix). We selected this task based on its high potential for teamwork. It necessitates more than one person and requires a significantly high degree of coordination and communication between team members for its successful completion.

### 11.4.3 Procedure

Each subject completed a demographics form ([Table 11.3](#), Chapter 11 - Appendix) and was randomly assigned to one of eight three-person teams. Four teams served as the control group, and remaining four teams received team skills training (this was team training group). Initially, all subjects in the control group and the team training group received individual skills training that provided technical information on how a turbine engine works, on the theory of turbine engines, and on major steps for removing and installing the engine. Subjects also received detailed information about different tools and their proper uses; tools used are listed in the Chapter 11 - Appendix as [Table 11.4](#). After individual skills training, teams in the training group received team training. Before starting the team training, teams in the training group performed a warm-up team exercise (see Chapter 11 - Appendix, [Table 11.5](#)).

The team training program was developed in cooperation with trainers and key personnel of a major aircraft repair and overhaul facility and instructors from an A & P school. The training program used some, though not all, of the team training strategies we described above. We combined the team skills with team training research to develop a behaviorally based, team training program focused on improving specific team skills. First, we tested the team training program using AMTs from our partner repair facility for a specific aircraft maintenance task. However, we do not report results of the field study at the aircraft repair facility; they are forthcoming in other papers. We modified and refined our team training program based on the field study's results and used the revised version in the current study. The training program had five stages, with each stage requiring 2-3 hours (see Chapter 11 - Appendix, [Table 11.6](#)). Teams remained intact through the entire team training process and the study's duration.

Following team training, teams in the training group performed the engine removal and installation task. Teams in the control group performed the same task. Unlike the team training groups, control group teams performed the task directly after they received individual skills training. When they completed the entire task, we debriefed all teams and thanked them for participating.

## 11.5 Measuring Teamwork Skills, Team Attitude, and Task Performance

### 11.5.1 Teamwork Skills

A series of recent studies conducted with military teams offer insight into measuring the team process (Morgan, et al., 1986; Baker and Salas, 1992). Studies in teamwork assessment show that it is possible to observe and record changes in team behavior and to discriminate more-effective from less-effective teams (Oser, et al., 1989). Our detailed review of teamwork measurement literature

suggests that team process measures rely heavily on observation (Schiflett, et al., 1985; Morgan, et al., 1986) and that team studies use behaviorally anchored rating scales for data collection. For the current study, assessment tools (rating scales) were developed and refined to measure teamwork skills and team task performance.

We collected two types of data on the previously mentioned team skill dimensions by interviewing team members and instructors. One type of data reflected instructors' observations; the other, team members' perceptions. We collected the first type of data with the instructors' interviews (Chapter 11 - Appendix, [Table 11.7](#)). We collected the second type with the post-session interviews (Chapter 11 - Appendix, [Table 11.8](#)). Both the interviews use a Likert-type, seven point, agree-disagree scale: trainees and instructors indicated their response to each item. Instructors and student AMTs completed the respective interviews on completion of each session, i.e., engine removal and engine installation.

### 11.5.2 Team Attitude

Attitude measures attempt to gauge the trainees' opinions about whether they believe that training and teamwork will improve team performance. One of the most popular attitude measurement questionnaires is the CMAQ (Cockpit Management Attitudes Questionnaire) for assessing commercial aviators' attitudes about team training (Helmreich et al., 1986). In the current study, we used a modified version of an attitude questionnaire (Chapter 11 - Appendix, Tables [11.9](#) and [11.10](#)) in our interviews, administering it to student AMTs before the study's commencement and after its completion.

### 11.5.3 Task Performance

In addition to data on team behavior, data were also collected on speed, accuracy, and safety measures. We recorded this data using the data collection instrument in Chapter 11 - Appendix, [Table 11.11](#). Data were collected on the above-listed task performance measures for each phase of the engine removal and engine installation tasks. Results are reported with the Task Performance Summary Table (see Chapter 11 - Appendix, [Table 11.12](#)).

## 11.6 Results and Discussion

This study's results are indicative since comparisons are based on only four teams per group (training, control). However, these results do generally indicate that we are heading in the right direction. The data collection instruments and task performance summary provided data for 24 individuals from 8 teams. These data are reported in this section, divided into findings based on data from the instructors' evaluations, from self-evaluations, and from the task performance summary.

Figures [11.2](#) and [11.3](#) (Chapter 11 - Appendix) show instructors' overall ratings for the trained and untrained teams on each team skill dimension. The instructor's ratings on the instructors' interview were mapped onto different team skills. The chart shows that teams which had team training were ranked equal to or better than teams which did not have team training on each team skill dimension for both engine removal and engine installation phases. These results suggest that teamwork skills of the teams receiving training were perceived to be much better than those of teams not receiving training. Since no data were collected on individual team members, it is not possible to assess each individual's relative performance.

It is interesting to note that performance differences between trained and untrained teams are much larger on the engine removal phase (first session) than on the engine installation phase (second session). Teams which did not receive training showed improvement and better teamwork in the latter phase (engine installation). This could be because team interaction patterns are established, lessons are learned, and communication norms develop as the task proceeds. Experience helps refine

the team's interaction process so that it works more effectively on subsequent tasks. Much of the team evolution and maturation process for teams not receiving training was completed "on-the-job," while a large portion of this process for trained teams was completed during training. Despite differences, the data indicate team evolution and maturation effects for both teams. These results add weight to the claim that effective team behaviors can be identified and enhanced by having teams engage in those behaviors in a training environment.

To understand individual team members' perception of their team's performance, we analyzed the Post-session self-evaluation interview. Results are reported in the Chapter 11 - Appendix as Figures [11.4](#) and [11.5](#). Although the instructors' analysis of trained and untrained teams revealed a large difference in various team behaviors, we did not find a similar large effect here. Nevertheless, results of the self-evaluation interview are that the trained group's mean score was higher than the control group's on five of six team skills measures on the engine removal task and on four of six measures on the engine installation task. To gauge teams' attitudes towards teamwork and their understanding of the principles of teamwork, we analyzed pre- and post-training interviews. [Figure 11.6](#) (Chapter 11 - Appendix) shows that, although scores for both the trained and the untrained groups are comparable on the pre-training interviews, there are differences on the post-training interviews. The trained group's higher scores on six of eight questions reflect the effect of training in and understanding of teamwork and team principles.

To understand whether improved team performance translated into improved task performance, we collected task performance measures for both groups. The data for the trained and control groups are summarized in [Table 11.12](#) (Chapter 11 - Appendix). Measure 1 relates to speed; measures 2, 3 and 4, to accuracy; and measures 5 and 6, to safety. Teams in the untrained (control) group required significantly more time to complete the engine removal task. However, there was not a large difference on the engine installation task. This result could be attributed to the lack of coordination and communication among members of the control group present in the first stage and absent in the second. Over time, teams in the control group improved coordination and communication, resulting in reduced task time on the engine installation task. Similarly, the trained group made fewer errors for both engine removal and installation tasks and had superior scores on accuracy measures 2, 3 and 4. No significant differences were observed between the groups on safety measures. The most important result is that trained teams with effective team behaviors were overall more effective and more efficient. Trained teams demonstrated more behavior involving coordination and communication skills, i.e., coordinating gathering information, conveying the right information to the right person at the right time in the right format, receiving relevant information; error-correction skills, i.e., providing team members with performance feedback and helping resolve errors; and interpersonal skills; i.e., leadership, displaying appreciation for help provided, and making team-building statements. These behaviors resulted in improved task performance.

A correlation exists between successful team behavior and task performance. Though limited in its sample size, this study's results indicate that training AMTs on team skills improve coordination and communication skills. In turn, this translates into improved task performance.

## 11.7 Conclusions

This study was a first effort devoted expressly to evaluating the effect of team training in the aircraft maintenance environment. The study's implications are encouraging as to the potential team training has for improving team performance and overall task performance. We draw the following specific conclusions from this study:

- It is possible to identify team skills and to train student AMTs in teamwork skills critical for successful team performance in the aircraft maintenance environment.
- Teams which receive team training exhibit a larger percentage of behaviors related to team performance. Also, results suggest that members of teams which did not receive team training do not exhibit the high percentages of team behaviors as members of more-effective

teams.

Based on this study's results, training for student AMTs should emphasize generic and context-specific team skills, focusing on coordination, communication, interpersonal, and leadership skills. Our findings provide insight for developing future team training systems and for improving existing instructional technology. The elements of the team training program outlined in this study can easily be incorporated into A & P school curricula to prepare student AMTs for teamwork. Further, elements of the team training program can also be incorporated into formal methodology used to train AMTs at different aircraft sites. The operational setting for the current study provided the opportunity to observe teams in the field, rather than in a laboratory. Although results are encouraging, additional team research is needed to fully understand complex interactions existing in a team environment for different tasks and conditions. The following section outlines how team training can be incorporated in a typical A & P school curriculum and provides a functional description of a computer-based tool for team training which will be developed under Phase VI of this contract.

## 11.8 Future applications of TEAM TRAINING WITHIN A & P SCHOOL CURRICULUM

The previous study demonstrated team training's effectiveness for improving both teamwork skills and task performance for a specific aircraft maintenance task, using student AMTs. The results of the controlled study and recognition of the important role of teamwork establish a need to identify team projects which can train student AMTs in teamwork skills and prepare them for cooperative environments. This section outlines specific team-training projects which could be used in a typical FAA-licensed A & P school curriculum. [Table 11.13](#) (Chapter 11 - Appendix) outlines a typical A & P school curriculum, and Chapter 11 - Appendix, [Table 11.14](#) presents a condensed overview of various team projects which could be incorporated therein.

### 11.8.1 Computer-Based Tool for Team Training

As computer-based technology becomes increasingly cheaper, the future will see an increased application of advanced technology in training. Over the past decade, instructional technologists have provided numerous technology-based training devices promising improved efficiency and effectiveness. Examples include computer simulation, interactive video discs, and other derivatives of computer-based applications (Johnson, 1990(a)). The compact disc read only memory (CD-ROM) and digital video interactive (DVI) are examples of other types of technologies which will provide future "multi-media" training systems. Technologies such as Computer-Aided Instruction (CAI), Computer-Based Training (CBT), and Intelligent Tutoring System (ITS) are being used today, ushering in a revolution in training. Several new technologies have found a place in maintenance training (Johnson, 1990(a), 1992; Shepherd, 1992).

Hypermedia is a tool/instructional system finding acceptance as a tool for learning among learning theorists. Hypermedia involves non-linear organization of information, linking together discrete blocks (chunks) of information to create an information network. It can also be seen as a non-sequential method for presenting and accessing information in which users can move freely according to their needs. Hypermedia information is multimedia: text, graphics, animation, and audio. If information is only text, it is known as hypertext. Hypermedia systems have found extensive use in applications ranging from browsing to training. Jonassen and Gabringer (1990) list examples of hypermedia in instructional tools such as language learning, science teaching, and browsing in encyclopedias. Christensen, et al. (1993) developed a hypermedia-based instructional tool for teaching hypermedia system design. Koshy, et al. (In Press) developed a hypermedia version of a maintenance manual for diagnostic training. In each case, hypermedia was useful for learning and training applications.

The current research effort was devoted expressly to facilitating understanding and to examining

how team members interact and how team training can facilitate teamwork in the aircraft maintenance environment. Having met these goals, our next step is to consider training media which uses instructional techniques developed in this phase of the research in order to develop a training program enhancing team skills. Hypermedia has the potential to enhance learning and could prove to be useful for improving certain aspects of teamwork. In the next phase of our research, we propose to develop a hypermedia-based training tool designed to support learning teamwork in the aircraft inspection and maintenance environment. We provide a functional description of the proposed training tool below.

### 11.8.2 Functional Description

The Aircraft Maintenance Team Training (AMTT) software will be a computer-based hypermedia system for team training. It will be developed for student AMTs, focusing on generic and context-specific team skills. The system will be programmed using Visual Basic/Tool Book to operate on an IBM-compatible computer (486 DX2/66 Hz , 8 Mb of RAM), using Microsoft Windows and utilizing multiple media such as sound, text, animation and graphics. AMTT will consist of the two basic modules and other sub-modules outlined below.

#### 11.8.2.1 The Trainee's Module

The Trainee's Module will train AMT's on various aspects of teamwork, including generic and context-specific team skills. It will include the following basic elements:

##### 11.8.2.1.1 Team Overview Module

Introduction: This module will introduce trainees to the basics and objectives of teamwork (team mission). This module will use the Landing on the Moon exercise to demonstrate the importance of teamwork. The importance of and need for teamwork in aircraft inspection and maintenance will also be emphasized, identifying basic team skills and illustrating each skill's importance.

Tools for Making Team Decisions: This submodule will introduce trainees to decision-making techniques, providing examples of using the techniques in the aircraft maintenance environment.

Team Communication: This submodule will introduce trainees to aspects of written and verbal/nonverbal team communication, providing illustrations of appropriate and inappropriate communication in the aircraft maintenance environment. Specifically, communication examples will focus on: format, direction, frequency, length, conditions, context, and time. The importance of good communication for team performance will be emphasized.

Team Feedback: This submodule will provide trainees with guidelines for providing, receiving, and using feedback to communicate with other AMTs clearly about how tasks are being performed.

Team Coordination: This submodule will focus on the coordination required for team members to ensure well-orchestrated teamwork.

Team Leadership: This submodule will focus on the critical role of team leadership for accomplishing team tasks. For example, team members will be shown how to handle information overload under stressful conditions, specific behaviors exhibiting leadership and assertiveness, and methods of motivating others.

Team Evaluation: This submodule will expose the trainees to the instruments used to evaluate individual and team performance on a task.

Each submodule will first introduce trainees to basic principles and then provides examples applying the principles to enhance teamwork in the aircraft maintenance environment. Trainees will make an active response as they are exposed to new material and will be provided with immediate feedback as to their answer's correctness. This stage will be followed by a question and answer session for the material.

### 11.8.2.1.2 Team Building Exercise Module

This module's objective is to demonstrate the application of basic principles of teamwork emphasized in the Team Overview Module. Trainees will undertake a series of exercises requiring them to demonstrate their understanding of principles. The training will use training strategies such as role-playing, feedforward, and feedback. For example, roles of various team members will be modeled for certain task situations, using knowledge from experts. Examples of how interactions could proceed, with examples of poor and good behavior, will be demonstrated via simulation. Trainees will comment on the behavior's appropriateness and will be asked for inputs or suggestions to improve team performance. Trainees will be given guidance and feedback during and after the session.

### 11.8.2.1.3 Task Simulation Module

This module will provide trainees with graphical demonstration, animation, and flow charts of different scenarios for select aircraft maintenance tasks. Team members using this module can interact cooperatively to identify ways to improve teamwork for the representative simulated aircraft maintenance tasks.

## 11.8.2.2 The Instructors Module

### 11.8.2.2.1 Assessment Module

This module will provide the instructors with a means to assess trainees' understanding of using team principles and will allow instructors to evaluate trainee's and the team's performance while interacting with AMTT software. The module will provide the instructor with various data collection instruments used by both trainees and instructors.

### 11.8.2.2.2 Report Generation Module

The Report Generation Module will allow instructors to print reports of results. It will also allow instructors to generate printouts of data collection instruments and select material in the Team Overview Module. This will allow instructors to use the material in a classroom environment and to use data collection instruments for field study.

## 11.9 REFERENCES

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## Chapter 11 Appendix Team Training

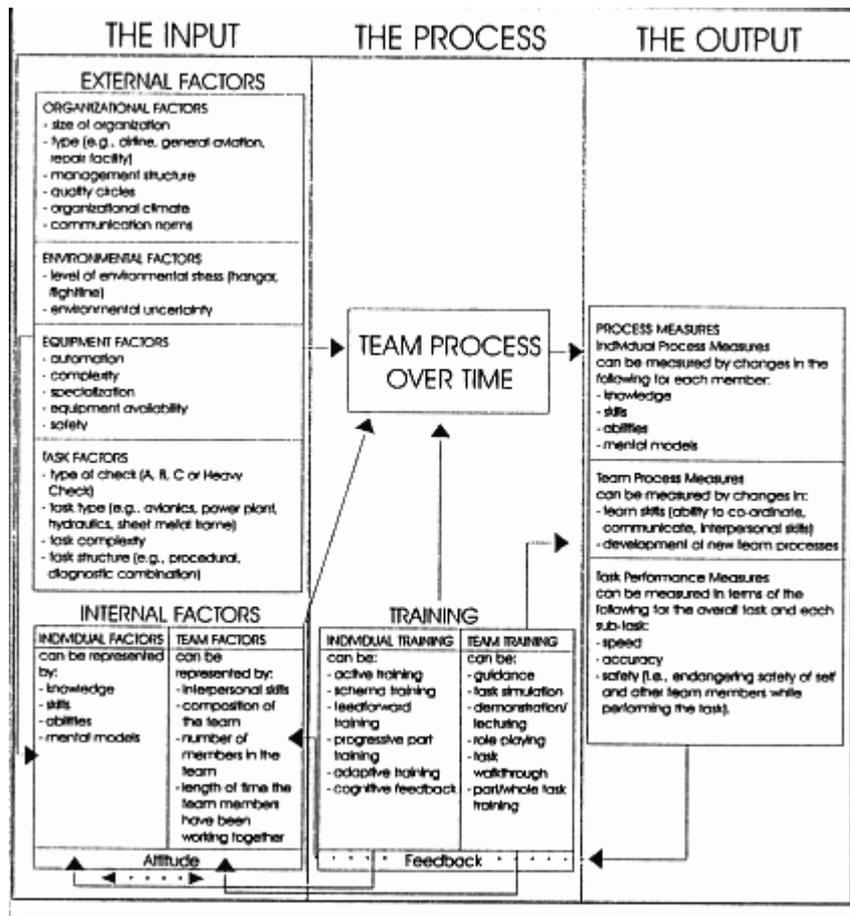


Figure 11.1 A Modified TEAM Effectiveness Model

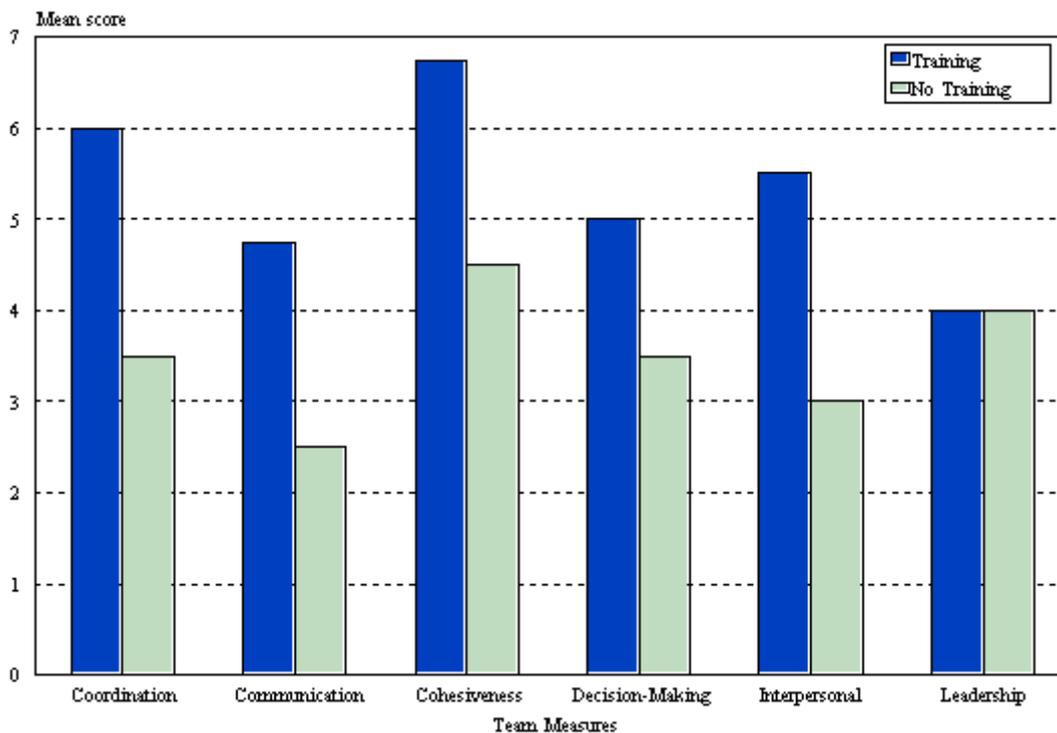
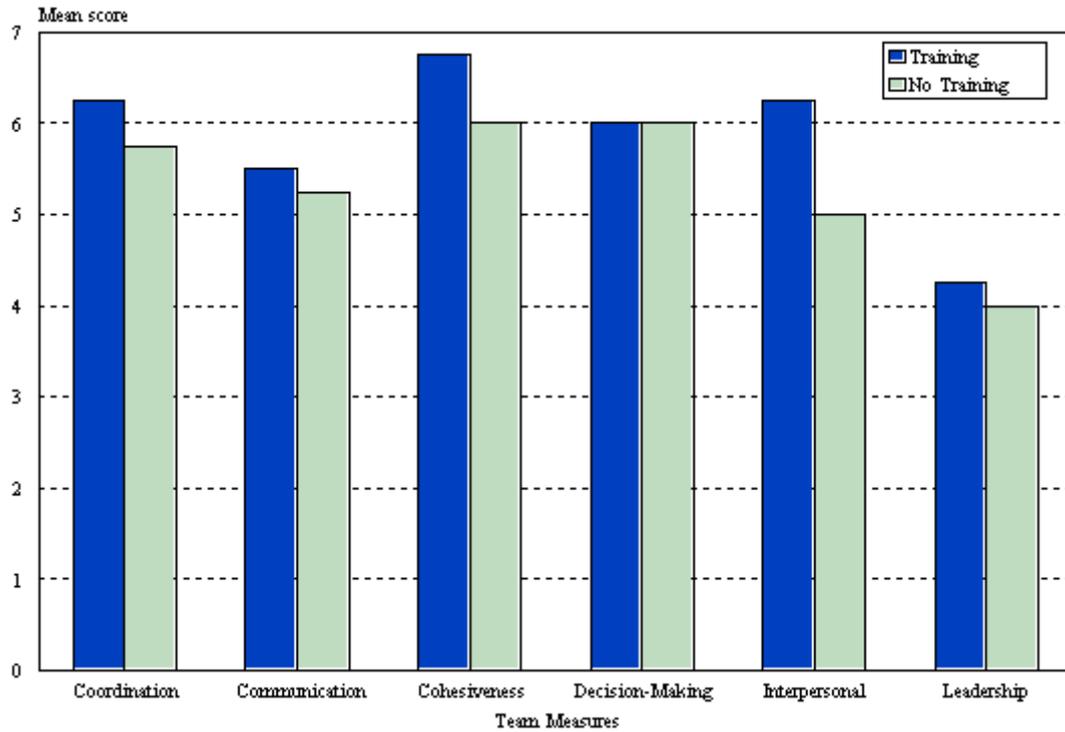
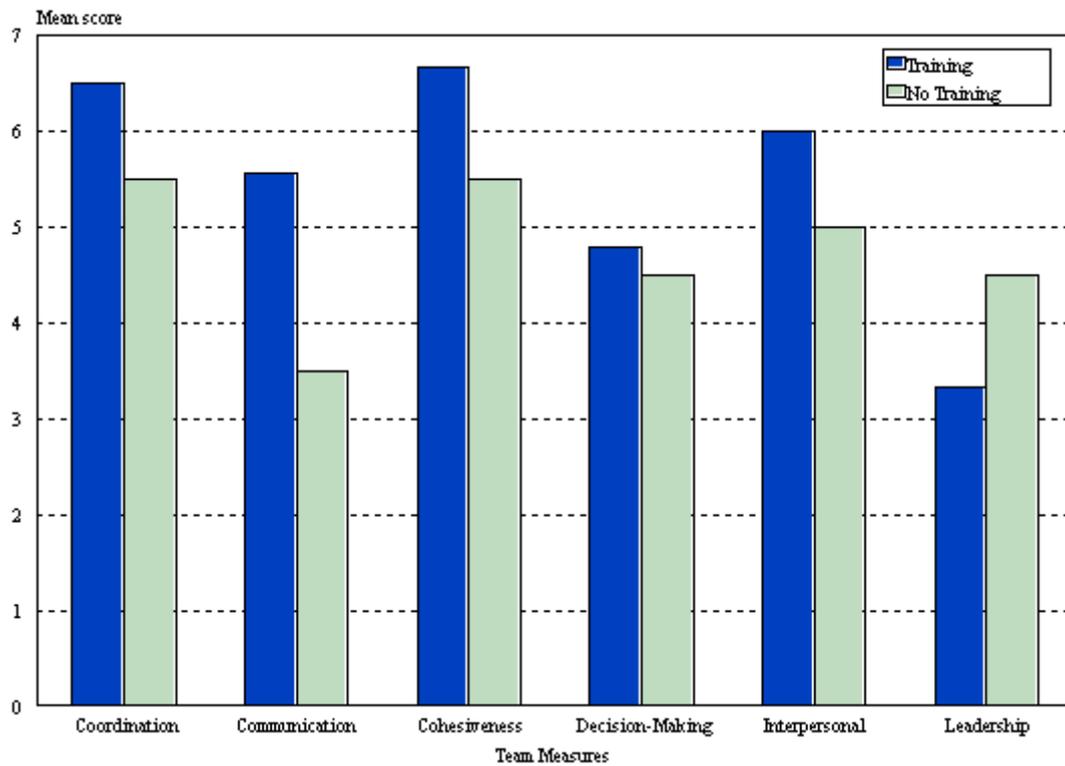


Figure 11.2 Evaluation of Team Performance Measures by Instructor - Engine Removal



**Figure 11.3 Evaluation of Team Performance Measures by Instructor - Engine Installation**



**Figure 11.4 Self Evaluation - Engine Removal**

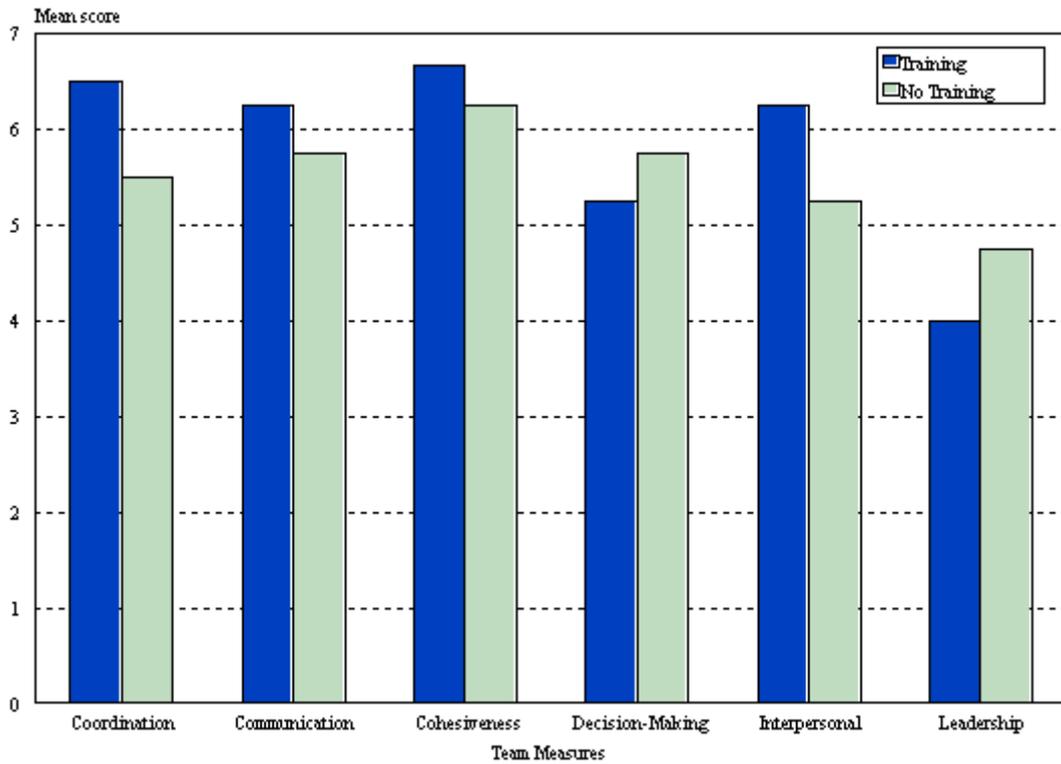


Figure 11.5 Self Evaluation - Engine Installation

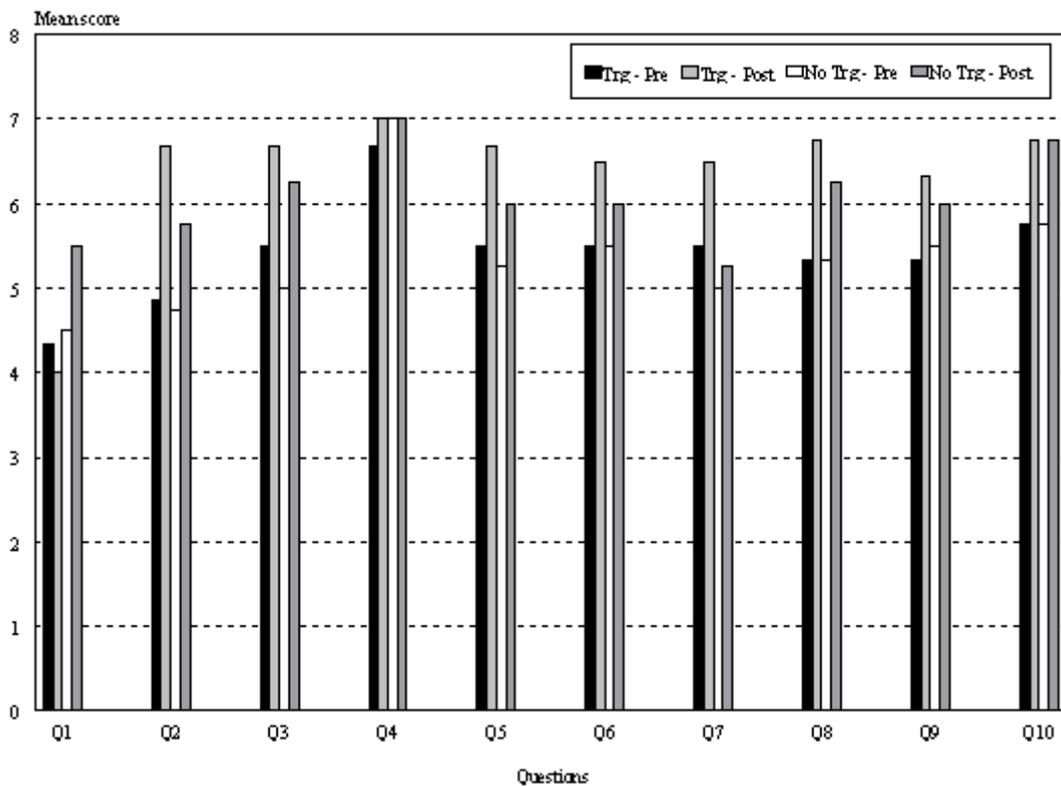


Figure 11.6 Pre and Post Training Data

Table 11.1 Team Skills

**Team Skills    Description**

- 1. Coordination** This refers to the team's ability to organize available resources and activities so as to accomplish the goal within the temporal constraints.
- 2. Communication** The process by which the team members clearly and accurately exchange information, using established procedures and language. It also encompasses the team members' ability to receive and provide constructive feedback on the performance of other team member(s) so as to help achieve the team goal.
- 3. Cohesiveness** This refers to the process by which all members of the team develop compatible models of the system and work together as one unit.
- 4. Decision-Making** This refers to the process by which teams can use judgement, analytical technique, and consensus methods to arrive at decisions by pooling together information and resources.
- 5. Interpersonal** This refers to team members' abilities to employ cooperative behavior to resolve interpersonal problems and optimize member interactions.
- 6. Leadership** This refers to the ability to assign, plan, organize, and motivate members to accomplish the goal.
- 7. Attitude**

**Table 11.2** Task Decomposition by Phases

## **ENGINE REMOVAL      ENGINE INSTALLATION**

- |  |  |
|--|--|
| <ol style="list-style-type: none"> <li><b>1. External Preparation</b></li> <li>a) Set up tail stand</li> <li>b) Disconnect electric power</li> <li>c) Remove top cowling</li> <li>d) Disconnect actuator</li> <li>e) Remove bottom cowling</li> </ol>  | <ol style="list-style-type: none"> <li><b>1. Engine Installation</b></li> <li>a) Install Engine</li> <li>b) Connect top V-brace</li> <li>c) Connect lower engine mounts</li> <li>d) Put bulhead bolts</li> <li>e) Unmount sling and hoist from engine</li> </ol> |
| <ol style="list-style-type: none"> <li><b>2. Engine Preparation</b></li> <li>a) Remove hoses and fittings</li> <li>b) Disconnect electrical leads</li> <li>c) Disconnect engine controls</li> <li>d) Drain oil</li> <li>e) Remove propeller</li> </ol> | <ol style="list-style-type: none"> <li><b>2. Engine Preparation</b></li> <li>a) Install propeller</li> <li>b) Fill oil</li> <li>c) Connect engine controls</li> <li>d) Connect electrical leads</li> <li>e) Put back hoses and fittings</li> </ol>               |
| <ol style="list-style-type: none"> <li><b>3. Engine Extraction</b></li> <li>a) Mount sling and hoist on engine</li> <li>b) Remove bulkhead bolts</li> <li>c) Disconnect lower engine</li> </ol>  | <ol style="list-style-type: none"> <li><b>3. External Preparation</b></li> <li>a) Put back bottom cowling</li> <li>b) Connect actuator</li> <li>c) Put back top cowling</li> <li>d) Connect electric power</li> </ol>  |

- mounts e) Remove tail stand
- d) Disconnect top V-brace
- e) Extract Engine

**Table 11.3** Demographics Form

### DEMOGRAPHICS FORM

The following information will remain confidential and is for research purposes only. Each team member should fill in all questions carefully and completely.

1. Have you attended a technical or vocational school other than this school?

Yes \_\_\_\_\_ No \_\_\_\_\_

2. If you answered yes to question 1, what type of technical training did you receive?

---



---

3. Have you ever worked in a team environment prior to this class?

Yes \_\_\_\_\_ No \_\_\_\_\_ Not Sure \_\_\_\_\_

4. If you answered yes to question 3, where did you work as a team member?

School \_\_\_\_\_ Work \_\_\_\_\_ Other \_\_\_\_\_

4 (a). What kind of work were you involved in as a team member?

---

5. Have you ever been fully employed prior to attending this school?

Yes \_\_\_\_\_ No \_\_\_\_\_

6. What kind of work did you do?

---



---

7. Have you ever had any team training before?

Yes \_\_\_\_\_ No \_\_\_\_\_

8. What skills did you learn?

9. Sex: Male \_\_\_\_\_ Female \_\_\_\_\_

10. Age: 17-20 \_\_\_\_\_ 21-30 \_\_\_\_\_ 31-40 \_\_\_\_\_ 41-50 \_\_\_\_\_ 51-60  
 \_\_\_\_\_ 61+ \_\_\_\_\_

**Table 11.4 Tool Description**

**STUDENT TOOL LIST - REQUIRED TOOLS**

**1. Tool box 6. Socket Set 1/4" Drive**

No larger than 20 inches high X 20 inches long. (No 5/32" Regular 6 pt  
 Rollaways) 3/16"  
 7/32"

**2. Chain and lock** 1/4"  
 9/32"

**3. Open-End Wrenches** 5/16"

1/4 x 5/16" 11/32"  
 3/8 x 7/16" 3/8"  
 1/2 x 9/16" 7/16"  
 9/16 x 5/8" 1/2"  
 5/8 x 3/4" 1/4" Deep 6 pt  
 11/16 x 13/16" 5/16"  
 3/4 x 7/8" 3/8"  
 15/16 x 1" 7/16"  
 1/2"

**4. Box-End Wrenches** Ratchet

1/4 x 5/16" Spinner Handle  
 3/8 x 7/16" Ext. 1 1/2"  
 1/2 x 9/16" Ext. 3"  
 9/16 x 5/8" Universal Joint  
 11/16 x 13/16"

3/4 x 7/8" **7. Screw Drivers**

15/16 x 1" Set of ten -  
 Range of Slotted and Phillips

**5. Socket Set 3/8" Drive** with a stubby of each.

3/8" Regular 12 pt

7/16" **8. Punch**

1/2" Deep 6 pt Pin Punch  
 9/16" 1/16 - 1/8"

5/8" Center Punch  
 11/16" 3/8"  
 3/4" Prick Punch  
 13/16" 3/8"  
 15/8" Plug Line-Up Tools  
 Ratchet 3/16 x 9 & 5/32 x 7"  
 3" Ext.  
 Case **9. Allen Wrenches**  
 6" Ext. Long  
 7/8" Deep Spark Plug Socket 5/64"  
 Universal Joint 3/32"  
 7/64"  
 1/8"  
 9/64"  
 5/32"  
 3/16"  
 7/32"  
 1/4"

## 10. Adjustable Wrenches - 10" **OPTIONAL TOOLS**

- 11. Measuring Tape 12 ft.**    **1. Cold Chisels**  
 1/4, 3/8, 1/2, 3/4"  
**12. Hammer, Ball Peen 8 oz.**  
**2. Allen Wrenches**  
**13. Hammer, Plastic Tip**    Short  
 .050"  
**14. Flash Light 2 Cell**    1/16"  
 5/64"  
**15. Pliers, Common 8"**    3/32"  
 7/64"  
**16. Pliers, Diagonal 7"**    9/64"  
**17. Pliers, Longnose 8"**    **3. Adjustable Wrenches - 6"**  
**18. Pliers, Duckbill**    **4. Machinist Square**  
**19. Pocket Knife 4"**    **5. Hacksaw**  
**20. Sheet Metal Snips**    **6. Hacksaw blades**  
 Left  
 Right    **7. Pliers Arc Joint 9"**  
**21. 10X Magnifying Glass**    **8. Socket Set 1/2" Drive**  
 Socket Regular 12 pt  
**22. File Set - 8" or larger**    7/16"  
 1 - Bastard    1/2"  
 1 - Round    9/16"  
 1 - Half Round    5/8"  
 1 - Triangular    3/4"  
                     11/16"  
**23. File Handles**    13/16"  
                     7/8"  
**24. File Card**    15/16"

- 1"
- 25. 1 - Extension Type Inspector Mirror** Deep 12 pt  
1/2" Ext. 6"
- 26. 1 - Mechanical Finger, 10 - 14 inch** 9/16" Ext. 3"  
5/8"
- 27. 1 - Retrieving Magnet, 10 - 14 inch** 3/4"  
11/16"
- 28. 1 - Thickness Gage Set** 13/16"  
.002 - .035 or better 7/8"  
15/16"  
Ratchet  
Universal Joint

**Table 11.5** Team Exercise on Lost on the Moon

### Lost On The Moon Exercise

Your spaceship has just crashed-landed on the moon. You were scheduled to rendezvous with a mother ship 200 miles away on the lighted surface of the moon, but the rough landing has ruined your ship and destroyed all the equipment on board, except for the 15 items listed below.

Your crew's survival depends on reaching the mother ship, so you must choose the items based on their importance for survival. Place number one by the most important for survival. Place two by the second most important, and so on through number 15, the least important.

<b>Your Item</b>	<b>Your Ranking 1 to 15</b>	<b>NASA's Error Score 1 to 15</b>	<b>Team Ranking 1 to 15</b>	<b>Team Ranking Score</b>	<b>Error</b>
----------------------	-------------------------------------	---	-------------------------------------	-----------------------------------	--------------

Box of matches

Food concentrate

Fifty feet of nylon rope

Parachute silk

Solar-powered portable  
heating unit

Two .45 caliber pistols

One case of dehydrated milk

Two 100 pounds tanks of oxygen

Stellar map (of the moon's  
constellations)

Self-inflating life raft

Magnetic compass

Five gallons of water

Signal flares

First-aid kit containing injection needles

Solar-powered FM receiver -  
transmitter

### **YOUR TOTAL ERROR SCORE**

**Table 11.5 (continued...)**

#### **Lost On The Moon - Team Rules**

1. Avoid arguing for your own ranking. Present your position as lucidly and logically as possible, but listen to the other members' reactions and consider them carefully before you press your point.
2. Do not assume that someone must win and someone must lose when discussion reaches a stalemate. Instead, look for the next-most-acceptable alternative for all parties.
3. Do not change your mind simply to avoid conflict and to reach agreement and harmony. When agreement seems to come too quickly and easily, be suspicious. Explore the reasons and be sure everyone accepts the solution for basically similar or complementary reasons.
4. Avoid conflict-reducing techniques such as majority vote, averages, coin-flips and bargaining. When a dissenting member finally agrees, don't feel that he or she must be rewarded by having his or her own way on some later point.
5. Differences of opinion are natural and expected. Seek them out and try to involve everyone in the decision process. Disagreements can help the group's decision because with a wide range of information and opinions, there is a greater chance that the group will hit upon more adequate solutions.

#### **Lost On the Moon - Scoring**

	Team 1	Team 2	Team 3	Team 4
<b>Total Error Points</b>	_____	_____	_____	_____

Error points are absolute difference between your rank and NASA's (disregarding plus or minus signs)

0 - 25 excellent

26 - 32 good

33 - 45 average

46 - 55 fair

56 - 70 poor

71 - 112 very poor (suggest possible faking or use of earth bound logic)

**Table 11.5 (continued...) Lost On The Moon - Answers**

Item	NASA's Reasoning	NASA	Team	Error	Team	Error	Team	Error	Team 4	Error
	Rank	1	Points	2	Points	3	Points	Points		
	Rank	Rank	Rank	Rank						
Box of matches sustain flame: worthless	No Oxygen on moon to		15							
Food concentrate energy requirements	Efficient means of supplying		4							
Fifty feet of nylon rope injured together	Useful in scaling cliffs, tying		6							
Parachute silk	Protection from sun's rays		8							
Solar-powered portable heating units	Not needed unless on dark		13							
Two .45 caliber pistols propulsion	Possible means of self		11							
One case of dehydrated Pet milk concentrate	Bulkier duplication of food		12							
Two 100 pound tanks of oxygen	Most pressing survival need		1							
Stellar map (of the moon's constellations)	Primary means of navigation		3							
Self-inflating life raft may be used for propulsion	CO2 bottle in military raft		9							
Magnetic compass not polarized: worthless	Magnetic field on moon is		14							
Five gallons of water liquid loss on lighted side	Replacement for tremendous		2							
Signal flares ship is sighted	Distress signal when mother		10							
First-aid kit containing injection needles aperture in NASA space suit	Needles for vitamins, medicines, etc. Will fit		7							
Solar-powered FM receiver transmitter	For communication with mother ship, but requires line of sight (short range)		5							

**Table 11.6 Team Training Program****Session 1 - Basics of Teamwork****Goals**

Provide trainees an understanding of teams, need for teamwork, introduction to team concepts, and an outline of future sessions

**Major Elements**

- Initial attitude survey
- Why there is a need for teams
- Establish the need for consistency and clarity in goals: team goals and individual goals
- Goals of team building
- Team work exercise
- Overview of future sessions

**Session 2: Decision Making****Goals**

Introduce trainees to scientific approach to decision-making

**Major Elements**

- expose trainees to different tools for decision-making
- identify the merits and demerits of the tools
- use of decision-making tools within the aircraft/maintenance environment context (which tool? when to use? How to use?)
- exercise involving different tools
- decision-making by consensus

**Session 3: Group Dynamics 1: Communication and Interpersonal****Goals**

To provide each trainee with an understanding of the essential elements of communication

Identify steps to minimize interpersonal problems

**Major elements**

- establish need for oral communication and written communication
- principles of good communication (format, terminology, direction, when, how, how much/little)
- examples of appropriate forms of communications (written and oral) within the aircraft maintenance environment
- importance of providing team members with positive and negative feedback and how to receive feedback (When to give? How it works? How to receive? ...)
- exercise involving correct and incorrect communication within the aircraft maintenance

environment

**Table 11.6 (continued...) Team Training Program**

**Session 4: Group Dynamics 2: Coordination and Cohesiveness**

**Goals**

To train on the importance of coordination and cohesiveness in achieving the team goal

**Major Elements**

- Methods to eliminate barriers and behavioral problems
- Demonstrate the importance of coordination as it relates to aircraft maintenance and inspection
- provide examples of good and bad coordination and demonstrate the effects on task performance
- Identify every member's role and explain interdependency
- Help establish accurate expectations of the contributions of other team members to overall performance

**Session 5: Team Activity**

**Goals**

To demonstrate how team skills can improve team performance for an aircraft inspection/maintenance task

**Major Elements**

- construct examples of team activity
- illustrate importance of different team skills in accomplishing the activity
- role play
- provide feedback to teams

**Table 11.7 INSTRUCTORS' INTERVIEW PERFORMANCE MEASUREMENTS**

The purpose of this questionnaire is to evaluate the effectiveness of team training on team performance. The facilitator is in a position to observe any improvements or lack of improvements in team performance, so please take time to consider each statement. All responses will be kept confidential.

Rate each statement on a scale of 1 - 7

**Number of times,**

**Lowest, Poor, Never, etc.**                      **Neutral**                      **Highest, Best, Always, Very, etc.**

1   2   3   4   5   6   7

Team 1   Team 2   Team 3   Team 4

1. The team members worked well together.
2. The team resolved conflicts effectively.
3. All members of the team participated in the decision-making process
4. The team members discussed new ways to tackle the task.
5. The team was effective in establishing ground rules.
6. One person dominated the team.
7. There was at least one person who was disruptive.
8. There was at least one person who did not participate in team discussions.
9. One member took charge of assigning the tasks and coordinating activities of other team members.
10. Team members provided each other with performance feedback
11. The team members worked cohesively.
12. Team members responded well to team training.
13. The team members follow the agenda (accomplished the objectives).
14. There was a noticeable improvement due to team training.

**Table 11.8 POST SESSION INTERVIEW**

Please rate the following statements on a scale of 1 - 7 by circling the response that best fits your opinion concerning the statement. All response will be kept confidential.

**Definitely Not**

**Definitely**

1. The team followed the agenda for the session.                      1   2   3   4   5   6   7

2. You were satisfied with the level of

- participation by team members. 1 2 3 4 5 6 7
3. Everyone contributed and was involved in team decisions. 1 2 3 4 5 6 7
4. You had a good attitude about your work and the task. 1 2 3 4 5 6 7
5. Team members allowed personality conflicts to interfere with work. 1 2 3 4 5 6 7
6. You were satisfied with the level of the teams' achievement towards the established goal. 1 2 3 4 5 6 7
7. Team members were able to settle conflicts effectively among themselves 1 2 3 4 5 6 7
8. You feel the teams' performance was very good. 1 2 3 4 5 6 7
9. You feel the final result of the task was very good. 1 2 3 4 5 6 7
10. Your opinion was considered. 1 2 3 4 5 6 7
11. One member took charge of assigning the tasks and coordinating the activities of other team members. 1 2 3 4 5 6 7
12. Team members were aware of each others responsibilities. 1 2 3 4 5 6 7
13. You were satisfied with the material used for team training. 1 2 3 4 5 6 7
14. You were satisfied with the material used for technical training. 1 2 3 4 5 6 7
15. If provided with another opportunity, you would want to participate in a team activity. 1 2 3 4 5 6 7
16. If provided with another opportunity, you would participate in a team activity

with the same group.            1   2   3   4   5   6   7

**Table 11.9 PRE-TRAINING INTERVIEW**

Please circle the response that best reflects your opinion of each statement. All responses will be kept confidential.

	<b>Strongly Disagree</b>	<b>Neutral</b>	<b>Strongly Agree</b>						
1. I believe teamwork is the best way to accomplish work tasks in all situations.		1	2	3	4	5	6	7	
2. In team environments, it is important to follow an agenda.		1	2	3	4	5	6	7	
3. All team members should contribute to team decisions.		1	2	3	4	5	6	7	
4. If one team member doesn't understand, other team members should help him or her.		1	2	3	4	5	6	7	
5. Team leaders should keep the team on track to accomplish goals.		1	2	3	4	5	6	7	
6. Team decisions are superior to individual decisions.		1	2	3	4	5	6	7	
7. All tasks are not suited for team environments.		1	2	3	4	5	6	7	
8. I am comfortable participating in team decisions.		1	2	3	4	5	6	7	
9. The success of the team is important to each individual.		1	2	3	4	5	6	7	

10. Training improves team performance.            1   2   3   4   5   6   7

**Table 11.10** POST-TRAINING INTERVIEW

Please circle the response that best reflects your opinion of each statement. All responses will be kept confidential.

- |  | <b>Strongly<br/>Disagree</b> |   | <b>Neutral</b> |   | <b>Strongly<br/>Agree</b> |   |   |   |  |
|--|------------------------------|---|----------------|---|---------------------------|---|---|---|--|
| 1. I believe teamwork is the best way to accomplish work tasks in all situations.    |                              | 1 | 2              | 3 | 4                         | 5 | 6 | 7 |  |
| 2. In team environments, it is important to follow an agenda.                        |                              | 1 | 2              | 3 | 4                         | 5 | 6 | 7 |  |
| 3. All team members should contribute to team decisions.                             |                              | 1 | 2              | 3 | 4                         | 5 | 6 | 7 |  |
| 4. If one team member doesn't understand, other team members should help him or her. |                              | 1 | 2              | 3 | 4                         | 5 | 6 | 7 |  |
| 5. Team leaders should keep the team on track to accomplish goals.                   |                              | 1 | 2              | 3 | 4                         | 5 | 6 | 7 |  |
| 6. Team decisions are superior to individual decisions.                              |                              | 1 | 2              | 3 | 4                         | 5 | 6 | 7 |  |
| 7. All tasks are not suited for team environments.                                   |                              | 1 | 2              | 3 | 4                         | 5 | 6 | 7 |  |
| 8. I am comfortable participating in team decisions.                                 |                              | 1 | 2              | 3 | 4                         | 5 | 6 | 7 |  |

9. The success of the team is important  
to each individual.            1   2   3   4   5   6   7
10. Training improves team  
performance.                    1   2   3   4   5   6   7

**Table 11.11** Data Collection Instrument on Team Performance

1. Total time to complete the entire task.  
-----  
1 (a). Total time to complete the External Preparation  
Phase.  
-----  
1 (b). Total time to complete the Engine Preparation  
Phase.  
-----  
1 (c). Total time to complete the Engine Extraction Phase.
2. Total number of mistakes made by the team while  
completing the entire task.  
-----  
2 (a). Total number of mistakes made by the team during  
External Preparation Phase.  
-----  
2 (b). Total number of mistakes made by the team during  
Engine Preparation Phase.  
-----  
2 (c). Total number of mistakes made by the team during  
Engine Extraction Phase.
3. Number of times the instructor had to point out the  
mistakes being made and correct them during the entire  
task.  
-----  
3 (a). Number of times the instructor had to point out the  
mistakes being made and correct them during the External  
Preparation Phase.  
-----  
3 (b). Number of times the instructor had to point out the  
mistakes being made and correct them during the Engine  
Preparation Phase.  
-----  
3 (c). Number of times the instructor had to point out the  
mistakes being made and correct them during the Engine  
Extraction Phase.
4. Number of times team did not follow correct procedures  
during the entire task.  
-----  
4 (a). Number of times team did not follow correct procedures  
during the External Preparation Phase.  
-----

4 (b). Number of times team did not follow correct procedures during the Engine Preparation Phase.

-----

4 (c). Number of times team did not follow correct procedures during the Engine Extraction Phase.

### Table 11.12 Summary of Task Performance

#### Engine Removal (averaged over 4 teams)

Task Performance Measures	Training Group	Control Group
1. Total time taken to complete the task of engine removal (hrs./mins.)	6 hrs 10 mins.	7hrs 38 mins.
2. Number of mistakes made by the team during engine removal	3	9
3. Number of times the instructor had to point out the mistakes being made and correct them during the task of engine removal	3	6
4. Number of times the team did not follow correct procedures during the task of engine removal	1	5
5. Number of times safety of fellow team members was endangered during the task of engine removal	0	0
6. Number of times safety procedures were not followed during the task of engine removal	3	1

#### Engine Installation (averaged over 4 teams)

Task Performance Measures	Training Group	Control Group
1. Total time taken to complete the task of engine installation (hrs./mins.)	13 hrs 32 mins.	14 hrs 15 mins
2. Total number of mistakes made by the team during engine installation	1	5
3. Number of times the instructor had to point out the mistakes being made and correct them during the task of engine installation	2	6
4. Number of times the team did not follow correct procedures during the task of engine installation	2	4
5. Number of times safety of fellow team members was endangered during the task of engine installation	0	0
6. Number of times safety procedures were not followed during the task of engine installation	1	2

### Table 11.13 AMP School Curriculum

#### Year 1    Year 2

#### Fall Semester    Fall Semester

General Regulations	Bonded Structures & Welding
Aircraft Drawings	Utility & Warning Systems
Ground Handling and Servicing	Landing Gear Systems
Materials and Corrosion Control	Airframe Inspection

Assembly and Rigging Propellers and Components  
 Algebra, Geometry, and Trigonometry I Professional Communications

**Spring Semester Spring Semester**

Basic Aircraft Electricity Lubricating Systems  
 Wood, Dope, Fabric, and Finishes Ignition Systems  
 Sheet Metal Layout and Repair Turbine Engine Overhaul  
 Reciprocating Engine Overhaul Engine Inspection  
 Conceptual Physics I Engine Electrical, Instrument, and  
 Fire Protection Elective

**Summer**

Aircraft Environmental Systems **Summer**  
 Hydraulics and Pneumatic Systems Powerplant Fuel Systems  
 Aircraft Electric Systems Induction Cooling and Exhaust  
 Aircraft Fuel Systems Technology and Culture Elective  
 Personal/Interpersonal Psychology

**Table 11.14** Team Projects

**Year 1**

Course: Ground Handling and Services

Team project title: Aircraft towing

Number of team members: 4

Description: Given an aircraft and aircraft towing equipment, the team will tow aircraft from the hangar to a preselected location within the areas marked for the landing gear. All the movement of aircraft will be conducted in a highly precautious and coordinated manner. Team members will have to follow standard operating procedures.

Team project title: Aircraft operation

Number of members in a team: 3

Description: Given manufacturers' operating instructions, team will locate, select, connect, and operate ground support equipment. Team will start and operate engine through normal operating range and perform shut down procedures.

Course: Assembly and Rigging

Team project title: Installing flight control

Number of members in a team: 4

Description: Team members will identify appropriate service manuals, tools, equipment, and forms. Team members will assign roles to remove, inspect, repair, and reinstall one flight control and make required maintenance record entries. All work performed needs to meet manufacturers'

specifications. Team members will play the role of inspector, buy-back inspector, and maintenance personnel.

Team project: Installing vertical stabilizer

Number of members in team: 4

Description: Team members will identify appropriate service manuals, tools, equipment, and forms. Team members will assign roles to remove, inspect, repair, and reinstall vertical stabilizer and make required maintenance record entries. All work performed needs to meet manufacturers' specifications. Team members will play the role of inspector, buy-back inspector, and maintenance personnel.

Team project: Aircraft control rigging (different sub-systems)

Number of members in team: 3

Description: Given an aircraft with cable operated flight control system, service manuals, tools, and equipment. The team will have to coordinate work and assign roles to inspect the system for proper rigging, record the discrepancy, and make repairs, rig the flight controls, and record the work. The members will play the role of a inspection and maintenance crew on a rigging check.

#### **Table 11.14** (continued...) Team Projects

##### **Year 2**

##### Course: Utility and Warning Systems

Team project title: Position Indicating and Warning Systems

Number of members in a team: 4

Description: Given an aircraft with retractable landing gear and position indicating and warning systems, ground support equipment, and the manufacturers' maintenance and service instructions, the team will have members with assigned roles of an inspector, buy-back inspector, and maintenance personnel. The team will first perform an operational check of the landing gear, inspect components of the position indicating and warning system (inspectors), troubleshoot and repair malfunctions (maintenance crew), and ensure that the work meets standards (buy-back inspector).

##### Course: Landing Gear Systems

Team project title: Aircraft Jacking

Number of members in a team: 4

Description: Given an aircraft with operational retractable landing gear, manufacturers' service manuals; other information, and ground support equipment, the team will have to assign roles and coordinate work to accomplish the following: jack the aircraft, check, inspect, repair, and service the landing gear so that work is accomplished within the allowed time frame. The team will have to ensure that the operation of the systems and the manufacturers' adjustment procedures are followed precisely and that the system meets "return-to-service" standards.

##### Course: Airframe Inspection

**Team Project: Airframe Inspection and Maintenance**

Number of members in a team: 4

Description: Given an operational aircraft ground support equipment and manufacturers' service manuals, the team will have members with assigned roles of an inspector, buy-back inspector, and maintenance personnel. The inspector (first team member) will perform an annual inspection of the aircraft, record conditions at the time of inspection, and make the appropriate aircraft record entries to communicate information to other members of the team (maintenance crew consisting of 2 team members). Team members responsible for maintenance activities will conduct maintenance and have it inspected by another inspector (fourth member of the team) to ensure that the maintenance work meets standards.

**Course: Turbine Engine Overhaul****Team Project: Engine Overhaul**

Number of members: 4

Description: Given a turbojet or turboprop engine, manufacturers' maintenance manuals, special tools, and shop equipment, working as a team, the team will disassemble, clean, inspect, identify repairs, and reassemble both cold and hot sections of the engine within a specified time frame. All activities and practices will be performed in accordance with manufacturers' maintenance instructions.

**Team Project: Engine Removal and Installation**

Number of members: 4

**Table 11.14** (continued...) Team Projects

Description: Given an aircraft with an operational turbojet engine, manufacturers' maintenance manuals, and engine removal and installation equipment, working as a team, the team will perform the engine removal and reinstallation procedures to meet manufacturers' standards and within the allocated time frame.

**Course: Reciprocating Engine Overhaul****Team Project: Engine Overhaul**

Number of members: 4

Description: Given a reciprocating engine, manufacturers' maintenance manuals, and special tools and shop equipment, working as a team, the team will disassemble, clean, inspect, identify repairs, and reassemble the engine within a specified time frame. All activities and practices will be performed in accordance with manufacturers' maintenance instructions.

**Team Project: Engine Removal and Installation**

Number of members: 4

Description: Given an aircraft with an operational reciprocating engine, manufacturers' maintenance manuals, and engine removal and installation equipment, working as a team, the team will perform the engine removal and reinstallation procedures to meet manufacturers' standards in the allocated time frame.

# Chapter 12

## Training and Certification in the Aircraft Maintenance Industry

### *Technician Resources for the Twenty-First Century*

*Ray Goldsby  
HKS & A, Inc.*

#### 12.0 INTRODUCTION

The Federal Aviation Administration (FAA) is committed to exploring ways of restructuring the regulatory process as it pertains to training, qualification and certification of advanced skills (specialties) in the aviation maintenance industry. They recognize a need for a flexible, forward looking and more efficient system, geared to the rapid technological and industry changes taking place as we approach the 21st century. This project will evaluate the issues, analyze pertinent information and present a plan for development of such a system. Included will be an evaluation of both US and international aviation maintenance technical training and qualification standards, and certification systems in other industries that require skill level standards.

Pertinent information from other studies, such as Pilot and Aviation Maintenance Technician Blue Ribbon Panel, Aviation Maintenance Technician Job Task Analysis, and Human Resources in the Canadian Aircraft Maintenance Industry, will also be included.

The system will be based on evaluation of other industries where individuals are certified to performance standards that are approved and kept current by recognized industry professional organizations. Candidates for certification are required to complete specific training and competency testing approved by the appropriate regulatory agency (the FAA, for purposes of this project), based upon the specific industry group's standards. Examples of this are found in the certification of medical technologists, electronic technicians, structural welders, and various other critical safety intensive professions.

The initial focus of this study is to research alternative ways to develop industry input for training and certification standards for advanced aircraft maintenance skills. This project will provide a basis for an implementation plan, development of the standards approval process and the selection of technical agencies that can validate, issue, and maintain these standards. The possibility of forming a national aviation industry forum that would provide information for industry standards development groups and advise the FAA will also be analyzed.

This effort is an extension of the regulatory actions work being done by the Federal Aviation Administration on revising rules that specify the training and certification of aircraft maintenance personnel (Federal Air Regulations Parts 147 and 65). Included in the final report will be an evaluation of the US system of certification for Aviation Maintenance Technicians (AMT) and Aviation Repair Specialists (ARS).

The project will be accomplished in two phases. This first phase, that began in July of 1994 and completes at the end of March 1995, will include investigation, information and data gathering. The second phase, April through December of 1995, will focus on development of proposals and the final report.

#### 12.1 BACKGROUND

There is increasing evidence that validates FAA and Industry concern that the current background

information and industry input into the FAA system for training, qualification and certification of aviation maintenance personnel may be insufficient. There is also concern that the FAA certification process is not geared for rapid revision and technical updates. Regulator actions have not kept pace with changing aviation technology and the industry's maintenance skill requirements. These concerns are focused on persons certified as Airframe and Powerplant Mechanics (A&P), and Repairmen, as prescribed in FAR Part 65. There must be sufficient input to ensure that aviation maintenance personnel will continue to meet the current and future needs of continuing air worthiness. It is necessary to explore means that will enhance the role of the industry's technical leadership working together with the FAA to keep the system current.

In November 1989, a joint industry / FAA part 65 review group was formed to evaluate and review certification requirements for mechanics and repairmen. The review group's objective was to develop and present a unified position on recommended changes to part 65. The group was composed of representatives from several aviation associations and was coordinated by the Professional Aviation Maintenance Association (PAMA). FAA interests were represented by the Aircraft Maintenance Division (AFS-300) of the FAA.

After conducting a series of panel discussions throughout the United States, the Industry / FAA Part 65 Review Group Working Paper was published in January of 1991. This paper presented the issues on which there was general agreement and those issues that the group believed would require further discussion.

During 1991, the FAA also conducted both a historical review of part 65, subparts D and E, and a survey of FAA regional offices on the certification of mechanics, holders of inspection authorizations, and repairmen. Results of both the historical review and the regional office survey showed clear support for a full review and update of part 65.

Another major reason for review and revision of the Aircraft Mechanic and Repairman regulation is based upon the level of professionalism in these career fields. The Pilot and Aviation Maintenance Technician Blue Ribbon Panel Report pointed out that the US. Department of Labor Dictionary of Occupational Titles lists aircraft mechanics and repairers as semi-skilled. The panel recommended that this be reviewed. The FAA believes it is necessary to increase the level of professionalism within these occupations and have Aviation Maintenance Technicians and Aviation Repair Specialists recognized as highly skilled.

## 12.2 AVIATION INDUSTRY DYNAMICS AND REGULATORY CHANGE

The Pilot & Aviation Maintenance Technician Blue Ribbon Panel Report (Aug. 1993) explains: *The majority of new-hire AMTs come from FAA-certificated AMT schools, where they have 15 to 18 months of structured training in a variety of subjects. Although the FAA recently revised the curriculum requirements for these schools, the new curriculum remains broad-based to fit a variety of technical disciplines, and it may not give AMTs the skills and competencies needed to maintain the increasingly sophisticated transport category aircraft. Therefore, new-hire AMTs working on newer aircraft will have to master skills that many AMT schools do not offer, if they are to become productive members of air transportation teams.*

*Thus, the industry will face a problem with AMTs similar to the problem with pilots: A decreasing supply of qualified AMTs, combined with increasing skill and experience requirements, will yield a deficit not in the number of minimally qualified individuals but in the number with the necessary skills and experience. This gap will have to be bridged by additional focused and specialized training. Europe and Asia are effectively addressing the future skills shortages and becoming stronger competitors, causing dramatic increases in the amount of U. S. work done in foreign repair stations.*

The aviation industry will continue moderate growth well into the next century. At the same time the forces of competition in the de-regulated air transportation environment mandate lowering prices to

the consumer, with a resulting focus on lowering operating costs and the need to optimize maintenance processes and practices. This competition has also spurred the development of improved aircraft technology and operational efficiency. Today's aircraft are significantly more sophisticated, from both a materials and systems standpoint, than those built and certified when the current maintenance regulations were developed.

The industry finds itself in a challenging situation. Significant changes are being made by air carriers with respect to internal maintenance programs and the contracting of second and third party agencies to maintain and modify their fleets. In the past most carriers completed a majority of maintenance work in-house, but it is now often more efficient and cost effective for them to have major work and modifications accomplished by others. The numbers of aircraft that are owned by leasing companies, maintained by various agencies worldwide and moved from operator to operator, have dramatically increased. Along with the international aspects of movement of aircraft within different fleets and maintenance programs, is the dramatic increase in the number of foreign certified repair stations and maintenance work begin done "off shore." These factors, mixed with numerous technology changes, have increased the complexity of aircraft maintenance. All of this has created both FAA and industry concern.

The present maintenance regulatory system is cumbersome; it was not designed for rapid change. Changes due to new technology and the dynamics of the global business environment make it difficult for the rules that regulate training and qualification to keep pace. Finding methods that will allow for a more responsive regulatory system under the rules, while at the same time focusing on international harmonization, is essential.

### 12.3 THE AVIATION RULE MAKING ADVISORY COMMITTEE (ARAC) PROCESS

The ARAC was established (56 CFR 2190, January 22, 1991) to assist the FAA in the rulemaking process by providing input from outside the Federal Government on major regulatory issues affecting aviation safety. This process is designed to provide opportunity for those groups in the industry who are significantly affected by rulemaking to become involved in the process. Since affected parties are involved in the process the rules produced should be more complete, require less direct effort on the part of the FAA, have few elements of contention from the public when published and move rapidly from initial review to final effectivity.

The ARAC includes representatives of air carriers, manufacturers, general aviation, organized labor groups, universities, associations, airline passenger groups, and the general public. Formation of the ARAC has given the FAA additional opportunities to solicit information directly from all elements of the industry. There are several working groups under ARAC that meet to exchange ideas about proposed rules and existing rules that should be either revised or eliminated.

Formed initially in November 1989, as the Joint Industry / FAA Part 65 Review Group, the Aviation Rule Making Advisory Committee Working Group for FAR Part 65 (ARAC - 65) has been meeting officially since May 24, 1991. The working group is made up of representatives from aviation industry professional organizations, aviation training providers, air transport labor unions, industry representatives, and the general public. One of the major objectives of ARAC is to shorten the time it takes to revise regulations by involving all interested parties in the process. This working group is responsible for regulatory review and recommending changes to FAR Part 65, Certification of Airmen Other Than Flight Crew Members, specifically the portion regulating mechanics, mechanics holding inspection authorizations and repairmen. Their efforts have yielded significant changes and upgrades to FAR Part 65 which are scheduled to be released as a Notice of Proposed Rule Making (NPRM) in the winter of 1995 / 1996. Substantive recommended changes to Part 65 are outlined in Appendix 12-A.

If the process remains on schedule, the new rule (consolidated as FAR Part 66) may become effective in mid-1998. This means that the process to review FAR part 65 will have been in the

works for nine years. The process of evaluating and recommending changes to Federal Air Regulations remains long and cumbersome.

## 12.4 ARAC - 65 ACTION REGARDING ADVANCED OR SPECIAL CERTIFICATION

The ARAC - 65 working group has discussed and evaluated a significant number of issues regarding advanced certification. The group's consensus is that a new process needs to be developed and that the research project described herein is a necessary step toward reaching that objective. Suggested changes in the current Airframe and Powerplant, and Repairman Certificates reflect the complexity of today's technology, and represent a wide range of input toward the development of an advanced certification process. Since the members represent a large cross section of the industry, their views may be considered as a reasonable representation of the industry's thinking on this issue.

The Airframe and Powerplant Certificate (A&P) is based on a broadly focused 1900 hour minimum curriculum specified in FAR Part 147. The Airframe or Powerplant privileges of the certificated may be issued separately under the current rule. The certification under the new Part 66 rule will be titled Aviation Maintenance Technician (AMT), will include a common set of privileges and be issued only as a single certificate. Advanced certification will be provided with the addition of the Aviation Maintenance Technician - Transport (AMT-T) privilege. This certification will require an additional curriculum, approximately 600 hours above the 1900 hours required in the current rule, that is specific to the current technology of Part 25 (air transport fixed wing) and 29 (air transport rotor craft) certified aircraft, along with additional competency testing. Persons may select the level of certification for which they wish to qualify. An AMT-T, however, will be required to return transport category aircraft to service once the rule becomes final.

Through the creation of the AMT-T operators of aircraft certificated under FAR Parts 25 and 29 (commercial airplanes and helicopters) will be assured that the holder of an AMT-T certificate possesses the knowledge and skill to approve these aircraft for return to service (or "sign off" of a maintenance release). This will allow operators to employ aviation maintenance personnel who will more quickly meet the requirements of their operating environment without having to attend extensive operator-sponsored training programs before performing maintenance on transport aircraft. Operators would be able to focus their training on aircraft type, aircraft differences, modifications, and technology upgrade of transport aircraft. Aviation maintenance technician training schools (certified under FAR Part 147) would be able to focus on the fundamental concepts and basic skills of aviation maintenance. They would also have the option of providing the additional knowledge and skill required for AMT-T certification.

The Repairman Certificate is currently issued to an individual for a specific maintenance task(s), appliance or component repair / overhaul, for FAR Part 121 or 135 Operators under subpart J and L, Fixed Base Operators (FBO), or FAR part 145 Certified Repair Stations. They are also issued by the FAA to those individuals constructing amateur-built aircraft for their own non-commercial use. The Repairman Certificate process has been significantly revised under the new FAR Part 66.

The new certification will grant specific repair and maintenance privileges to Aviation Repair Specialists (ARS). The ARS will be issued in three categories, defined as follows:

1. ARS-I - May be issued by the FAA upon completion of an industry developed standards-based training curriculum and appropriate competency testing and / or validation to an individual. The individual who has earned such certification may only exercise these privileges while employed at a Certified Repair Station, Part 121 or 135 Operator. This provides limited portability for this level of certification. The skill areas where ARS-I certification will be granted are to be determined based on the outcome of this project, and the Job Task Analysis project being completed by Northwestern University's Transportation Research Center. Also included may be areas with current standards such as non-destructive inspection (NDI).

2. ARS-II - Issued as a replacement for today's Repairman Certificate and will be issued under similar regulations.
3. ARS-III - Issued by the FAA to amateur builders, producing "home built" aircraft for their own non-commercial use, as in the past.

## 12.5 Suggested Skill Areas for Advanced or Special Certification (ARS-I)

The working sessions of ARAC-65 generated presentations from various industry groups that stimulated discussion regarding advanced certification and appropriate skill areas. No firm decisions were made specifying what functional areas may be finally selected for advanced certification. It was concluded that there may eventually be new ARS-I categories beyond those listed below. The group agrees with the FAA that training, qualification, and certification will be based on nationally and internationally recognized standards developed by the aviation maintenance industry. The following skill areas have been selected as those that will be considered for advanced certification standards and ARS-I certification:

- Aircraft Electronics (Avionics)
- Composite Structural Repair
- Non-destructive Inspection
- Metal Structures Repair
- Balloon and Glider Repair

As rule making evaluation and change continues, there may be other skill areas identified and added to the list. There has been a good deal of work completed toward development of training, qualification and certification standards in the following areas:

### 12.5.1 Aircraft Electronics

In its broadest definition, aviation electronics, also known as avionics, encompasses all aircraft electrical / electronic systems and their components. The term "avionics" now goes beyond a more basic definition that once included only communication, navigation and auto-flight systems.

One of the major changes in today's aircraft is the extensive use of digital electronic data processors, computers, electronic controls, and fly-by-wire technology. Aircraft have become fully integrated from a systems standpoint. While additional emphasis has been placed on avionics in the proposed Aviation Maintenance Technical - Transport (AMT-T) rating in FAR Part 66, there is a large group within the aviation industry that strongly supports an ARS - I level avionics technician certification. Maintenance and alteration of these systems requires a highly specialized set of skills and knowledge that go beyond AMT and AMT-T requirements.

The Association for Avionics Education (AAE), with the support of the Aircraft Electronics Association (AEA), is in the process of developing a training and qualification standard for Aviation Electronics Technicians. Their working documents have been presented to ARAC-65 on two occasions for review and comment. The ARAC-65 group has concluded that there will not be a separate avionics rating as part of AMT or AMT-T certification. They have encouraged AAE to continue with their standards development process, addressing aircraft electronics as an ARS-I certification.

### 12.5.2 Composite Structural Repair

Composites are non metallic structures that include materials such as fiberglass, carbon fiber,

kevlar<sup>®</sup>, and graphite filament. They are usually chemically compounded or laminated with resins and bonded to metal, or other composite, support structures with adhesives to make light-weight, non-corroding, high-strength aircraft structural components. They are often formed and cured under heat and vacuum. Special equipment and working environments are often required to construct or repair composite structures. Special skills are required as improper handling or repair techniques can cause extensive damage and the materials themselves can create both worker health and environmental hazards.

Most indicators point toward the increased use of composite materials in aircraft construction, particularly transport aircraft. Some aircraft currently in production are "all composite." It has become a very complex and highly specialized segment of aviation maintenance. The knowledge and skills necessary for composite maintenance require an expertise beyond the AMT and AMT-T certification requirements.

The Commercial Aircraft Composite Repair Committee (CACRC), sponsored by the Society of Automotive Engineering (SAE), is in the process of formulating a standard for this skill area. The format from Air Transport Association (ATA) Specification 105 (Non Destructive Inspection) is being used as a model. The CACRC group has gained international stature, based in representation from the European aviation maintenance community. They have been meeting for over two years developing their standards and have made a good deal of progress with the document. The group is close to the release of a draft that will include guidelines for composites materials handling, preventative maintenance, inspection, repair, alteration / fabrication, and protective coatings.

### 12.5.3 Non-destructive Inspection

Non-destructive inspection (NDI) has become a very highly specialized skill area that requires the use of sophisticated tooling and diagnostic equipment for the evaluation of defects and flaws. Technology ranges from magnetic particle and dye penetrant methods through x-ray, ultrasonic, eddy current and some currently emerging technologies. The technician is responsible for the setup and operation of these systems, plus the reading and interpretation of their output. Competency in non-destructive testing requires a high degree of both knowledge and skill. Proficiency also requires a good deal of hands-on practice and recurrent training.

There have been recent improvements in non-destructive inspection technology. Sandia Laboratory in Albuquerque, New Mexico has a dedicated facility and a staff, complete with air transport category aircraft, for the development and application of non-destructive testing technology. There are also human factors studies underway that are focused on improving visual inspection tools and processes. These studies are expected to produce human engineering results that will enhance techniques, therefore benefiting the technician's ability to conduct visual inspections.

The Air Transport Association Non Destructive Inspection Sub Committee has developed Specification 105, [Guidelines for Non Destructive Inspection](#). The document includes training curricula for the various NDI processes and associated inspection techniques. Also included are qualification standards for NDI personnel. ATA Specification 105 represents a quality body of work that was developed with input from all elements of the aviation manufacturing and maintenance industry.

The American Society for Non Destructive Testing standards have been in place for a number of years. They are kept current with state of the art processes and emerging technology. These standards specify training, qualification and certification of NDI specialists in each of the NDI processes, from the basics through the most complex radiography. Their standards are recognized by several industries other than air transport and they are considered as the model.

While there are two other standards that are recognized in the non destructive inspection discipline, the aviation industry recognizes ATA Specification 105 and ASNT as the baseline. One, or both, of these could become standards that are accepted by the FAA for ARS-I certification.

### 12.5.4 Metal Structures Repair

Aircraft structure maintenance, modification and repair is an area of increasing focus and concern. Several factors are causing changes in the nature of work content and specialization of personnel within this element of the maintenance industry. Specifically, the need to reduce operating costs is motivating the air transport community to conduct business differently:

- Increasing amounts of modification and repair work (up to and including D check level) is being accomplished by second and third party maintenance providers.
- The number of aircraft classified as aging is increasing. By definition and structural status, these aircraft require extensive structural inspections, repairs and modifications in order to remain airworthy.
- The size of the leased aircraft fleet is at an all time high, with continued growth forecast for the future. These aircraft move from operator to operator and are maintained by various AMOs around the world.
- Many airframe specialists are not certified because they are not required to return aircraft to service. They specialize in structures repair, and are not Airframe and / or Powerplant certificate holders. They usually work at AMOs and are covered under FAR Part 145 repair station certification.
- Since a large percentage of the work done by second and third party maintenance providers is competitively bid, workload for these operations is cyclical with variable staffing demands. This has created a significant number of temporary contract aircraft maintenance personnel agencies. The workers in this field are assigned by contract to operations worldwide that need maintenance staff. They are transient, moving from company to company and place to place as needed. Most of these workers are non certificated structures mechanics with training, qualifications and backgrounds that are supported only by resumes and word of mouth.

An independent Structures Repair Committee (SRC) was formed by several participants involved in the CACRC is also in the process of developing a standard for aircraft metal structures repair specialists. The intended purpose is to create a document that will describe the training, qualifications, and certification of aircraft metal structures repair specialists as an ARS-I. They are at about the same point of development with the structures repair standards as CACRC is with the composite materials repair standard. Meetings to continue development work have been held as recently as February 14, 15, and 16, 1995. Progress continues to be made and this effort will continue to be evaluated as a part of this project.

There is a strong body of thought within the industry that aircraft structures repair should be covered by a standard and require certification at the level required to meet ARS-I certification. This was demonstrated in results from a recent survey that is discussed in section 12.6.

### 12.5.5 Balloon and Glider Repair

Balloon maintenance and repair although a relatively small segment of the industry, is currently asking for specialty status and fits under the ARS-I concept. Balloons are not true airframes, nor do they have conventional powerplants, yet under current definitions they fall under the same FAA rules as standard aircraft. Balloons must be maintained by A & P mechanics and IA's under FAR Part 91 as general aviation aircraft. They may also be repaired by repairmen in certified repair stations. It is the contention of many in balloon operations and maintenance that safety is compromised from lack of specific training, qualification and certification standards. Commercial operators contend that there should be a set of minimum standards for both repair facilities and maintenance personnel.

A proposed standard, supported by several operators, was presented to the FAA at one of the Maintenance Regulatory Reviews in December of 1989. It included a minimum equipment list for

hot - air balloon repair stations, and a minimum task list (qualifications) for certified balloon repairmen.

The FAA concurs with the direction taken by the balloon industry and will encourage the completion of standards that may be accepted for ARS-I certification.

While there is no specific information available at this time, the FAA has also recognized that a similar situation to the balloon sector also exists in the glider maintenance and repair sector. Means of having this sector develop acceptable ARS-I certification standards will be explored.

### **12.5.6 Other Potential Skill Areas**

There is general agreement in ARAC and the FAA that the skills listed above represent the areas of primary need and focus. Continuing research and investigation during the second phase of this project will focus on these and other skill areas that are potential candidates for specialist certification. Working with Northwestern University's Maintenance Job Task Analysis team's initial data should also serve to verify what the ARAC has accomplished. This data should also illuminate any other obvious areas where specialist certification needs to be considered.

## **12.6 INFORMAL FAR 145 REPAIR STATION TECHNICIAN SURVEY**

A member of CACRC, with agreement from the group, conducted a survey of a cross section of FAR 145 repair station operators. This survey was random, not intended to be formal nor statistically validated. However, it does provide worthwhile information, available nowhere else, on the subject of advanced certification for specific skill areas in certified repair stations.

The survey was sent to 40 Part 145 repair stations, selected from the World Aviation Directory (WAD), who perform work on large transport category aircraft. It asked for information concerning the array of technicians employed at these facilities. The questions targeted A & P certified mechanics, and the four potential specialist groups considered for ARS-I certification by the ARAC-65 working group. Twenty-three of the repair stations responded, which at over 57% is a very good response. They were asked to provide the following information:

- Total number of technicians employed
- Total number of certified A&Ps
- Total non-certified structural / sheet metal technicians
- Total number of Avionics technicians
- Total number of Avionics technicians with FCC licenses
- Total number of Avionics technicians holding repairman certificates
- Total number of NDI technicians
- Total number of Composites technicians

In addition, they were asked to respond to these questions:

- What type of maintenance training does your company offer?
- Would the company be better served by technicians trained to industry standards?
- Would the company support development of specialist ratings in:
  - Avionics
  - Non Destructive Inspection

## - Structures

Unlike the major air carriers, where at least 90% of maintenance personnel hold A&P certificates, the Part 145 operators employ maintenance staff where less than 50% hold A&P certification. Structures repair technicians represented almost 35% of the population of employees covered by the survey, none with certification of any type. It was also interesting to note that only 61% of the respondents conduct training for technicians in the specialties surveyed. This points out that there could be a significant gap in competencies between the air carrier and second or third party maintenance personnel.

All respondents indicated that industry standards in the specialties listed above would benefit their operations. The survey shows that there is interest within the industry in the development of standards. Those responding were fully supportive of avionics and NDI standards and were within one percentage point of full support for composite and metal structures repair.

In discussions with individuals from all areas of the industry, there seems to be general agreement that the development of such standards is a worthwhile and necessary undertaking.

## 12.7 ESTABLISHED TRAINING AND CERTIFICATION STANDARDS

Looking at systems and processes by which other industries and disciplines develop and maintain standards for training, qualification and certification of skills will provide examples of how this may best be accomplished in the aviation maintenance industry. A broad brush snapshot of other industries, with both technical and non-technical knowledge and skill requirements, has shown that there is a set of consistent characteristics. There are two general approaches to skill and knowledge certification:

- Imposed and maintained by governmental agency (Federal, State, County, City or District) through rules and regulations.
- Self-imposed certification, based on standards that are designed to maintain specific levels of performance. In most cases the development of these standards and the resulting training, qualification and certification systems are under the auspices of non-profit professional organizations. Such standards are usually put in place for the purpose of ensuring public safety, elevating the professional standing and / or perception of a craft, career field, or profession, and in some cases to avoid or preclude imposed certification / regulation, i.e., American Welding Society, Professional Association of Diving Instruction, etc.

There are various national organizations that have developed training and certification standards, for a wide range of skills, that are in continuous use today. Each organization has a board of directors, governors, or standards committee, consisting of recognized "senior" experts in the respective fields. While the actual skills for which the training and certification standards have been developed vary a great deal, the processes by which they were developed, applied, and maintained are similar. Some examples of these organizations and information pertinent to their successful, currently operational, training qualification and certification systems are as follows:

### American Red Cross (ARC)

While far removed from the technical world of aviation maintenance, one of the best examples of a successful training and certification process, which has been effective for nearly a century, is the method used by the American Red Cross. This organization has a solid training and certification system that is recognized around the world. Their national headquarters establishes and maintains standards for training and certification of various public safety related skills such as: First Aid, First Aid Instructor, Jr. Life Saver, Sr. Life Saver, and Water Safety Instructor.

The organization is completely self contained and accomplishes all training and certification through a comparatively small compensated staff and a large and complex national network of

volunteers. Many organizations recognize Red Cross certification as pre-requisite for other training, such as Emergency Medical Technician, or as a job requirement as in Life Guards and Swimming Instructors.

### American Welding Society (AWS)

The FAA does not require additional certification for aircraft construction or repair welding beyond the Airframe and Powerplant ratings. Based on the most recent revision of FAR Part 147, A&P mechanics must be able to differentiate between acceptable and unacceptable welds, but are no longer required to demonstrate welding proficiency. (The state of the art has progressed well beyond basic acetylene gas and electric arc welding.) Many airlines and repair facilities, however, require welders (especially those performing "exotic" and critical welding) in component and engine repair shops to be AWS certified.

The AWS was founded in 1919 to advance the science, technology and application of welding. It is a non-profit organization that conducts welder, welding inspector, and welding educator certification programs. The Society's over 42,000 members consist of educators, engineers, researchers, welders, inspectors, technicians, welding foremen, company officers, and supervisors. Disciplines include automatic, semi-automatic and manual welding, as well as brazing, soldering, ceramics, robotics, thermal spraying and lasers. (All of these processes are used in the aviation maintenance industry.) Activities include initiatives in research, safety and health, education, training, business, and government liaison. Their standards are considered as benchmarks in the welding craft. They also maintain a system of accredited education and test facilities in the fifty States and overseas locations.

An example of their system and the process that relates to advanced certification for the aviation maintenance industry is their Certified Welder program (similar standards exist for Welding Inspector and Welding Educator qualification and certification). The Society's Certified Welder Program is established to identify all elements necessary to implement a National Registry of Certified Welders.

The four key elements of the system include:

1. Welder performance qualification standards.
2. Standard welding procedure specifications.
3. Accredited performance qualification test facilities.
4. AWS welder certification requirements.

The purpose of the Standard for AWS Certified Welders is:

1. To determine the ability of welders to deposit sound welds in accordance with standardized requirements.
2. To impose sufficient controls on the documentation and maintenance of certification to allow transfer between employers without re-qualification, where allowed by Standard of Contract documents.

Specific specialties for advanced certification include: Chemical Plant, Petroleum Refinery Piping, and High Rise Construction.

Application for certification is extensive and includes verification of background, experience and education. They also require medical certification of acceptable visual acuity completed not sooner than six months prior to testing and certification.

The AWS standards are well-defined voluntary consensus standards, developed in accordance with the rules of the American National Standards Institute (ANSI). They provide an excellent basis on which to pattern the development of standards for training, qualification and certification of aviation maintenance skills.

### Radiological Technologists / X-Ray Technicians

The system of training, qualification and certification of Radiological Technologists in the state of California is typical of processes for this discipline across the United States.

The program is administered by California Health Services, Radiological Health Branch. This organization sets the standards for training and curriculum for Radiological Technologists. It is generally a 2 or 3 year program conducted by the state's community colleges. Successful completion of such a program qualifies the learner to take the state examination. The examinations are conducted by Comprehensive Personnel Services (CPS), a for profit organization that conducts these, and similar tests, for governmental agencies. CPS only does testing, they conduct no training or other related activities.

There are also Limited Permit Technicians who are qualified with shorter duration, specific focus courses, often taught by business schools or medical technician schools. These courses generally certify technicians to perform X-rays on specific parts of the body, such as podiatry, chest, etc. They are qualified through on the job training, and certified upon successfully passing a state administered test.

Board Certified Radiologists (Physicians) automatically receive state certification. Other physicians may sit for and pass exams to gain certification.

Schools apply to the California Health Services Administration for approval of their programs by completing an extensive application showing their curriculum content. Oversight is conducted by Inspectors from the California Health Services staff. Limited Permit Programs generally receive more scrutiny than the programs conducted at the community colleges.

There is a National Society of Radiological Technologists and a California Registry of Radiological Technologists. The national organization sets the pattern for standards from which the California program is adapted.

Changes are a regulatory process that may be driven by the California State Legislature. For instance, there is current interest in assuring quality in mammography. This is also being developed as a new advanced certification category. It will require additional training and examination after initial certification.

Re-certification is required every 2 years. The re-certification is automatic if the application is timely. A continuing education requirement will become effective in July of 1996.

The National Society of Radiological Technologists and the Society of Nuclear Medicine conduct conferences that often include post graduate programs (similar to Inspector Authorization renewal conducted at PAMA conferences). These groups are at the level of industry organizations and do not develop standards for training, qualification and certification.

### Emergency Medical Technicians (EMT) and Paramedics - (*California*)

EMT and Paramedic training programs are operated under standards, generally based on national guidelines, but developed and maintained by individual states. It is also a system that uses partnership between government regulatory agencies, where the public and private educational sector provides the training, qualification and certification for individuals entering a specific career field.

The U. S. Department of Transportation issues national curriculum standards upon which California bases their curriculum requirements. The DOT has advisory standing with the states.

The California Office of Emergency Medical Services Authority is the regulatory agency. They administer 3 programs:

- EMT 1 Basic
- EMT 2 Intermediate

- EMT 3 Paramedic

**EMT 1 & 2** certification is acquired through an approved training agency, usually Community Colleges or Junior Colleges. EMTs are generally classified as highly qualified first aid givers, but not as medical technologists. A standard 110 hours of instruction is required, usually provided by Community Colleges, in a 4 to 5 month course. Commercial schools may also be approved. EMT 1 & 2 may be administered at the County level, or through an association of counties in less populated areas. Trainees are given written and practical tests. The County agencies can accept the final exam from an approved training program, or they may administer their own tests. The California State Fire Marshal and California Highway Patrol also administer EMT 1 programs.

State certification, granted after passing the initial written and skill examination, is good for two years. Continuing education credits, or a refresher class, is required to renew certification each subsequent two year period.

**Paramedic** certification (EMT 3 - Paramedic) requires successful completion of EMT 1 & 2 qualification, plus 1,000 hours of required training, usually provided by a Community (Junior) College. Persons with this certification are considered medical technologists who can carry out specific medical practices. These include intravenous injections, and operation of certain medical test and life support systems.

State certification is by initial written and practical skill demonstration examination and remains current for two years. Currency is maintained by completing 48 hours of continuing education every two years, reported to the state board.

In order to gain certification, schools submit their curriculum and qualifications to the State for approval. Approval allows schools to be included on an approved list and authorizes their programs for instruction.

The California Office of Emergency Medical Services Authority goes through a full Office of Administrative Law process when changing their requirements or regulations. There is a 45 day notice and solicitation of public comments, then a hearing, etc.

There is a National Registry of EMTs and Paramedics. The National Registry is a not-for-profit, non-governmental organization. It is governed by a Board of Directors made up of users of their services and professional medical people. They have been in operation since 1970. They conduct certification and re-certification exams for those states and organizations who choose to use them. They conduct tests that some states use for certification. They feel they set the standards for the nation. They refer to the DOT standards, but base their standards on a job analysis. Changes to the standards are cyclical. Sometimes the DOT initiates a change to which they respond and sometimes technology or technique improvement requires change.

There is also a National Association of EMT and Paramedics. Some state and local organizations provide forums and there are some private organizations that put on conferences and trade shows.

#### American Sailing Association (ASA)

There are no government agencies, including the US Coast Guard, that require any type of certification for recreational, non-commercial, water vessel operators. There is no demonstration of skill necessary for commercial skippers operating water vessels under 500 tons displacement under Coast Guard regulations; passing of a written examination only meets the certification requirement. The ASA standard is an excellent example of a certification process that is maintained by a specific industry without any governmental regulatory oversight.

The American Sailing Association is dedicated to promoting safe recreational sailing in the United States by administering an internationally recognized educational system. ASA is an association of sailors, professional sailing instructors, sailing schools and charter companies.

ASA is a private, for profit, organization recognized around the world. Their association with the International Sailing School Association (ISSA) allows for recognition of ASA certification by many national authorities, charter and insurance companies around the world. The group was formed to promote sailboat operations safety and ensure acceptable levels of proficiency for various levels of sailboat chartering and rental.

Their Official International Log Book provides information about the standards and certification requirements for various levels of sailboat operational skills (including instructor certification). This group has developed and maintains standards of training and certification for non-commercial skippers who become certified in order to rent "bare boat" charter sailboats for pleasure cruising, or various other sail boats for personal recreation. The document is excellent. It is clear, brief and concise yet complete in all essential details. The Log Book is also used to record completion of the various levels of certification. Review of the Log Book is required by charter companies before a boat is released to a skipper. This system is very similar in nature to the requirements that a pilot must meet in order to rent an aircraft.

The training system is progressive and encompasses both knowledge and skill requirements. All standards are considered as minimum for the respective certifications. There are pre-requisites for more advanced certifications. Starting with the entry level in the Basic Keelboat Sailing Standard that has no pre-requisites and is described as: "Able to sail a small boat of about 20 feet in length in light to moderate winds and sea conditions in familiar waters without supervision. A preparatory Standard with no auxiliary power or navigation skills required." The skills advance through Basic Coastal Cruising, Advanced Coastal Cruising, though the most advanced Offshore Passage Making that has the prerequisites of all previous keelboat and navigation standards and is described as: "The sailor is able to safely act as skipper or crew of a sailing vessel on offshore passages requiring celestial navigation."

All written testing on "Sailing Knowledge" must be passed with a score of 80% or higher and demonstration of skill competency, "Sailing Skill," is evaluated by an ASA certified instructor. All certification is provisional until reviewed by the organizational headquarters who issue the final seal of approval. This process is very similar to FAA Airman certification as it relates to their system of written testing, an oral and practical test conducted by a designated examiner, followed by review and final certificate issue.

#### Professional Association of Diving Instruction (PADI)

PADI is another example of a non-governmental certification system. While not as complex as others, it serves the interest of public safety by ensuring at least basic knowledge before individuals may rent Self Contained Underwater Breathing Apparatus (SCUBA) or have air supply tanks filled.

Approximately 28 hours of instruction, that includes at least one actual "deep water sea trial" (not in a swimming pool) dive. Certification includes both a written test and skills demonstration to the satisfaction of a PADI certified instructor. Lack of recent experience requires re-certification to assure the diver remembers the safety factors and can properly use and operate SCUBA equipment.

The system is very similar to the one that was developed by ASA and has all the basic characteristics of agencies that are in the standards and certification arena.

There is no question that excellent models for building an organization to develop standards of education, qualification and certification exist within the US. The organizations discussed in this chapter have provided information freely and would lend support to others wishing to develop such systems. It appears that the aviation maintenance industry, by looking at the example set by others with similar charters and interests, could move toward the development of a national standards organization without a high degree of difficulty.

## 12.8 the Canadian aircraft maintenance specialist certification system

It was not possible to visit and meet with officials at Transport Canada in Montreal as planned. This visit and in depth discussions, will take place during Phase II of this project. There is, however, a good deal of information about the Canadian certification system that is pertinent to this phase of the project. There are aspects of the Canadian system that are directly applicable to the directions being taken in the US and may serve well as a model.

The Canadian aviation regulatory and certification system is the responsibility of Transport Canada (TC) which is their equivalent of our FAA. While similar to the United States system in many ways, there are some differences that should be considered:

- The Canadian aviation maintenance industry is smaller than that of the USA. The current number of Aircraft Maintenance Engineers (AME), who are the equivalent of Airframe and Powerplant Mechanics (A & P), is about 32,000, versus about 148,000 A&Ps in the USA.
- Transport Canada has recently revised the AME certification process, moving more toward a system similar to the FAA system. This moved Canada away from their former system that was closer to their European history and the International Civil Aviation Organization (ICAO) standards and practices. Under ICAO all maintenance certification authority is vested in the Approved Maintenance Organization (AMO). An AME is trained as a generalist with specific aircraft type-training requirements, return to service privileges, and is independently certified.
- There is a group similar to ARAC in Canada; Canadian Aviation Regulatory Advisory Committee (CARAC) with a working group on maintenance certification and control. In activities much like those that have been conducted by the ARAC - 65 working group, the Canadians are moving toward broader AME licensing privileges and specialist licenses. It appears that their certification process will move even closer to that of the FAA than it is at present.
- Apprenticeship programs are in place through which an individual may become certified as an AME. These individuals are under the supervision of a qualified trades person learning the principles, skills, tools and materials of the trade while observing, practicing and accomplishing work. They also attend short technical courses at a college or technical institute.

A 1991 Price Waterhouse study, Human Resources in the Canadian Aircraft Maintenance Industry, sponsored by Employment and Immigration Canada produced similar findings to those of the Pilot and Aviation Maintenance Technician Blue Ribbon Panel.

Canada has also recognized the need for certified specialists in specific skill areas. They have in place the Canadian Aviation Maintenance Council (CAMC) which was formed for the following purposes, as stated in their introductory pamphlet:

*The council was created to address challenges facing the industry. These challenges were identified in a comprehensive human resources study prepared for the industry that included:*

- *The need to overcome the lack of formal training programs available for non-licensed skilled tradespersons.*
- *The need to meet ever - rising requirements for the entry into skilled trades.*
- *The need to establish criteria to recognize skills of the aircraft maintenance workers.*
- *The need to increase retention of new recruits especially among smaller employers.*

*The CAMC is a decision-making body. It manages current business, sets specific objectives, policies and procedures, and coordinates the efforts of various committees. The committees cover topics such as occupational standard, training programs, communications and financing, among others. The Council supports and encourages initiatives to develop the overall strength and economic well being of the Canadian Aviation Maintenance Industry both locally and internationally.*

The membership of the group covers the full industry spectrum, represented by an equal number of employer and employee organizations including:

- Air Transport Association of Canada
- Aerospace Industry Association of Canada
- Canadian Auto Workers
- International Association of Machinist and Aerospace Workers
- Canadian Federation of AME Associations

CAMC has identified 22 occupational areas and is currently developing occupational standards for these thirteen aviation maintenance skills:

- Avionics
- Electrical Component
- Electroplating
- Gas Turbine Repair and Overhaul
- Interior Refinishing
- Machinist
- Mechanical Component
- Non-Destructive Testing
- Painting
- Reciprocating Engines and Propellers
- Structural Repair
- Welding

To ensure high quality standards, a technical committee, composed of knowledgeable tradespersons, is established for each skill area ("trade•).

## 12.9 JOINT AVIATION REGULATIONS (JAR) 65 REVISION STATUS

Joint Aviation Regulations (JAR) 65, which is the European Economic Community (EEC) equivalent to FAR Part 65 has been in the process of development through seven revisions. It is being developed under the control of the Joint Aviation Authority (JAA) which is the EEC regulatory body. The rule is not scheduled to become fully implemented until July of 1999. Harmonization with the FAR 65/66 is on the agenda, but was not placed on the docket for 1995 / 1996 as of the last working group meeting in March of 1995.

The [JAR](#) 65 approach is very different from that of both the USA and Canada, in that all maintenance certification authority will be vested in the Approved Maintenance Organizations. It seems apparent that JAA is committed to a model that will handle differences and variances that exist between the member nation states through accommodation. This suggests that the AMO will remain the basis for the total maintenance certification control program.

Historically, many "flag• carriers have become accustomed to near regulatory control within their own country. These carriers seem hesitant to give up this level of influenced and control. The countries that have their own certification system are not comfortable with loosing their independence to a system of AMO control.

Some countries place high value and specific requirements on structured formal training as part of certification, while others place emphasis on certification based in on-the-job training. In some cases maintenance personnel are trained to a level of qualification with no certification requirement. It appears difficult for any consensus to be achieved in this environment without accommodating many divergent points of view.

The USA and Canada, who have taken the approach of centralized certification control, through regulating training, qualifications and certification, feel that this is best for all concerned. Since there is a strong core of agreement between the two countries, and given the recent North American Free Trade Agreement (NAFTA), they are moving toward harmonization in North America, which may also include Mexico.

Harmonization between JAA and the FAA may not be as simple, especially in the area of maintenance technician certification, as initially thought. It also appears that it has become a lower priority than it was only a few months ago. The challenges presented, and differences that exist, between the proposed JAA system and both the US and Canada do not appear to be approaching resolution in the near future.

## **12.10 Organizations that are POTENTIAL Certification Standard Developers and "Keepers of the flame"**

Several professional organizations have been suggested and / or discussed as having potential to become those who may develop and maintain aviation maintenance advanced certification standards. It has also been suggested (for purposes of harmonization) that such organizations may need to be compliant with International Standards Organization (ISO) standards series 9000, and / or by the Board of Accreditation (RAB) that is part of the National Standards Institute (NSI). Following is a listing of possible organizations:

Aircraft Electronics Association

American Society for Nondestructive Testing

Society of Automotive Engineers

Air Transport Association

Aircraft Industry Association

Performance Review Institute

National Aerospace and Defense Contractors Accreditation Program

Commercial Aircraft Composite Repair Committee (and several others that may become interested)

There is another point of view that suggests that it may not be in the national interest to specify one or more of these existing organizations to hold the "keeper of the flame" responsibility. It may be more advantageous to allow all recognized groups who develop, validate and maintain standards to prepare training, qualification, and certification standards for aviation maintenance advanced skills as they see fit. These standards, however, may be required to conform to a set of overall requirements, developed and maintained by a national steering, oversight, or executive committee. This committee, with membership consisting of high level industry "experts" would act as the "keeper of the flame" and endorse standards for aviation maintenance advanced skills and certification. The FAA, in turn, would accept certification standards that meet the specific requirements of this high level group for ARS-I certification. This approach bears some similarity to the CAMC system in Canada, which will be studied further.

Determination of the industry and FAA views on this subject will be researched further; studied, reviewed, and reported upon in the next phase of this project.

## 12.11 OTHER REGULATORY IMPROVEMENT Elements TO CONSIDER

During the course of this project, there are other areas that may be reviewed as having potential for creating an improved method for obtaining information from the regulator's perspective and input from industry, while upgrading industry / government participation in rulemaking.

- Integration of ARS standards and FAR Part 145
- Future training scenarios
- AMT School self testing
- FAR Part 147 flexible curriculum
- More privileges for AMT (Annual inspections for part 91 aircraft, etc.)
- Harmonization - Canada, NAFTA, and rest of the World
- "Seamless" maintenance training scenarios from primary through recurrent.

## 12.12 CONCLUSIONS

The aircraft maintenance industry is in a state of change. While this state of change has been in process over the last decade, the rate of change has increased over the past three to four years. All indications point toward the continuation of this trend, at perhaps even a faster and more dramatic rate. The regulatory process, as witnessed by the long overdue changes to FAR Part 147 and the changes currently in process for FAR Part 65, is slow to respond and has failed to keep pace with ongoing industry changes.

While the ARAC process may be a starting point for regulatory management, it needs to continue to evolve. There is also an apparent need to conduct a more in depth evaluation of the need to convene a national aircraft maintenance standards oversight council, or committee. The membership may consist of high level aviation industry and FAA officials who have strong process orientation. The group would have the "Big Picture" of both the technology and maintenance processes with insight into how they may best be applied. It could also serve as the umbrella organization that provides oversight for other groups that have been qualified to issue and maintain training and qualification standards. This group could be similar to the board that has this type of function in Canada.

As the study moves forward, support for this type of system continues to grow. The supporters of specialists, advanced skills certification and improvement of aircraft maintenance technician professionalism far outnumber the dissenters. This majority is also cognizant of the need to harmonize regulations and standards, where possible, within the international community. They also believe that regulatory congruence with Canada and other NAFTA countries' aviation maintenance regulations will be of significant benefit to North America as we move toward harmonization with the [EEC](#), Austral-Asia and Middle Eastern countries.

There seems to be little doubt that a system of this type is needed. The next phase of this project will more completely explore the alternatives, opportunities and necessity for development of systems to provide advanced aviation technical training, qualification & certification. It will provide the foundation of information necessary to begin putting the process in place, and will have established the multi - discipline network required to move forward.

## 12.13 REFERENCES

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Parts 65 and 66, Revision of Certification Requirements: Mechanics and Repairmen; Proposed Rule (Notice of Proposed Rule Making: Notice No. 94-27)

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American Welding Society Publications as follow:

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OC5-G 1992 - Guide to AWS Welding Educator Qualification and Certification

QC7-93 - Standard for AWS Certified Welders

QC7-93 Supplement C - Welder Performance Qualification Sheet Metal Test Requirements

QC7-93 Supplement F - Chemical Plant and Petroleum Refinery Piping

QC7-93 Supplement G - AWS Performance Qualification Test

Employment and Immigration Canada, Human Resources in the Canadian Aircraft Maintenance Industry: Price Waterhouse, March, 1991.

Canadian Aviation Maintenance Council, Introductory Pamphlet

JAR 65 Draft, NPA 65-0 (dated 1.2.1995)

#### APPENDIX 12-A - SUBSTANTIVE RECOMMENDED CHANGES TO PART 65

- Removal of Gender -Specific Terms
- Re-designation of the Term "Mechanic"
- Equivalency of Ratings
- Replacement of Lost or Destroyed Certificates by Facsimile
- Demonstration of English-Language Proficiency and Removal of Exception Criteria for Applicants Employed Outside the United States Who Are Not Proficient in the English Language.
- Establishment of a Requirement for Aviation Maintenance Technicians To Pass a Written Test on all Applicable Provisions of Chapter 14.
- Clarification of Requirement To Pass all Sections of the Written Test Before Applying for the Oral and Practical Tests
- Recognition of New Written Testing Methods
- Specification of Experience Requirements in Hours
- Establishment of Basic Competency Requirements
- Use of Equipment-Specific Training to Qualify for Certificate Privileges

- Use of Instructional Time by Aviation Maintenance Instructors to Satisfy Currency Requirements
- Establishment of Training Requirements for Certificated Aviation Maintenance Technicians Exercising the Privileges of their Certificates for Compensation or Hire
- Extension of Inspection Authorization Duration
- Expansion of Inspection Authorization Renewal Options

# **Work Order 2 Final Report (1995)**

## **A Human Factors Study of Information Dissemination and Display for the Flight Standards Service**

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# Chapter One

## Review of Current Information Sources and Displays

### 1.1 Summary

The Flight Standards Service (AFS) is interested in the efficient collection, analysis, and dissemination of data among operators, manufacturers, and the government in its effort to maintain aviation safety. New research and development efforts like the Performance Enhancement System (PENS) have demonstrated that the use of new technologies with refined software can improve the manner in which the AFS manages safety related data.

The following is a description of a detailed study of several AFS database systems to determine the state of the existing information systems. The study consisted of several meetings with information managers and Aviation Safety Inspectors (ASIs) from various Flight Standards District Offices (FSDOs) across the country. These meetings focused on the usage, strengths and weaknesses of the AFS database systems.

The study resulted in a number of significant findings:

- An initial survey identified the Flight Standard Automation System (FSAS) as the most heavily used system by the ASIs and their managers; therefore, this study focused primarily on FSAS because of its wide use.
- Many of the other database systems are rarely used.
- During the discussions with the ASIs, the only strength that was identified was that the database systems contained a wealth of data. This was quickly followed by a complaint about how difficult it was to access this data and some concerns about the integrity of the data.
- While there are many weaknesses in these systems, there are some common weaknesses across the systems.

### 1.2 Purpose

This document identifies and briefly explains the functionality of the systems that are most frequently used by ASIs. The report details the weaknesses of these systems and highlights the new systems' enhancements identified during the study.

There are three major systems being used by AFS personnel. These systems are the Flight Standards Information System (FSIS), the Logistics and Inventory System (LIS) and the Integrated Personnel and Payroll System (IPPS). Each of these major systems contains a number of subsystems. The focus of this study was on the subsystems in FSIS, since these subsystems are widely used by the ASIs. The LIS and IPPS systems were beyond the scope of this study.

### 1.3 Systems Description and Weaknesses

FSIS was formerly known as the Aviation Safety Analysis System (ASAS). However, the ASAS subsystems were reorganized under the current title in 1991.

FSIS is a nationally distributed information network designed to collect, store, and organize aviation

safety data under a single system. It consists of a number of separate subsystems designed to improve the AFS' ability to gather and analyze aviation safety data within all AFS offices nationwide. Through improved computer operations, information management and administration, FSIS provides data support to identify present and potential safety issues, supplies management with the information necessary to use its resources more effectively, and gives each office the ability to respond to internal and external requests for information.

The majority of the FSIS subsystems reside on an IBM mainframe computer, while a smaller number of these subsystems reside on Data General computers and on personal computers (PC) running on local area networks (LAN). Each FSDO has PCs running on a LAN. Each Regional Office has PC and a Data General computer. The main computing center in Plano, Texas has an IBM mainframe, PCs, and a Data General computer.

The systems on the Data General computers are currently being moved to the client/server environment. In this environment a powerful PC functions as a database server which services the requests of applications running on client PC workstations.

The following is a brief description and a list of weaknesses of the subsystems that constitutes FSIS. FSAS and its related subsystems are covered first, because they are the largest component. All other systems are covered in alphabetical order after FSAS.

### **1.3.1 Flight Standards Automation Subsystem (FSAS)**

FSAS is a set of subsystems used in Flight Standards field offices to store and organize inspection and safety data, ranging from certifications to routine inspections. It consists of the following subsystems:

- Program Tracking and Reporting Subsystem (PTRS)
- Operations Specification Subsystem (OPSS)
- Vital Information Subsystem (VIS)
- Job Aids Subsystem
- Key Manager Subsystem
- Planning Subsystem
- Operational Training Needs Assessment (OPNA)

FSAS is a PC-based system that operates locally on a Novell Netware 3.11 local area network. It uses the Paradox database system. Data entered locally into the system at a Flight Standard District Office (FSDO) are uploaded daily to the mainframe in Plano, Texas. The data are then verified and redistributed to the appropriate field offices on the following day. Data residing on the mainframe are stored in the national database. Therefore, field offices can exchange information through the national database. Data transfer between the mainframe and the [LAN](#) is semi-automated. The network administrator has to initiate this process on a daily basis.

#### *Program Tracking and Reporting Subsystem (PTRS)*

PTRS was designed to enable the FSDOs to compile and track information gathered by PTRS datasheets. These datasheets are data entry forms used by ASIs to document their work before they enter it into PTRS. PTRS allows AFS personnel to efficiently forecast, plan, monitor inspector activities, monitor work program accomplishments, and monitor trends affecting aviation safety. It is the most frequently used system in FSAS.

#### *Operations Specification Subsystem (OPSS)*

OPSS was designed to automate the process of Operations Specifications document preparation for commercial air carriers and other air operators. It standardizes the document format across AFS

regions and FSDOs and it provides inspectors with up-to-date documents for more accurate inspections for Federal Aviation Regulations (FAR) Part 121 and Part 135 Air Operators. The OPSS system works in conjunction with the VIS system.

### *Vital Information Subsystem (VIS)*

VIS was designed to enable FSDOs to maintain and analyze information about air operators, air agencies, designated airmen, check airman, facilities, and organizations engaged in non-certificated activities. This system interacts with the OPSS system by way of providing an air operator record. OPSS then attaches an Operations Specification document to the air operator record.

### *Job Aids Subsystem*

The Job Aids Subsystem was designed to enable FSDOs to print job aids (similar to checklists) for the PTRS, OPSS and VIS Subsystems. These job aids help the inspector in gathering information and performing inspection activities.

### *Key Manager Subsystem*

The Key Manager Subsystem was designed to enable FSDOs to generate a list of key personnel associated with air operators who lost their certification as a result of an emergency revocation.

### *Planning Subsystem*

The Planning Subsystem was designed to enable FSDOs to develop a surveillance work plan for the fiscal year. The Planning Subsystem builds a unique surveillance work plan for each FSDO based on the data stored locally in VIS. The Planning Subsystem examines the contents of VIS, and assembles a set of records that identifies the activities that a FSDO will perform over the course of the next fiscal year. The surveillance work plan identifies the number of air operator, air agency, and airman inspections that a FSDO expects to conduct over the course of the fiscal year. The Planning Subsystem allows FSDOs to maintain both required surveillance activities and planned activities. Required surveillance activities are assigned by each regional office and represent the minimum number of inspections that a FSDO must do under the National Program Guidelines (NPG). Planned activities represent the number of inspections that FSDOs can do over and above the inspections required by national guidelines. The Planning Subsystem generates a work program for inspectors. This system then updates the PTRS system with these work programs.

### *Operational Training Needs Assessment (OPNA)*

OPNA was designed to allow district offices to use data in the FSAS databases to determine the training needs of its ASIs. The subsystem is accessed on a yearly basis. It uses the information in the PTRS and the VIS files to determine if additional ASI training is required over the course of the next fiscal year.

## **1.4 FSAS Weaknesses**

The following is a list of weaknesses that were identified by ASIs and information managers during the analysis of FSAS. In general, most users feel that the subsystem is outdated and that it is often difficult to use.

- **Poor Data Quality:** The quality of the data in the FSAS database is very poor. It is often difficult to produce reports on a particular topic because the required data for the report is often not a required entry. This is directly related to the data entry constraints of the

subsystem. FSAS needs to provide more data entry guidance to its users. To alleviate this problem some FSDOs create customized data entry forms that guide the local ASIs in terms of required data entry fields. For example, the Harrisburg FSDO has generated several of these customized data entry forms. Examples of these forms are shown in Appendix A. The form illustrating data entry into PTRS for a complaint requires the fields Activity Number, Call Up Date, Designator and Investigation Number. PTRS does not require the fields Call Up Date and Investigation Number. Without these fields, reports generated from the PTRS database on how quickly complaints are being addressed by a FSDO are useless because the date of the complaint (Call Up Date field) is unknown. Similarly, the data entry form for an incident (shown in Appendix A) requires the fields Activity Number, Call Up Date, Designator, LOC/Departure Point and Investigation Number. PTRS does not require Call Up Date, LOC/Departure Point or Investigation Number. Again, generating an incident report on the date and location of an incident without data in these fields is of little value. In order to support their reporting needs, FSDOs sometimes use certain data entry fields for purposes that were not intended. Hence, the data from one FSDO to another could be very different which defeats the AFS primary goal of having homogeneous data across FSDOs.

- **Lack of Integration of Subsystems:** FSAS in general needs to be more tightly integrated. An area in the system where this problem is evident is in the VIS and OPSS Subsystems. If a user removes an air operator from VIS, the user must also perform a second task to remove the related operational specification document from OPSS. Another example is, if a user adds a new aircraft to OPSS, the user must also add the information for that aircraft to VIS. Because FSAS is not well integrated users occasionally forget to add or delete the data in all the required areas of the system. This problem leads to data integrity problems which add to the poor state of the FSAS data.

Even within a subsystem database duplicate data entry is a prevalent problem. An example of duplicate data entry is in VIS, where identical inspector related data are required both in the Air Operator and Environment files. Again, this often leads to data integrity problems, because users sometimes forget to enter this data in all the appropriate places.

The ASIs and other AFS users often use Windows software packages such as Microsoft Word and Excel along with FSAS on a daily basis. In order to access FSAS while the Windows software is running, the user must exit Windows, then start FSAS. Both systems cannot run simultaneously. A clear need exists to have all AFS systems running under a single integrated environment; this will cut down on the time and effort it takes to access important safety related systems.

- **Poor User Interface:** The data entry screens for comments are too difficult to access. In order to access these screens, a user is required to step through several intermediate screens. This is often inconvenient because frequently data entry is required only on the first screens and on the comment screens.

A spell checker would be a tremendous benefit for all comment sections in FSAS. This will eliminate the chance of ASIs inadvertently saving unreadable comments to the system. This functionality will aid in improving the quality of data in the FSAS databases.

The Ad-hoc reporting function within the FSAS System is too difficult to use. In order to use the Ad-hoc function, knowledge of the Paradox Database System is required. Due to its complexity, many ASIs do not use this feature. If an ad-hoc report is needed, the network administrator typically is asked to generate this report. Because of the delay and inconvenience involved, many ASIs do not request these reports. Several ASI's indicated that if this feature were easier to use, they would use it.

An example of the existing FSAS Query system is shown in Figures 1 through 3 (these figures use simplified representations of the actual screens to facilitate paper reproduction). [Figure 1.1](#) illustrates the first screen that a user sees when the Query function is selected from the main FSAS menu. [Figure 1.2](#) shows the Ad-Hoc Report Maintenance screen. On this screen, if a new report is to be created, the user would first select the change function, select

an existing report then modify that report to create the new report. The user would then design a query that meets the criteria for the report. Screen 3, which is represented by [Figure 1.3](#) would then be accessed. On screen 3, the user would select the fields of interest to be printed on the report and the position in relation to other fields. As the diagrams illustrate, the ad-hoc reporting system is time consuming and extremely difficult to use. To use the system, an in-depth knowledge of the Paradox Database System and the structure of the FSAS databases are required.

User:RSM	Flight Standards Automation System	2/03/95 13:33
WorkSpace	Query Maintenance Menu	
	Query	
	<ol style="list-style-type: none"> <li>1. Place a Query onto the Workspace</li> <li>2. Query Functions (Save/Delete/Copy)</li> <li>3. Workspace Functions (Add/Remove/Clear)</li> </ol>	
	Reports	
	<ol style="list-style-type: none"> <li>4. Enter Ad-Hoc Report Maintenance Menu</li> </ol>	
	Query On Workspace:	
<hr/> [Enter] Menu Selection [Alt-F1] Help [F2] DO_IT! [Esc] Back Up		

**Figure 1.1 Ad-hoc Report Screen #1**

User:RSM	Flight Standards Automation System	2/03/95 13:33
Ad-hoc Report Maintenance Menu - Local Reports		
Reports		
<ol style="list-style-type: none"> <li>1. Report Functions (Change/Design/Run)</li> <li>2. Delete a Report</li> <li>3. Copy Report to Network</li> </ol>		
Report#	Report Name	Query
Report:		
<hr/> [F2] Change Report [Enter] Menu Selection [Alt-F1] Help [Esc] Back Up		

**Figure 1.3 Ad-hoc Report Screen #3**

```

User:RSM           Flight Standards Automation System           2 03/95 13:33
=====
....+....10....+....20....+....30....+....40....+....50....+....60....-....70....-....80
--page-----
mm/dd yy           INSPECTOR ASSIGNMENTS 3           Page 999
---group Principal Ops Inspector-----
|--tbl--|-----|-----|-----|-----|
DSIG      NAME      FAR      POI  PMI  X      CITY      ZIP      PHONE
-----
AAAA      AAAAAAAA  AAA      AAA  AAA  A      AAAA  AAAA  AAAAA  AAA
|--tbl--|-----|-----|-----|-----|
---group Principal Ops Inspector-----
--page-----
=====

```

Figure 1.2 Ad-hoc Report Screen #2

- Limited Search Capabilities:** The searching capabilities in FSAS are very limited. For example, searching can only be done by Record ID in PTRS. If a record needs to be retrieved for update and the Record ID is not known, it will be very difficult for an ASI to find the appropriate record. In this situation a special query will have to be run against the database to identify the record. An example of the current search capabilities is shown in [Figure 1.4](#). This example illustrates the search function in the PTRS system. Future upgrades to FSAS should include a generic search function that will allow a search on any field within the subsystem.

User:RSM                      Program Tracking & Reporting Subsystem                      2/03/95 143:35  
Update Transmittal Record

RECORD SELECTION

Enter the Record ID: SQ11

Inspector Name Code:  
Activity Number:  
Status:  
Results:

---

[F1] Look-up Help [Alt-F1] Help [F2] Do\_It! [Esc] Quit

**Figure 1.4 PTRS Search Screen**

- **Poor Communication Facility:** A FSDO does not have an efficient method of responding to another FSDO's comments in FSAS. For example, suppose a FSDO does an inspection on an aircraft that has its Certificated Holding District Office (CHDO) elsewhere. If the FSDO that did the inspection indicates in the PTRS Subsystem that a problem exists with the aircraft, there is no direct way for the CHDO to communicate back to the FSDO that the particular problem was corrected. To add to the problem, the CHDO does not readily know that a response is required. Many FSDOs generate a report that lists all the records that need responses. However, this list usually consists of several records. A great deal of time is required to go through this report. Many ASIs currently handle this problem by placing a telephone call to the CHDO to inform the responsible party of the problem. Some form of automated two-way communication system between FSDOs is needed.
- **More Help Facility:** Although FSAS provides help in relation to valid entries for some fields, it needs to provide more field related help.
- **Job Aids Subsystem:** The Job Aids subsystem needs to be updated. In addition to needing more job aids, existing job aids need to be updated. An example of this would be adding fax numbers on forms generated by the Job Aids Subsystem. Although the Job Aids Subsystem is not being used much by experienced ASIs, it is often used by new ASIs in order to guide them through entering data in FSAS.
- **OPSS Issues:** OPSS is too rigid. Adding or updating operating specifications cannot be done by a user. The software itself has to be modified in order to add or update additional specifications. An example of this problem would be adding de-icing specifications to the operations specification document for an air carrier. There is no way for a user to add this additional specification to OPSS. FSDOs currently handle this problem by manually typing the additional specification and appending it to the printed document. This is an obvious inconvenience because each time the same specification is needed it will have to be retyped.

The Text Editor, used for entering comments in the subsystem, is extremely difficult to use. One obvious inconvenience with this editor is that it splits lines *within* words instead of *between* words.

When entering data into the system, the cursor (focus) does not automatically move to the next field if the current field is fully populated. The user has to use the "enter" key to get to the next field.

- **OPNA Functional Issue:** The entire FSAS system is inhibited when the Operational Training Needs Assessment (OPNA) runs. Before OPNA runs all users are required to exit the FSAS system. OPNA requires exclusive use of the FSAS databases to generate its reports.
- **Key Manager Subsystem:** is not used by most FSDOs, if at all.

## 1.5 Summary of Remaining FSIS Subsystems

A formal and complete review of the following subsystems would be beyond the level of support provided for this subtask. Therefore, a brief review of each available subsystem is provided with a few comments given to us by the ASIs who had exposure to these subsystems.

### 1.5.1 National Flight Standard Automation Subsystem (NFSAS)

NFSAS is a read only mainframe subsystem which retains the FSAS data uploaded from all FSDOs. It is functionally equivalent to FSAS. However, NFSAS contains data from all the national field offices. National users can access this subsystem to view this information and produce reports. On-line manipulation of data at the national level (on the mainframe) is not allowed. NFSAS consists of the following subsystems:

- National Program Tracking and Reporting Subsystem (NPTRS)
- National Vital Information Subsystem (NVIS)
- National Operations Specifications Subsystem (NOPSS)
- Regional Automated Mainframe Planning System (RAMPS)

#### *National Program Tracking and Reporting Subsystem (NPTRS)*

NPTRS contains the latest available PTRS data from all Flight Standards offices. This subsystem allows users to view or print all reports that show inspection and surveillance activities. In addition, reports concerning total work program accomplishments and National Program Guideline data can be easily accessed.

#### *National Vital Information Subsystem (NVIS)*

NVIS contains the latest available VIS data from all Flight Standards offices. This subsystem allows users to view or print all records and reports concerning reference data on air operators, air agencies, airmen, aircraft, and facilities.

#### *National Operations Specifications Subsystem (NOPSS)*

NOPSS contains the latest available OPSS data from all local Flight Standards offices. This subsystem allows users to view or print all records and reports concerning operations specifications.

#### *Regional Automated Planning System (RAMPS)*

RAMPS is a mainframe system which uses NVIS and NOPSS to create a required surveillance plan for each FSDO. This surveillance plan represents the minimum number of inspections that a FSDO must do under the NPG. RAMPS examines NVIS and NOPSS files, generates the required items and sends this information to each FSDO. This occurs at a date late in the fiscal year to ensure that all FSDOs have the opportunity to review the information they store on the local level.

### **1.5.2 Automated Federal Aviation Regulations Subsystem (AFARS)**

AFARS is a mainframe subsystem which provides users with the capability to access the latest available full text of all Federal Aviation Regulations (FARs) as well as all FARs which were in effect during the past two years. The system also allows users to view or print a particular section of a FAR, search for all FAR references on a particular topic or word, and find citations and cross references within the regulations. AFARS is a read only system, therefore, users do not have the capability to add, update, or delete data. This system resides on the IBM mainframe.

### **1.5.3 Airworthiness Directives Subsystem (ADS)**

ADS is a mainframe system which contains the full text of all the current and the historical Airworthiness Directives (AD). An AD is a document issued by the Federal Aviation Administration that specifies a required safety-related maintenance procedure or set of procedures for a specific aircraft or aircraft component. An inspector can expediently research the Airworthiness Directives applicable to the particular aircraft that is about to be examined and have that information presented on-line. The inspector can then view or print the researched information. This system resides on the IBM mainframe and replaces the slower microfiche and hard copy filing methods.

### **1.5.4 Automated Exemption Subsystem (AES)**

AES is a mainframe system which provides users with access to information about completed exemption projects required by District, Regional, and Headquarters offices. This system makes it possible for users to centrally record and maintain current, expired, and denied exemptions. It also allows them to query and correlate information about petitions and exemptions. The system is mainly used by aviation safety inspectors and regulators to obtain access to exemption information relating to a specific FAR. The system is used by regulators to study trends. The regulators use it to identify cases where an exceedingly large number of exemptions are requested for a particular regulation, which would suggest that the regulation needs to be modified. The AES system resides on the IBM mainframe.

### **1.5.5 Accident/Incident Data Subsystem (AIDS)**

AIDS is a mainframe system which provides automated support for the collection and analysis of data related to aircraft accident and incident occurrences. The information supports FAA certification and rule making activities. AIDS contains specific information relevant to each accident or incident including data on the aircraft, the crew, the type of flying, the weather conditions, the location of the accident or incident, facilities, injuries and causal factors. The system allows users to produce reports on specific aircraft accidents and incidents as well as summary reports. This system resides mainly on the national Data General computer in Plano, Texas. AFS personnel access AIDS by dialing up the Data General computer in their regional office, which in turn will automatically connect them to the system on the national Data General computer. AIDS summary information is also available on the IBM mainframe. This summary information is copied twice per week from the national Data General computer to the IBM mainframe.

### **1.5.6 Enforcement Information Subsystem (EIS)**

EIS is a mainframe system which allows field and regional offices to monitor pilots and air operators violations. The subsystem provides automated support for violation and enforcement actions. EIS allows users to add, update, or change enforcement data, to access data regarding the violator or the violation, and to track events and people involved in an investigation. The subsystem resides on all nine regional Data General computers. It also resides on the national Data General and IBM computers in the form of summary files. The subsystem at the national level does not contain the full data for each region.

### **1.5.7 Integrated Safety Information Subsystem (ISIS)**

ISIS is a mainframe interactive querying system which provides fast and easy access to much of the information in other FSIS subsystems regarding air operators, aircraft, and airmen. ISIS can be reached from most screens by pressing the F6 function key. The subsystem accesses live data from 12 AFS systems. Some common systems accessed by ISIS are Airworthiness Directives, Comprehensive Airmen Information, Accident/Incident Data, and Enforcement Information. In fact, [EIS](#) summary information is accessed through ISIS. This subsystem resides on the IBM mainframe.

### **1.5.8 Master Minimum Equipment List Subsystem (MMELS)**

[MMELS](#) is a mainframe system which automates the process of creating, revising, approving, and distributing the text of aircraft Master Minimum Equipment Lists. MMELS are documents that specify under what conditions a given make and model of aircraft may be permitted to operate temporarily with specified items of equipment inoperative. These MMELs serve as the basis for approving related operator-specific minimum equipment lists. This subsystem resides on the IBM mainframe.

### **1.5.9 National Aircraft Registration Information Subsystem (NARIS)**

NARIS is a read only mainframe subsystem which allows users to access aircraft registration information and related historical data at the National Aircraft Registry and to then display or print the information. This subsystem also provides users with the capability to review aircraft registration data, request copies of microfiche aircraft records, and query the subsystem to identify aircraft for which complete identification is not available.

### **1.5.10 Policy Subsystem (PS)**

The Policy Subsystem is a mainframe subsystem which provides users with rapid access to the full text of Orders and Notices, Handbooks, Handbook Bulletins, Flight Standards Information Bulletins, Advisory Circulars, Policy Memoranda, Preambles, Legal Interpretations, Air Carrier Operations, Bulletins, and Medical Guidelines. It allows documents to be selected, viewed or printed by document number or according to user-specified criteria. PS also allows the text of rules associated with a document to be viewed by directly accessing the Automated Federal Aviation Regulations Subsystem. This subsystem resides on the IBM mainframe.

## **1.6 Subsystems Weaknesses**

When [MMELS](#) are updated for a particular aircraft, the FSDOs often do not get the documentation specifying what section of the document was updated. An ASI can spend hours comparing the newly acquired MMEL with the local MEL to find the discrepancy

Each subsystem, including FSAS, requires a different User Id and password for access. Some inspectors and managers have up to six different User Ids and passwords. They often write these

User Ids and passwords down on paper for reference. This defeats the purpose of having system security.

Although these mainframe subsystems contain a tremendous amount of data, many users of these system do not know how to access the data and they often do not know that the information exists.

Access to the mainframe subsystems needs to be more reliable and efficient. Access is currently made via modem and often the connection to the mainframe is denied because all of the available ports are busy. Under the current configuration, only a certain amount of concurrent connections are allowed on the mainframe. Therefore, if all connections are busy, access is denied until a connection is released.

## 1.7 Miscellaneous Systems

The following is a list of systems that are commonly used by FSDOs. Each FSDO is unique in the way it uses these systems and in the number of systems it uses.

### 1.7.1 Automated Correspondence Express (ACE)

ACE Documentation is a Windows based program which provides AFS personnel with the capability to use a standardize letterhead for correspondence. It works in conjunction with Microsoft Word. This program is a customized package which was specifically designed for use at the FSDOs.

### 1.7.2 CUFF

CUFF is a Windows-based budgeting program which allows AFS personnel to efficiently manage their yearly budget.

### 1.7.3 Travel Manager Plus

Travel Manager Plus is a commercial Windows-based product which combines travel regulation automation, electronic document processing and government forms generation into one easy-to-use software package. It allows AFS employees who travel to accurately fill out their travel paperwork on their PCs in a fraction of the time it takes to do it manually. This enables them to get their reimbursements in a more timely fashion.

### 1.7.4 South West Regional Data Tracking System (SWRDTS)

SWRDTS is a Windows-based product which allows AFS personnel to use a standardized letterhead for correspondence. Like the ACE product, this system works in conjunction with Microsoft Word and it was designed for use at the FSDOs. Several FSDOs use SWRDTS instead of ACE.

## 1.8 Known Systems Enhancements

During this evaluation several efforts to improve the AFS database systems were identified. The following items were at different stages of completion. These items could have an impact on any future system enhancements plans. Recommendations were added to these efforts based on the information pointed out to us by the ASIs and their managers.

- **Client/Server Environment:** CACI is presently building a database infrastructure for AFS. This infrastructure will allow all AFS systems to eventually migrate to the client/server environment with the consent of the owners of these systems. Great care will have to be taken to make sure that all related systems are migrated together and that all essential AFS

hardware and software contractors are well briefed on any migration efforts.

This migration effort will place the AFS data into three separate database systems (Mainframe, Paradox and Oracle). The migration effort will most likely be handled by multiple contractors. Therefore, some design standards need to be established to ensure that the user interface from one application to another will have a similar look and feel.

- **Two-Way Communication:** The two-way communication system between FSDOs that was mentioned earlier in this document is currently being worked on. Therefore, any effort to enhance FSAS will have to take this work into consideration.
- **Redesign of EIS:** The EIS system is presently being redesigned. The subsystem is being moved from the Data General computers to the client/server environment.
- **Redesign of AIDS:** AIDS is presently being redesigned. It is being down-sized to the client/server environment. It will run on Microsoft SQL Server using the Windows NT operating system. AIDS will then be referred to as the Improved Accident/Incident Database System (IAIDS).
- **FSAS Subsystems:** Two FSAS subsystems have been moved to the Microsoft Windows and client/server environments. VIS and OPSS have been converted to run on the Microsoft SQL Server platform. The subsystems are written in Microsoft Access. They are still being beta tested and they have not yet been released. The SQL-based VIS and OPSS are functionally equivalent to the existing DOS-based systems. They do not address the weaknesses identified by this study.

## 1.9 Conclusion

While the AFS systems contain a vast amount of data, many systems, especially FSAS, have become just a large repository of data. The data in these systems are difficult to access because the tools to access them are not user friendly and the quality of the data is poor. Therefore, ASIs very rarely use these data for analysis purposes. One ASI summarizes the problems with FSAS with the following statement: "We are currently working for FSAS; we need to get FSAS to work for us." FSAS was designed over 10 years ago and it no longer accurately reflects the functions of the AFS. Data entry fields that were not required years ago, are now required. Ready-made reports that were useful some time ago are no longer used. In addition, the subsystems in FSAS do not function as one integrated unit. Therefore, maintaining data integrity across subsystems has become a massive effort. Many FSDOs have come up with a temporary solution to help improve the quality of the data at the local level, while other FSDOs do not have the time or the resources to address this problem.

This study, while keeping the overall informational goals of the AFS in mind, focused heavily on the user's perspective. A wide cross section of AFS users were interviewed and were observed as they used the systems. The majority of the identified weaknesses are unique to FSAS since it is the most frequently used system. These weaknesses negatively impact the way AFS personnel perform their work. Therefore, by enhancing FSAS and by accurately addressing these weaknesses, a number of important benefits will be realized:

1. Users will be required to spend less time interacting with the system and will have more time to address other safety related issues,
2. Data stored in FSAS will be easily accessed to assist the ASIs in conducting inspections or planning efforts,
3. ASIs will take more initiative in using the system because they were directly involved in the analysis and will be directly involved in the design,
4. And the quality of the data in the FSAS databases will be vastly improved by having standardized data entry requirements.

# Chapter Two

## Development and Evaluation of Improved Display Prototypes

### 2.1 Summary

The purpose of this task was to develop prototype displays to demonstrate how existing Flight Standards Service (AFS) reference documents and databases would benefit from the application of a user-centered design approach to display design. Two prototyping efforts were completed under this subtask. The first effort was to develop a user interface that would address the problem issues with the Flight Standards Automation System (FSAS) that were identified in a related subtask. The second effort was to develop a multimedia prototype of an Inspectors Handbook. These prototypes capitalized on graphical user interface (GUI) technologies and Human Factors research on information presentation (color, formatting, direct manipulation, etc.). These prototypes emphasized ease of use and information utilization. The research team evaluated these prototypes in cooperation with aviation safety inspectors (ASIs).

### 2.2 Database User Interface Prototypes

The detailed study of the Flight Standards Service (AFS) database systems, as documented in the previous chapter (Chapter 1), outlined the manner in which the ASIs interact with the numerous database systems provided for their use. As a result of this study, several inherent weaknesses that are unique to the Flight Standards Automation System (FSAS) were identified. Please refer to Chapter 1 for a detailed description of these weaknesses.

A prototype user interface display was developed to demonstrate how the FSAS user interface could be improved. During development, several trips were made to the Atlanta Flight Standard District Office (FSDO) to demonstrate the prototype and to gather feedback on our efforts. The responses received from the ASIs and managers were positive. They felt that the functionality which the prototype provided would be very helpful in allowing them to perform their daily tasks.

During the detailed study of the AFS existing database systems, we were informed that the AFS is planning to upgrade the existing Paradox database system to a client/server environment in the near future. In this environment, processing is split between powerful servers and desktop machines. A powerful computer usually functions as the database server, which services the clients' requests. A less powerful desktop computer running a Windows-based system functions as a client and makes request to the database server. The prototype demonstrates some of the benefits that the AFS will realize when it makes the conversion to the client/server database environment.

The prototype is not a fully functional FSAS system. It merely demonstrates how some of the FSAS weaknesses can be addressed. The prototype only emphasizes enhancements to the Program Tracking and Reporting Subsystem (PTRS) and Vital Information System (VIS). However, the issues addressed in these two subsystems are applicable to the other FSAS subsystems as well. The following is a detailed description of the prototype, the weaknesses it addresses, and how these enhancements will benefit the AFS.

#### 2.2.1 FSAS Weaknesses Addressed

To address all of the weaknesses identified in Chapter 1 would be beyond the level of support provided for this activity. The prototype demonstrates enhancements to a subset of the FSAS weaknesses identified. The following is a list of the items that the prototype covers.

1. Demonstrate FSAS improved functionality in the Windows environment.
2. Provide data entry guidance to users within the Windows-based FSAS.
3. Demonstrate a more efficient search function within the Windows-based FSAS.
4. Demonstrate an easier way to access supporting subsequent screens (e.g., comment screens) within the Windows-based FSAS.
5. Demonstrate a more efficient text editor for entering comments within the Windows-based FSAS.
6. Demonstrate how selected Windows-based FSAS subsystems interact if the subsystems were more tightly integrated.
7. Demonstrate how selected Windows-based FSAS subsystems function if the database was normalized resulting in the elimination of duplicated data between the subsystems.
8. Demonstrate an improved ad-hoc reporting function. This new reporting function was not demonstrated by the prototype, however, various ad-hoc reporting tools that work within the Windows and client/server environments were investigated and are documented in this report. These issues are explained in detail in the following sections.

### 2.2.2 FSAS in the Windows Environment

The current implementation of FSAS is a DOS-based, Paradox-driven application that is not compatible with the Windows operating environment. The ASIs and other AFS users often use several Windows-based software packages along with FSAS on a daily basis. Both FSAS and the Windows Operating System cannot operate simultaneously on the ASI's desktop computer. Therefore, if a user is in FSAS and he/she needs access to a Windows-based software package, the user will be required to exit FSAS and then start the Windows Operating System.

This prototype demonstrates how a Windows-based FSAS system would operate in a client/server environment and how it would benefit the AFS. Because this FSAS prototype adheres to standard Windows design, users who are already familiar with Windows will also be familiar with the functionality of the prototype. Each subsystem is designed using the MS Windows standards for a common look and feel thus ensuring similar functionality. Hence, very little time will be spent retraining users to use this system.

The prototype attempts to guide the users through the system. Emphasis is placed on ease of use and on presenting the users with valuable information when appropriate. [Figure 2.1](#) shows the main FSAS screen. From this screen all FSAS subsystems (PTRS, VIS, OPSS, KEYMGR, JOBAIDS, and PLANNING) are accessible. The user-id and user information displayed is acquired from the Flight Standard Electronic Office system (FSEO). The FSEO system provides a single point of user login. Please refer to Chapter 4 for a detailed description of the FSEO software. The prototype demonstrates how the user can be aided by presenting the most frequently used choices. [Figure 2.2](#) represents the VIS main entry screen which contains the most often used functions. The screen allows the user to select the appropriate form from the form type section and then to select whether to create a new form or open an existing one. The description on the bottom of the screen describes the form type that is selected. The options presented on the main screen (Open, New) can also be accessed from the Activity menu option. [Figure 2.3](#) is a representation of the activity menu. The Edit menu offers the standard edit options available in the windows environment such as Cut, Copy, Paste, and Clear.

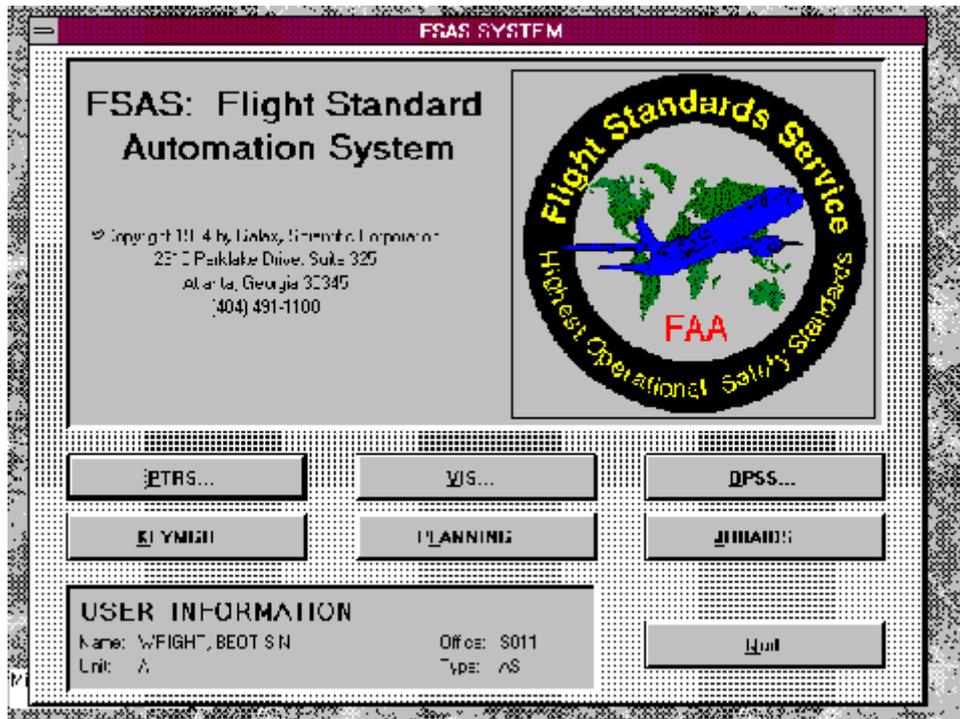


Figure 2.1 Main FSAS screen

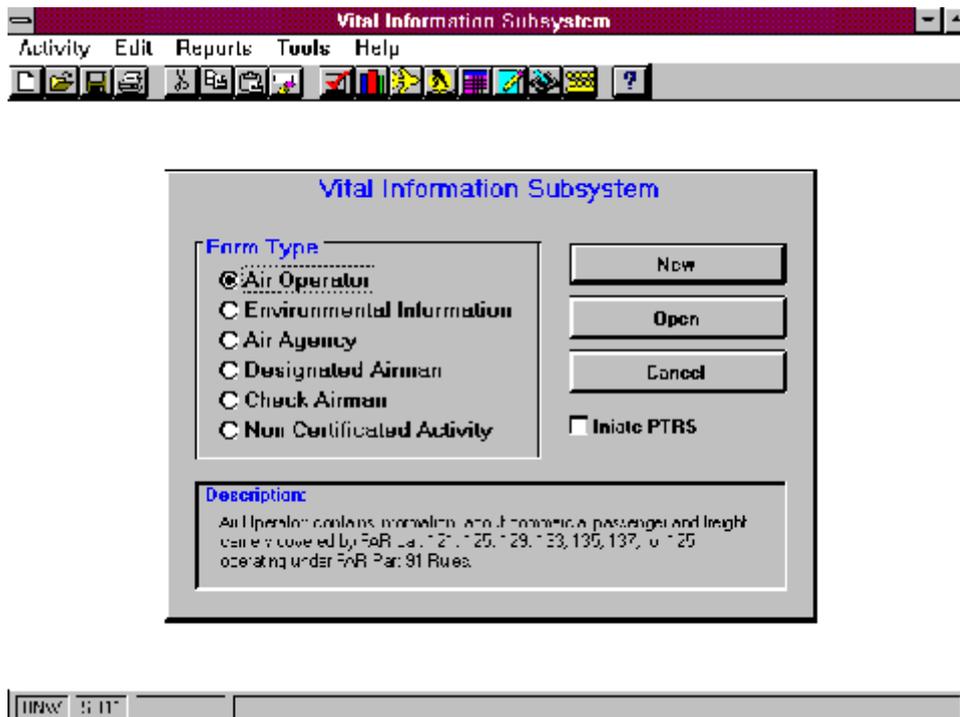
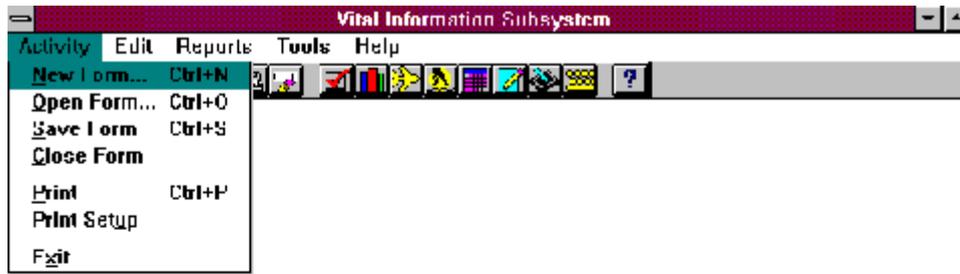


Figure 2.2 VIS main entry screen



**Figure 2.3 VIS activity menu**

These options under the Edit menu allow data to be copied within or between applications. The Reports menu option will provide access to pre-defined reports and to the ad-hoc reporting system. The Tools menu provides quick access to PTRS and VIS. The Tool Bar located at the top of the screen provides the same functionality as the menu items, but it presents the choices in a graphical form. A balloon help function was integrated into the prototype so that whenever the cursor is moved over an item on the Tool Bar, a brief description of the item is displayed. [Figure 2.4](#) illustrates this functionality. The Tool Bar can also be customized by the user. It can be used to gain quick access to frequently used applications. Therefore, some items on the Tool Bar, such as the one depicted in [Figure 2.5](#), are optional.



### Figure 2.4 Balloon help function

The AFS intends to convert all of the major safety-related database systems to run within Windows. When this takes place, the ASIs and other AFS users will no longer be required to exit one subsystem in order to start another. This will reduce the time and effort it takes to access these subsystems. In addition, by having all major systems running under the Windows environment, data can be easily transferred within and across subsystems. For example, if an ASI needs to write a memo in MS Word and he/she needs to reference information in FSAS, the ASI can transfer this information from the appropriate subsystem to the memo directly by using the standard cut and paste functionality in Windows. Another advantage of having all major database systems running in the Windows environment is that several safety-related subsystems can be run simultaneously. Therefore, a user can potentially have PTRS, VIS, and OPSS running at the same time, which is important if the user needs to copy information across subsystems. The only limit to the amount of subsystems that can be up and running simultaneously is the amount of memory that is installed on the user's desktop computer.



Figure 2.5 Optional tool bar

The AFS will eventually migrate its major applications to the Windows environment, but this will take time. This will result in some systems continuing to reside on the mainframe computers before the transition is complete. However, access to the mainframe via Windows will not be a problem because there are several software packages on the market that effectively address this issue. Procomm for Windows and IBM Personal Communication System are two such packages that will allow users working in the Windows environment to access the mainframe. This will allow a user to cut and paste information from mainframe applications to Windows-base PC applications.

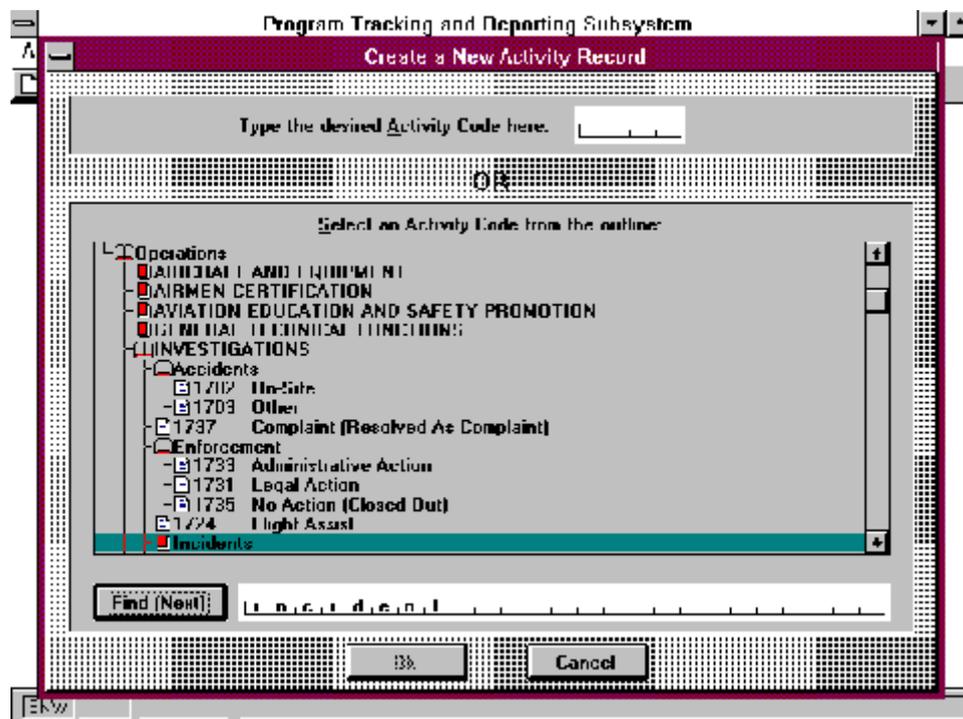
### 2.2.3 Data Entry Guidance

Although the existing FSAS provides some help in relation to valid entries for some fields, it is not enough and it is often too generic. The Windows-based FSAS prototype demonstrates how data entry guidance can be provided to the users. The prototype emphasizes two ways of providing

guidance to the users.

### 1. Easy Access to User Manual Data

First, it moves frequently used data from user manuals to on-line computer files and provides users with an easy and efficient method of accessing the data in these files. For example, [Figure 2.6](#) illustrates the activity numbers selection screen in the PTRS prototype. If the activity number is known, it can be entered directly. If it is not known, a search can be performed on a particular topic and then the appropriate activity number can be selected. This can be easily accomplished by entering the topic in the Find Next field, click on the Find Next button or by using the ALT F key combination. The subsystem will find the first occurrence of the topic and display a symbol representing a book. Clicking on the book will display the appropriate activity numbers relating to the specified topic. At this point the appropriate activity number can be selected by highlighting it and clicking on the OK button.



**Figure 2.6 Activity Numbers Selection Screen in PTRS Prototype**

### 2. Field Sensitive Information

Second, as the user moves to a field, a message is displayed on the bottom of the screen detailing the valid entries for that particular field. [Figure 2.7](#) illustrates this functionality. Each field has an associated help text, so the user will always have an idea of what to do next.

**Figure 2.7 Example of Field Sensitive Functionality**

## 2.2.4 Search Capabilities

The searching capabilities in FSAS are very limited, particularly in PTRS. In this subsystem, searching can only be done by Record ID. If a record needs to be retrieved for an update or for viewing and the Record ID is not known, a special query will have to be run by the system administrator to find the record. The prototype addresses this problem by providing search capabilities on fields that are more useful to the users. [Figure 2.8](#) shows the PTRS search screen in the prototype. A search can be done by Activity Number, Start Date, Record ID, Designator and NPG fields. In addition, a search can be done using a single field or multiple fields. This search function was originally developed in the Inspector's Field Kit. It was integrated into the prototype with minor modification.

## 2.2.5 Easier Access to Subsequent supporting Screens

The subsequent data entry screens for comments in the existing FSAS system are too difficult to access. In order to access these screens, a user is required to step through several intermediate screens. The FSAS prototype handles this inconvenience by allowing access to all subsequent screens from any screen. [Figure 2.7](#) illustrates this functionality. On the top of the each screen there are five tabs (1a Activity, 1b Activity, Personnel, Equipment, and Comments). Each tab represents a separate screen in the current FSAS system. In the prototype, if access is needed only on the 1a Activity screen then on the comment screen, it will be a matter of just clicking on the appropriate tabs.

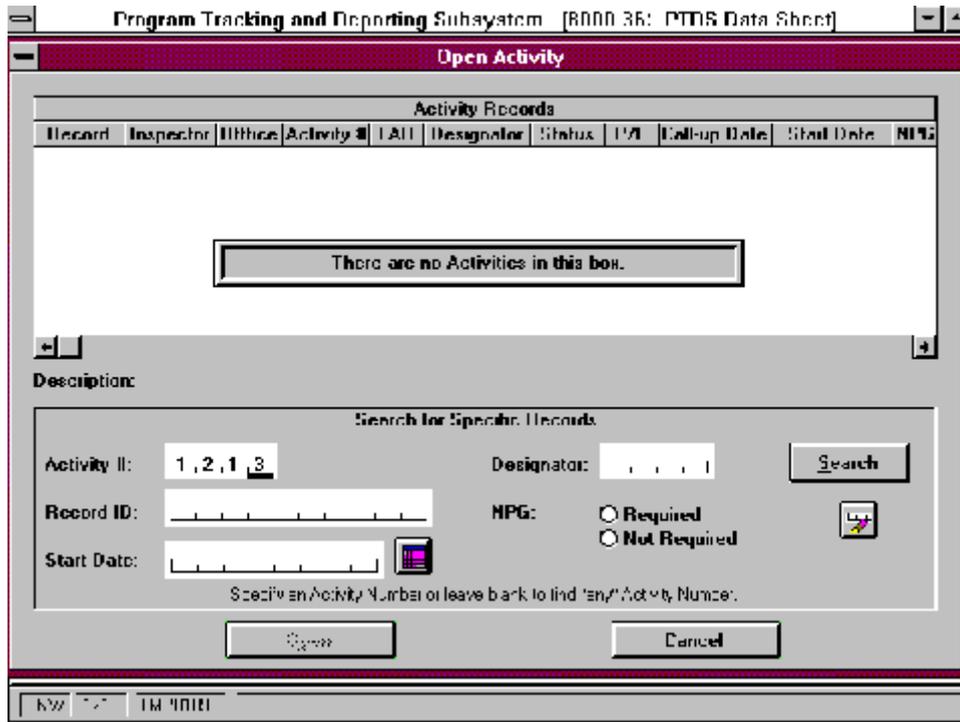


Figure 2.8 PTRS Search Screen

### 2.2.6 Text Editor

The Text Editor is used for entering comments. In the existing FSAS systems it is very difficult to use. One obvious inconvenience is that it splits lines within words instead of between words. [Figure 2.9](#) depicts a text editor resident in the FSAS prototype which provides most of the functionality of a word processor. It allows users to cut, copy and paste text within or across systems. In addition, it splits lines in the appropriate place.

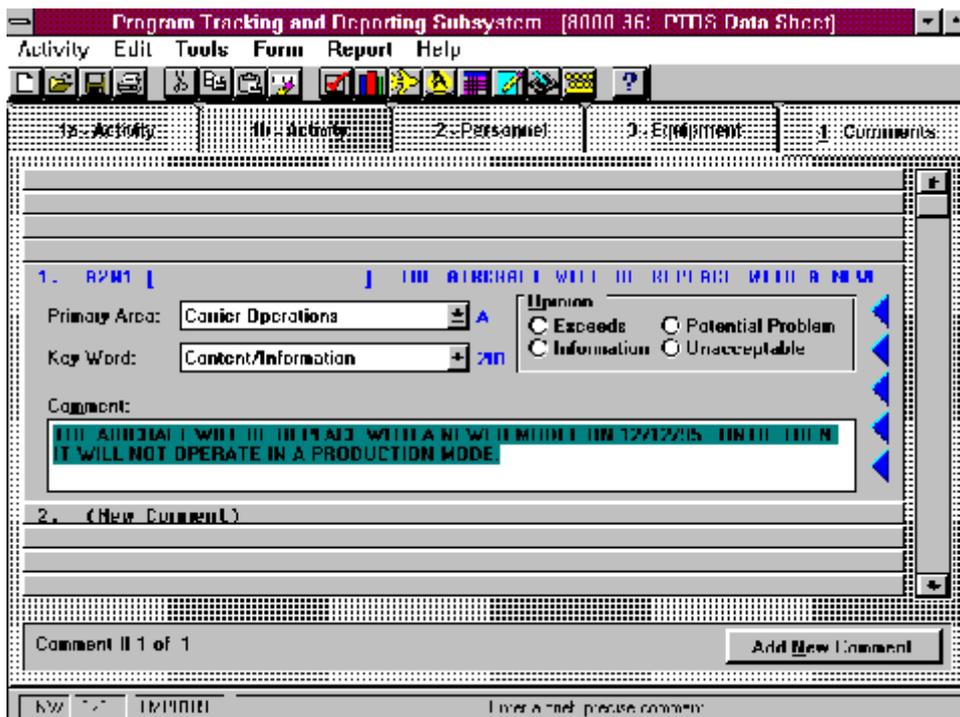
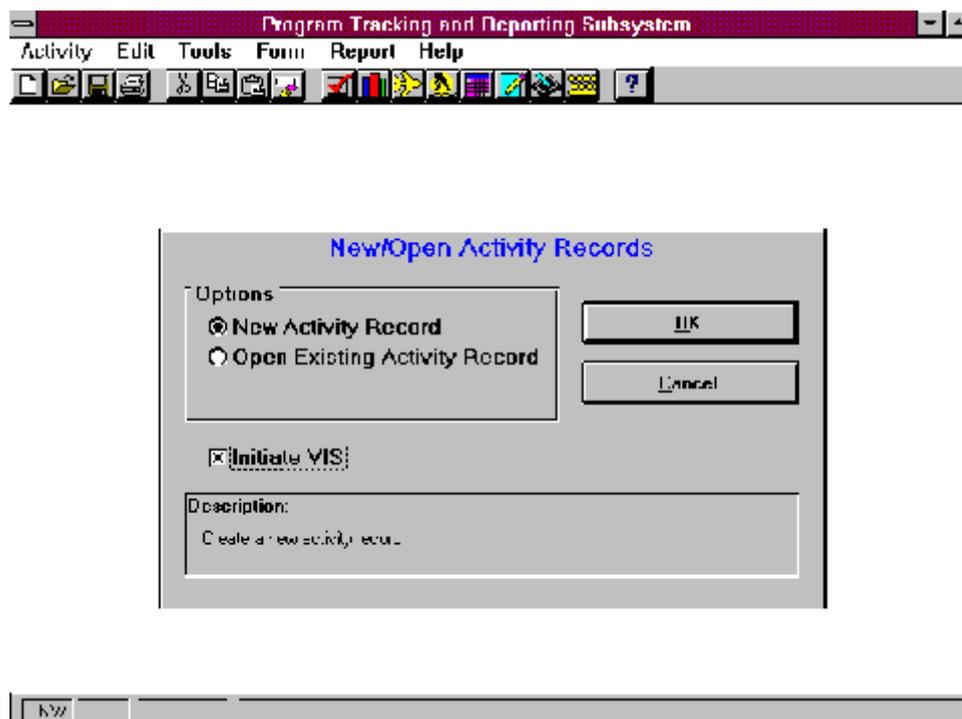


Figure 2.9 Duplicate Data Entry

### 2.2.6.1 Duplicate Data Entry

The ASIs log the majority of their daily tasks into PTRS. However, there are several tasks that require the ASIs to enter data into multiple FSAS subsystems. The same data elements are frequently entered across these subsystems. The task of adding an air operator requires that an ASI enters the same information relating to the FAR, Designator Code and Name, and Personnel into PTRS, VIS and the Operation Specifications Subsystem (OPSS). This is very time consuming, often frustrating to the users, and it also leads to data integrity problems.

The prototype remedies this situation by allowing the user to selectively choose to transfer data between subsystems, if the task requires it. For example, if a user wants to add an air operator, he/she would first access the PTRS. [Figure 2.10](#) shows the main startup PTRS screen. The user would then select the 'Initiate VIS' option on the PTRS startup screen because this task requires duplicate data entry across subsystems. After the user saves the information in PTRS, the VIS system is automatically started and the FAR, Designator Code and Name, and Personnel Name and Title fields in VIS will be automatically populated with the information entered in PTRS. [Figures 2.11](#) and [2.12](#) show the PTRS and VIS screens with the data entered. If the user had chosen to access VIS first, the same functionality would have been available through VIS.



**Figure 2.10 Main Startup PTRS Screen**

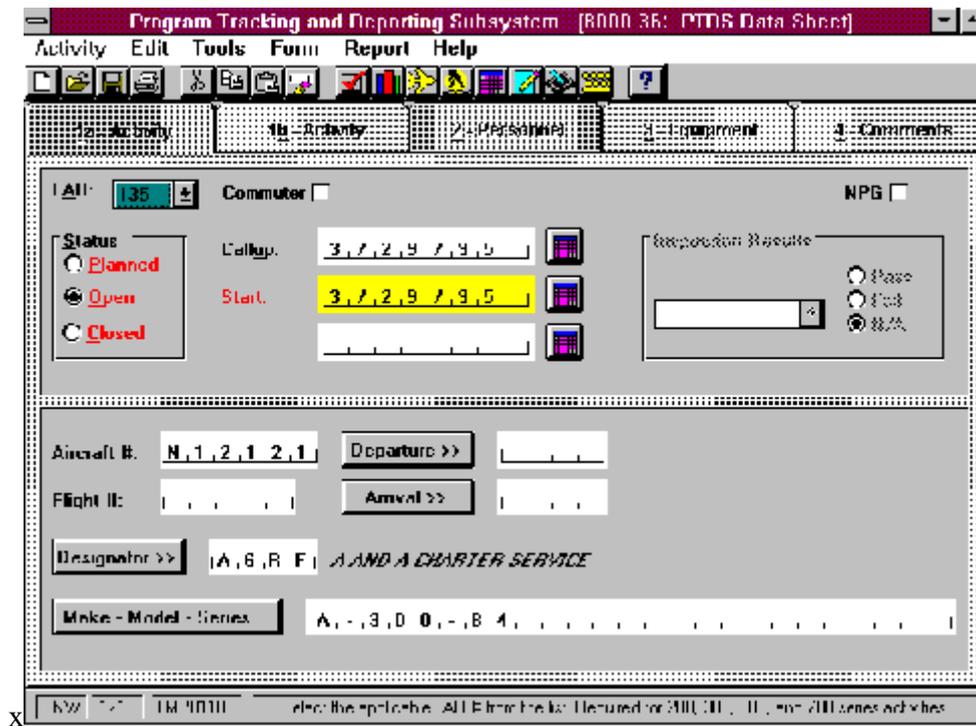


Figure 2.10 Main Startup PTRS Screen

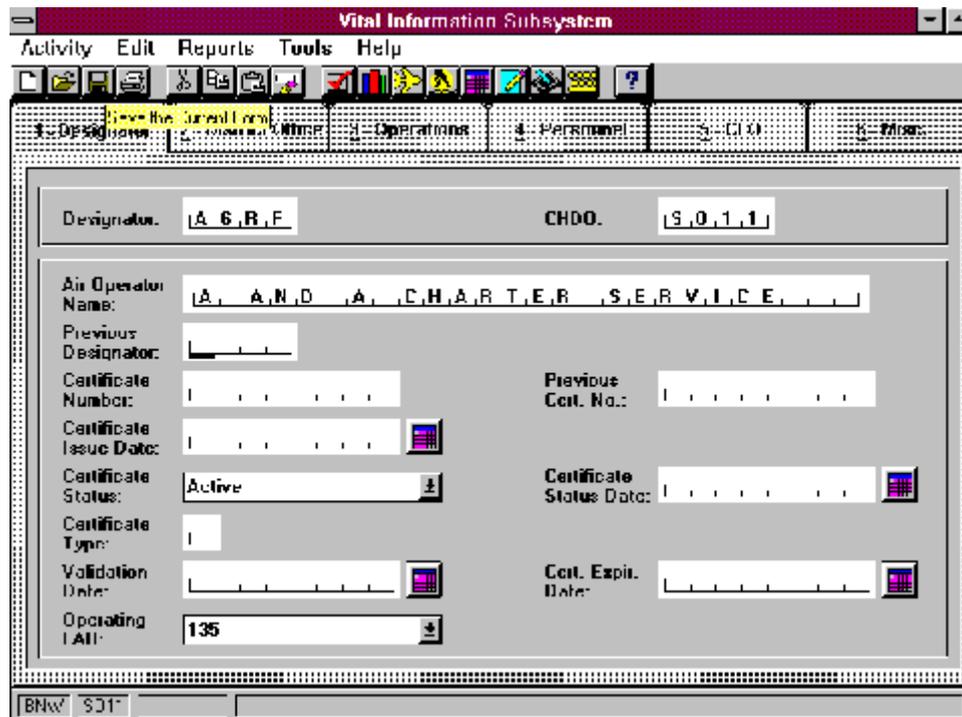


Figure 2.12 VIS Screen

### 2.2.7 Subsystems Integration

The prototype demonstrates how the FSAS subsystems can be more tightly integrated when running in a client/server environment with normalized databases. This allows data to be migrated from subsystem to subsystem because all subsystems will have a common source of data. The prototype also allows any subsystems to be started from within another subsystem. For example, while a user is

in PTRS, he/she can access VIS or OPSS by accessing the Tools menu and then select the appropriate system. At this point the user will have multiple systems running at the same time. The user will not be required to exit the current subsystem he/she is in before accessing another subsystem.

### 2.2.8 Ad-hoc Reporting tools

The ad-hoc reporting function resident in the existing FSAS is extremely difficult to use. In order to effectively use the ad-hoc function, a user needs an adept knowledge of the Paradox Database system. Many ASIs like the idea of an ad-hoc function, and they indicated that they would use this feature more if it was easier to use.

As was mentioned earlier, the AFS has decided to move to a client/server environment. Therefore, we looked at several ad-hoc reporting tools that could benefit the AFS and that could be easily integrated into any Windows-based database system. These tools all run in the client/server environment. Because access to a client/server environment was not available during the investigation period, the evaluation of these tools was based on documentation retained from the various software vendors and trade journals. The following is a brief description of three reporting tools investigated as well as their relative merits to the AFS.

#### *Crystal Reports Professional 4.0*

Crystal Reports from Seagate Software Company includes a report wizard that will walk a user through the process of creating various types of reports, such as standard columnar, cross-tab, and summary reports. In many cases a user can create a report in three simple steps. First, the user chooses the type of report he/she wants. Second, the user selects the fields and drags and drops them to the appropriate place on the report formatter. Finally, the user generates the report. Crystal Reports can benefit both the developers and the end-users alike. Developers' data dictionaries can be created, which store pointers to the databases and connection types that are used most frequently. The dictionaries could be passed on to the users, and let the users run ad-hoc reports without having to understand complicated table relationships and data types. Crystal Reports also has an excellent charting tool that provides users with the capability to view data in a graphical form.

#### *ReportSmith for Windows 2.5*

ReportSmith by Borland International Inc. is very similar in terms of functionality to Crystal Reports. However, ReportSmith is the fastest reporting tool of the three. It also provides a more extensive and flexible field criteria selection box. Therefore, very complex reports can be generated without any programming effort. Like Crystal Reports, fields can be placed on the report formatter by dragging and dropping them to the proper location. However, ReportSmith automatically calculates the best fit for the report and lays out the data on the screen accordingly. The users' ability to manipulate the report design is far better than any of the other two products. It also contains an integrated charting tool, which allows a user to view data graphically.

#### *R&R Report Writer 6.0*

R&R Report Writer by Concentric Data Systems Inc. was the most difficult to use of the three products. It was a bit difficult to select the fields a user wanted on a report in R&R. Unlike the other packages, there was no way to select all the fields at once to place them on the report formatter. The report formatter in R&R is the weakest of the three, providing only the traditional banded-style-report design tool. This formatter is very similar to the one in the current FSAS ad-hoc reporting system. R&R Report Writer does not provide an integrated charting tool. To create a graph, a user would have to export the data into a software package that supports graphics, such as Microsoft Excel.

Crystal Report and ReportSmith are two reporting tools that can definitely benefit the AFS users. These tools run in the Windows-based client/server environment and will allow users to generate ad-hoc reports by simply selecting the type of report, the necessary fields, and then generating the report. Prior knowledge of a programming language or database structures is not required. These reporting tools can effectively hide the complexity of table relationships and data types from users. Users are able to extract data from the database in the form of a report or graph without being concerned about where and how the data is stored.

## 2.3 Inspector's Handbook Multi-Media Prototype

There is a tremendous amount of information contained in the Inspector's Handbooks utilized by the ASIs. The ASIs currently use a paper version of these documents to assist them in performing their duties. Recently, versions of these handbooks have been produced in digitized form and distributed on CD-ROM. These digitized handbooks have several time-saving features such as word/phrase search, linking, and database navigation functions.

Flight Standards Service (AFS) aviation safety inspectors (ASIs) can increase their productivity by being provided with a tool to quickly and comprehensively access information contained in the Inspectors Handbooks. Such information serves as reference material and basic guidelines to the ASIs. A prototype of the Inspectors Handbook software was developed to address this need. This prototype incorporated several time-saving features such as word/phrase search, document linking, and efficient navigation. Multimedia technology was integrated into the software to provide the inspectors with a subjective evaluation in situations where traditional methods of instruction fail.

This task challenged the research team to determine if the ASIs could benefit from the intelligent integration of multimedia technology (primarily video and audio) in the handbooks, and if so, how it would best be implemented.

### 2.3.1 Requirements Definition

There are many factors to be considered in creating a multimedia-inspectors handbook. First, the system must be fully useable and understandable to the aviation safety inspector. This will be insured with a user-centered design approach: capitalizing on rapid prototyping and interactive development driven by user evaluation and feedback. Second, the system must be developed on computer technology that is compatible with FAA's current and evolving systems. This will be ensured by working closely with the Training and Automation Committee, and with other FAA research projects like PENS. Third, the multimedia information system should be easily modified to incorporate updates and document evolution. This will be insured by the use of commercial off-the-shelf software development tools.

Presently the ASIs have a choice of either carrying the handbooks with them in the field or leaving them behind. If the ASIs carry the handbooks with them, they find the handbooks are bulky and cumbersome to carry. The ASIs must then sift through large amounts of information. It is a mammoth task to search for something unless the location is specifically known. Cross-referencing documents also becomes a major problem. Another option is to leave the handbooks behind and just look up the information needed before leaving the office. This is not always possible. In such situations, the ASIs could jot down the information required and return to the office to look it up. This approach leads to inefficiency and delays as the information is not available on hand to look up. This could present a problem in certain situations where time is of the essence, for example in a ramp inspection situation. The ASIs would then rely on their past knowledge or experience which may not be up to date with the most recent revision of the handbooks.

Current multimedia technology can be used to deliver the Inspectors Handbook on-line, complete with an efficient searching function and hyperlinks between relevant documents. This will reduce the ASIs physical and mental workload. The integration of multimedia features also has the potential to

provide refresher training and/or initial training based on an individual inspector's need. The entire software could be put onto a portable notebook computer equipped with a CD-ROM which the ASIs could carry with them on the field. This way the ASIs would have instant access to the most current handbook information. This would enable them to perform their tasks more efficiently.

Through a series of meetings and discussions with ASIs, it was determined that the most promising application of multimedia information technology would be in support of tasks where the ASIs are required to make qualitative judgments based upon visual observations. Less experienced ASIs and all ASIs who perform some type of visual assessment could benefit from an on-line video or graphic to aid them in their decision-making process. Another promising application of this technology is to provide background or tutorial information concerning a complex or detailed issue.

### 2.3.2 Methodology

The Inspectors Handbook software prototype was developed using the principles of human-centered design. The tasks of the ASIs were first analyzed. During interviews with the ASIs, several observations were made as to how the handbooks were actually used by the inspectors. The following is a list of ASIs' activities observed and how handbooks were used:

- Looking for a specific reference by either using the Table of Contents to look up a specific chapter and/or browsing throughout the document looking for related information.
- Placing bookmarks at useful or frequently referenced sections in the document.
- Annotating a specific paragraph or section.
- Referencing another document related to the topic of interest.
- Physically inserting related reference documents in the handbook at appropriate locations.
- Comparing change notices with the old version of the document to determine what has changed and how it effects their activities.

The above observations revealed the need for developing a computer based software which would aid the ASIs in their day to day tasks. This entailed putting the Inspectors Handbooks on-line with various features such as search, hyperlinks, and multimedia which would help the ASIs navigate through the handbooks. For the initial prototype, it was decided to include a subset of the Inspectors Handbooks which would serve to demonstrate the capabilities of the software. The PC platform was chosen for developmental work as it was compatible with the FAA's current and evolving systems. The necessary digital documents, figures, and videos were created and integrated to ensure a comprehensive prototype. The initial prototype was developed and shown to the ASIs to get their feedback. The prototype was then cycled through several iterations based on their suggestions. Emphasis was placed on interactive development driven by user evaluation and feedback. Different scenarios were developed and evaluated for inclusion in the prototype. The prototype was also shown to different people internally to test for usability and to debug it.

The software prototype is PC compatible. The software prototype development environment was Windows for WorkGroups 3.11 running under MS DOS 6.2. The programming was done in Visual Basic 3.0 and Borland C++ 4.0 with support from Windows SDK 3.1. Database support was provided by MS Access 2.0 and Hypermedia Information System (an internally developed database.)

### 2.3.3 Description

#### 2.3.3.1 General

When the Inspectors Handbook software is started up, a screen similar to the one shown in [Figure 2.13](#) is displayed. Handbooks 8300-10 and 8400-10 can be accessed in the prototype. By directly placing the cursor on one of the titles and selecting it will bring up the table of contents. The table of

contents uses an outline type of index. For example, when the user first enters the screen, only the volumes contained within that handbook are displayed. Selecting a particular volume by moving the mouse over it and clicking on it brings up the list of chapters contained within that volume as showed in [Figure 2.14](#).

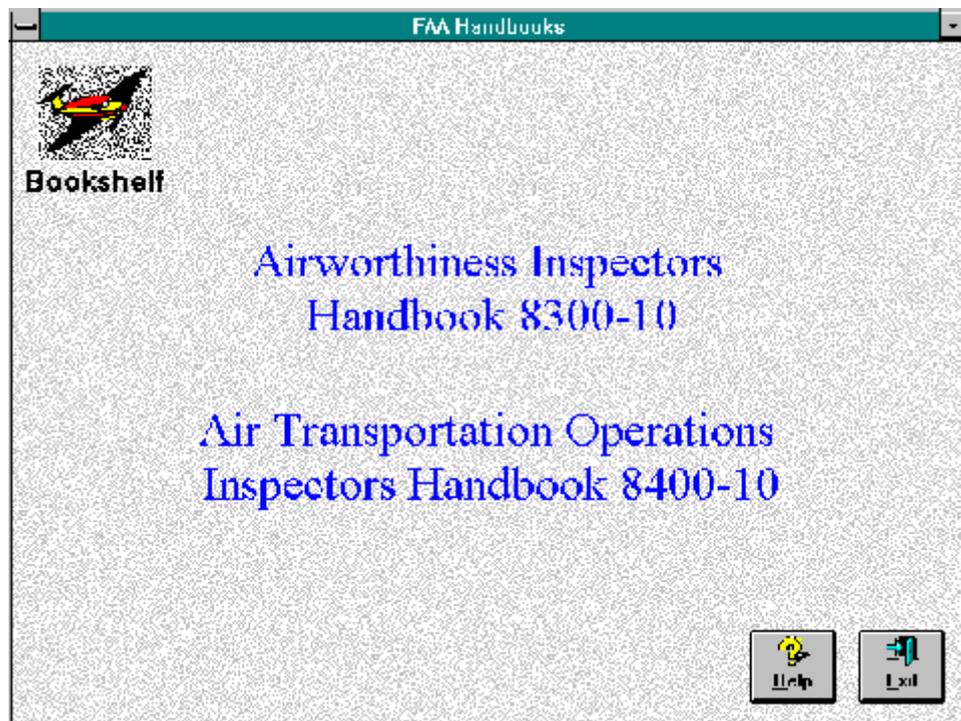


Figure 2.13 Inspectors Handbook

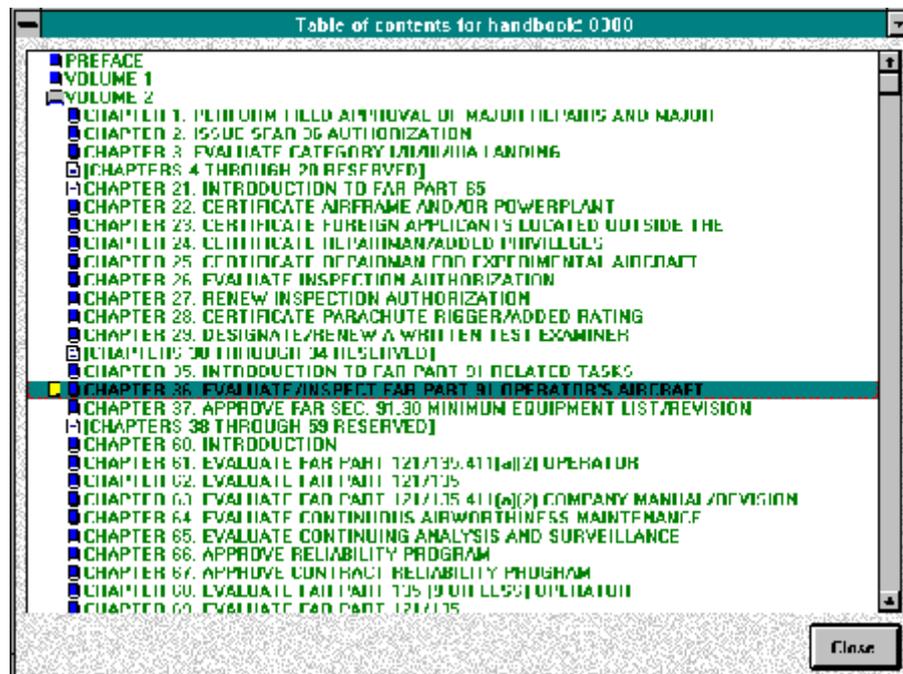
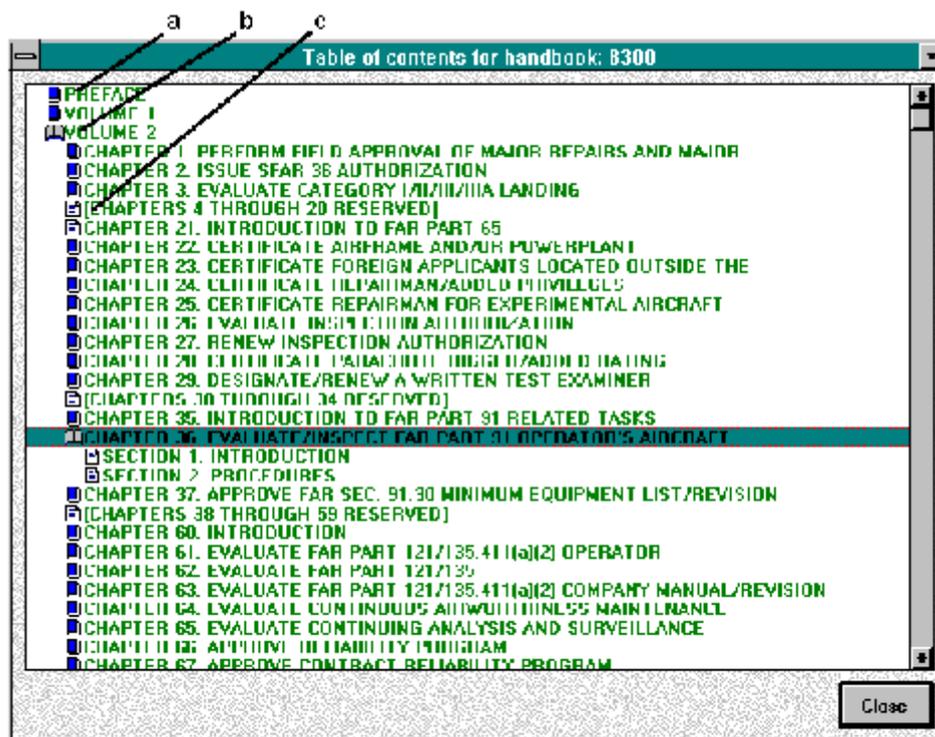


Figure 2.14 Table of Contents

The expanded volume has an 'open book' icon associated with it which indicates that the items contained within the volume have been displayed ('b' in [Figure 2.15](#)). The other volumes have a

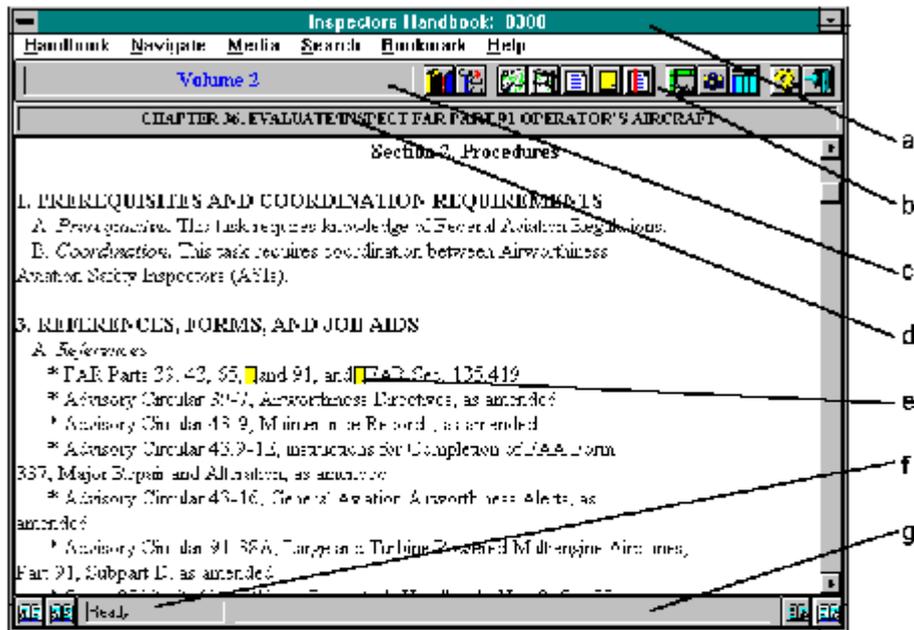
'closed book' icon associated with them indicating that they could be expanded to display their contents ('a' in [Figure 2.15](#)). Selecting a particular chapter brings up the list of sections contained within that chapter as shown in [Figure 2.15](#). The section items have a 'book leaf' icon associated with them indicating that the user could select any of the section items and directly navigate to the associated text ('c' in [Figure 2.15](#)). If the user selects another volume at this time, the earlier list of chapters and sections is automatically collapsed and the new list of chapters is displayed. The icons associated with each list entry automatically change to denote the updated status of each item.

Clicking on a particular section of the Table of Contents will bring up the text related to that section as shown in [Figure 2.15](#). The current position in the handbook is indicated by three information bars ('a', 'c', and 'd' in [Figure 2.17](#), which display the current handbook name, the current volume number, and the current chapter number and name. The user always has access to this information which helps in navigating through the handbook. The Inspectors Handbook prototype has a fully functional toolbar ('b' in [Figure 2.17](#),) which gives access to all the features contained within the software.



- a - closed book icon
- b - open book icon
- c - leaf icon

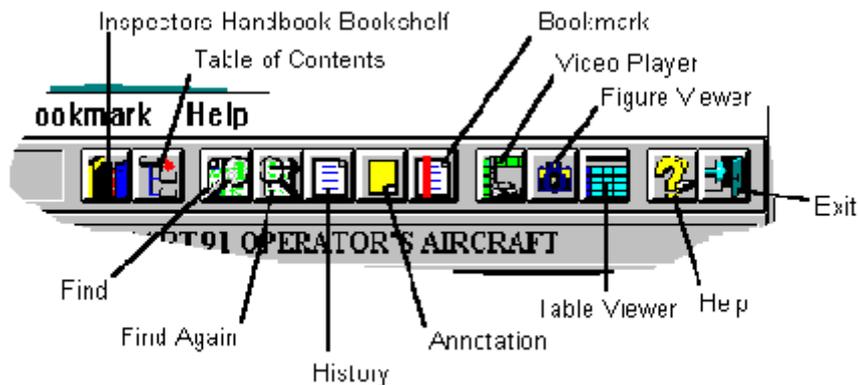
**Figure 2.15 Expanded Table of Contents**



- a - Handbook Title
- b - Toolbar
- c - Volume Number
- d - Chapter Number
- e - Annotation icon
- f - Application status bar
- g - Status bar

**Figure 2.17 Handbook Information Screen**

The expanded figure of the toolbar shows all the buttons contained in the toolbar (Figure 2.16) The 'Inspectors Handbook Bookshelf' button can be used to access a different handbook. The 'Table of Contents' button displays the complete break up of the current handbook. The 'Find' button is used to display the search dialog box. The 'Find Again' button is used to find a particular search term again. The 'History' button can be used to return to a previously navigated document. The 'Annotations' button brings up a list of the annotations for the current chapter. The 'Bookmark' button allows insertion/deletion of bookmarks. The 'Video Player' button brings up the video player along with a list of available videos. The 'Figure Viewer' button brings up the figure viewer along with a list of available figures. The 'Table Viewer' button is similar to the 'Figure Viewer' button. The 'Help' button brings up the help topics for the Inspectors Handbook prototype (not yet developed.) The 'Exits' button closes the application.



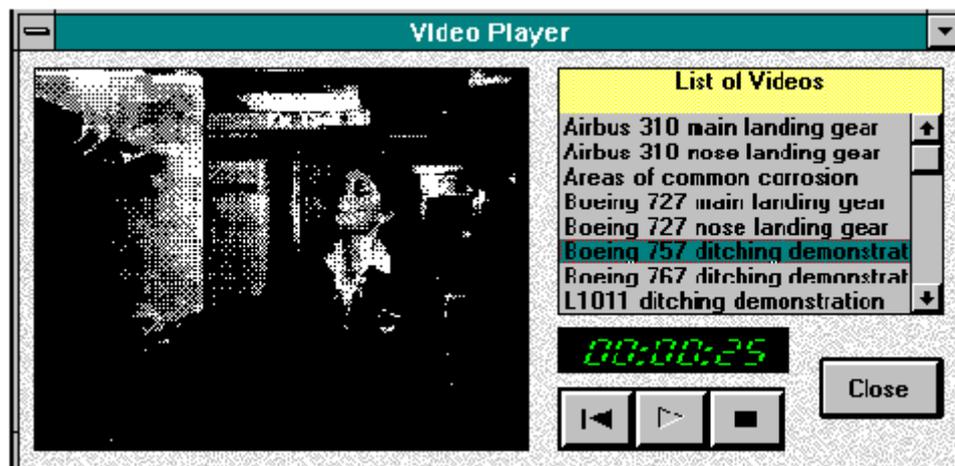
**Figure 2.16 Toolbar Functions**

### 2.3.3.2 Multimedia Information

Many of the tasks performed by the Airworthiness ASIs are visual in nature, such as looking for signs of corrosion, physical damage, and incomplete or improperly performed maintenance actions. Supplemental multimedia information would assist in such activities if they are new to an inspector or performed infrequently. Another use of multimedia information would be in providing training/refresher courses.

For example, the Inspectors Handbook prototype has video clips on corrosion which explain the corrosion process and describe the common areas where corrosion occurs. These clips could help a new ASI in learning more about corrosion. An ASI inspecting the landing gear of a particular aircraft may need more information about the procedures involved. The video clips related to landing gear information could be brought up on screen and the video clip related to the aircraft being examined could be played. These video clips would assist the ASIs in their inspection task.

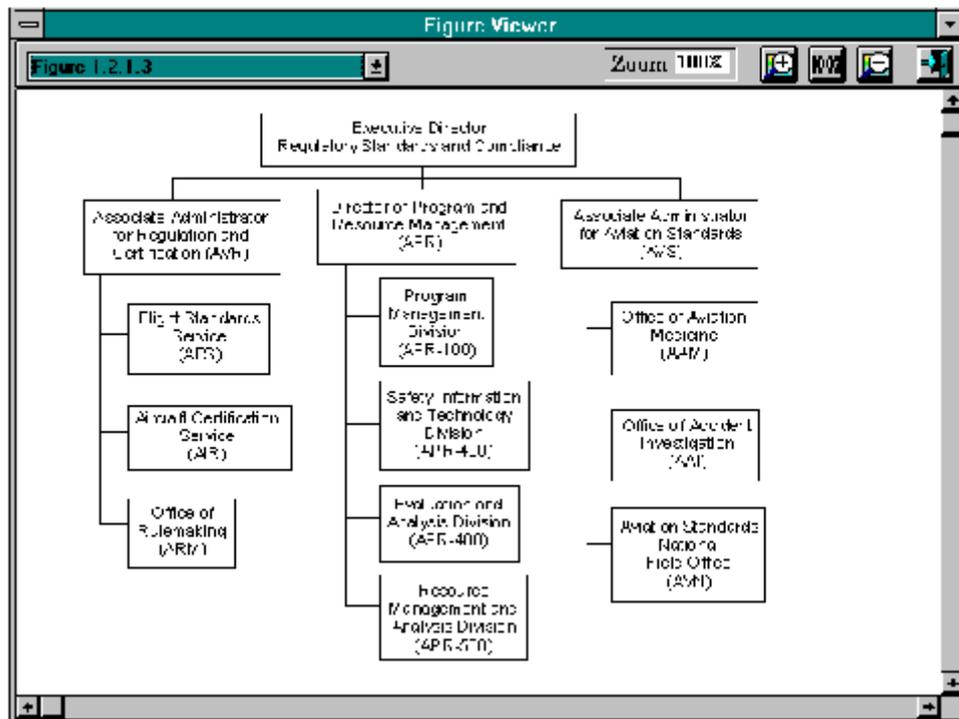
*Video Player:* The video player ([Figure 2.18](#)) allows playback of video clips related to a particular section in the document. The list of video clips is automatically selected based on the current document context. For example, if the user selected a video hyperlink describing corrosion, only the videos related to corrosion would be displayed in the list box. The time counter shows the elapsed time.



**Figure 2.18 Video Player**

Similarly, graphics or pictures may provide more information than words alone. For example, the severity of tire tread wear could be easily determined by comparing the acceptable tire tread wear photographs with the actual wear. This acceptable tire tread wear photographs could be easily accessed from the Inspectors Handbook software using the 'Figure Viewer' ([Figure 2.19](#)).

*Figure Viewer:* The figure viewer control ([Figure 2.19](#)) has the capability to display 'bmp', 'gif', and 'pcx' format pictures. The picture control has a zoom range of 1% to 999%. Selecting a figure hyperlink starts up the picture viewer and automatically loads up the relevant picture.



**Figure 2.19 Figure Viewer**

### 2.3.3.3 Software Specific Features

**Hyperlinks:** Three different types of hyperlinks have been implemented in this software. They are text hyperlinks, figure hyperlinks and video hyperlinks. The software automatically determines the type of hyperlink and executes the corresponding actions. Text hyperlinks allow navigation between relevant documents. Figure and video hyperlinks bring up related figures and videos.

**Search function:** The search function ([Figure 2.20](#)) has the option of searching through the current section or through the entire book. Boolean searches are allowed in the search function. Once the list of occurrences is brought up, it is possible to directly navigate to a particular occurrence. The ASIs can again return to this window to pursue other hits from the search.

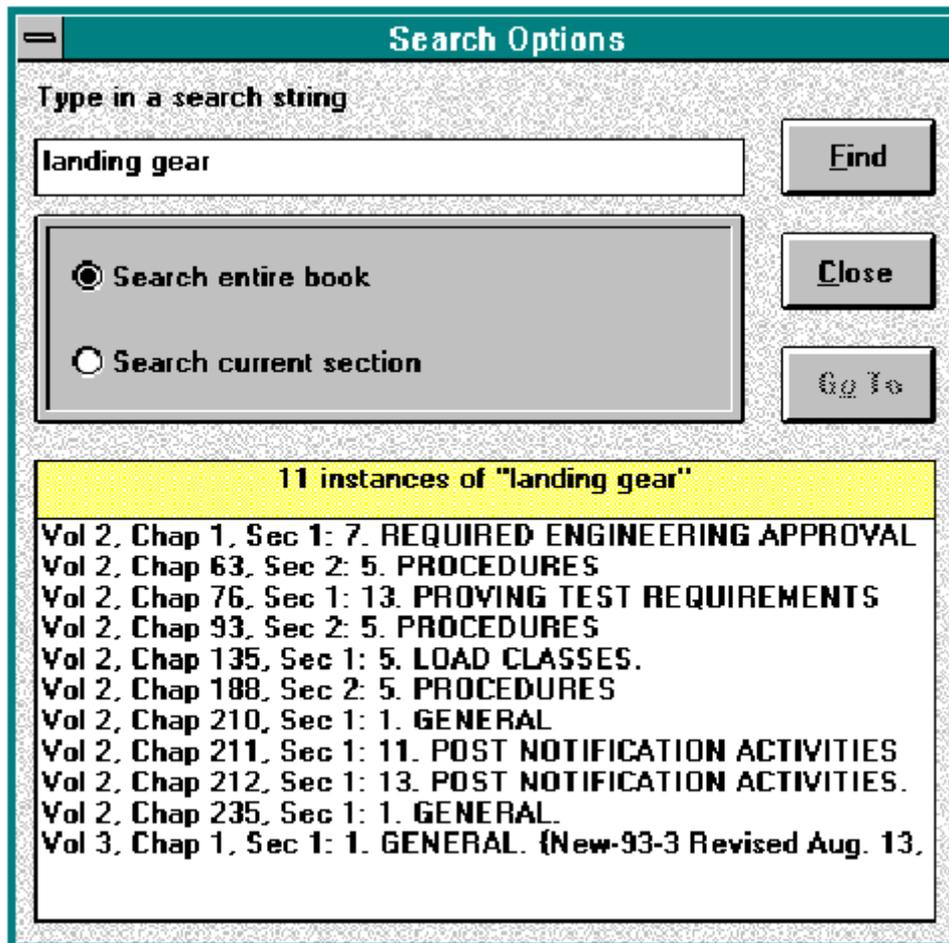


Figure 2.20 Search Function Dialog Box

*History function:* The history function ([Figure 2.21](#)) keeps track of user navigation through the chapter. Each section that the ASI views is recorded by this function. This facilitates an ASI in returning to a previously viewed section or switching back and forth between two or more sections.

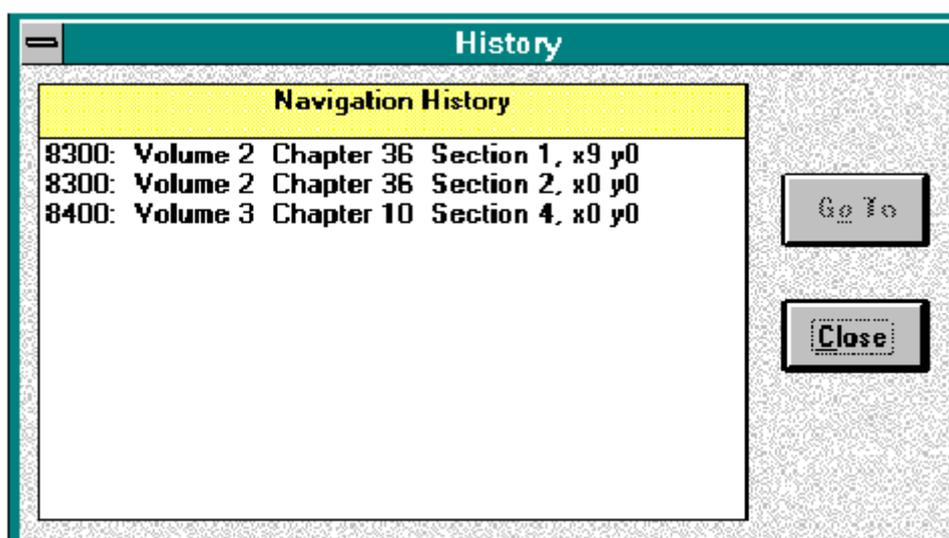
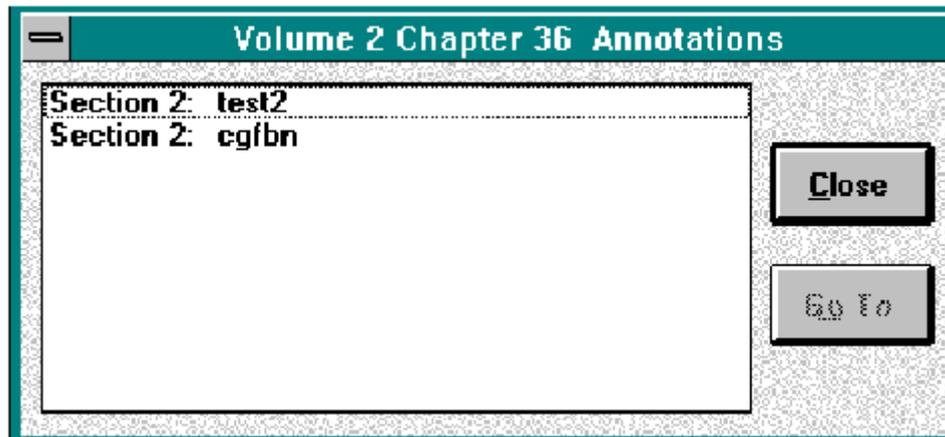


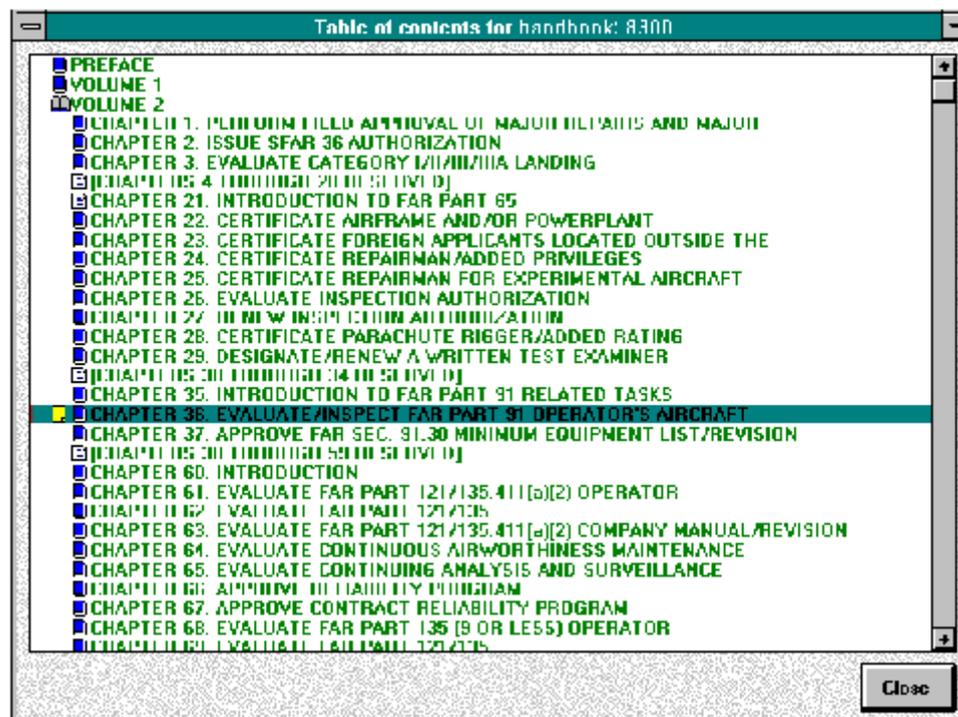
Figure 2.21 History Dialogue Box

*Annotation function:* The annotation function ([Figure 2.22](#)) allows users to annotate a particular section or paragraph. A small annotation icon comes up wherever the annotation is made ('e' in

[Figure 2.16](#)). The table of contents is also updated to show that annotations exist for a particular chapter by putting a small icon next to the chapter title ([Figure 2.23](#)).

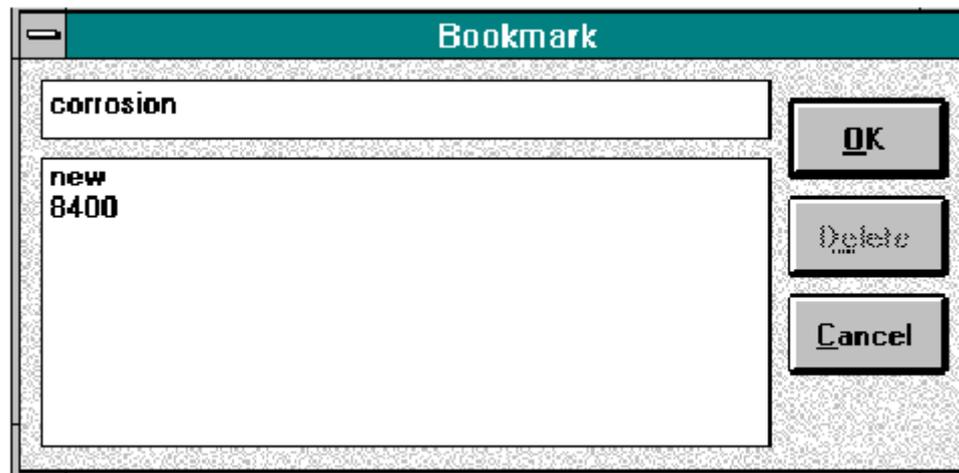


**Figure 2.22 Annotations Dialog Box**



**Figure 2.23 Annotation Icon in Table of Contents**

*Bookmark function:* The bookmark function allows users to define their own bookmarks at useful or frequently referenced sections in the document. The users can access these bookmarks by selecting them from the bookmark menu item ([Figure 2.24](#)).



**Figure 2.24 Bookmark Dialog Box**

#### *2.3.3.4 User Centered Features*

To aid the ASI in using this application, a series of features were added based upon MS Windows standards and related user-centered design research.

- A toolbar complements all menu item entries for easy access to software functionality ('b' in [Figure 2.16](#)). The complete functionality of the Inspectors Handbook prototype can be accessed from the toolbar.
- A status bar displays help information for the control over which the mouse currently rests ('g' in [Figure 2.16](#)).
- Another status bar displays the status of the application, whether it is ready for user input or whether it is working on something such as a global text search ('f' in [Figure 2.16](#)).
- The cursor automatically changes to a 'hand' cursor over hot spots or hyperlinks.
- To minimize user error, all the function buttons and menu items are grayed out (disabled) if they cannot be used for a particular operation.
- If the user is about to perform an irreversible action such as deleting an annotation or exiting out of the system, the software always prompts for user confirmation.
- If an error occurs anywhere, the software always displays a message as to the nature of the error and corrective actions if any.

#### **2.3.4 Conclusion**

The Inspectors Handbook prototype would increase the productivity of the ASIs by allowing them instant access to all the necessary documents. It would cut down on the delays associated with accessing information and would make routine searches more efficient. It would further serve as a refresher/training medium by showing relevant video footage to the ASIs if so desired.

Future enhancements to the software would include combining prototype with the Inspectors Field Kit which would allow users to fill out requisite forms and look up information at the same time. Another addition would be to link the FARs to the Inspectors Handbook prototype for enhanced information retrieval. Finally, all of the information could be accessed remotely from a central server which would help reduce the equipment carried around by the ASIs.

Future concerns include maintaining the digital handbook information current and updating the various hyperlinks within the handbooks. A suitable method needs to be developed which would automate the process of creating and updating hyperlinks from digitized data. By doing this, the ASIs would have access to the most current information at any given time.



# Chapter Three

## Advanced Technologies for Display and Database Automation

### 3.1 Summary

The objective of this activity was to investigate advanced technology tools for transferring data into the Flight Standards Service (AFS) databases. A detailed study of the AFS database systems and the manner in which the Aviation Safety Inspectors (ASI) interacted with these database systems was completed in Chapter One. Based upon the results of this study, several advanced technology tools were identified and investigated. These technology tools included optical character recognition, personal digital assistants, and speech recognition. Each will be explained in detail in this report.

### 3.2 Optical Character Recognition

The data an ASI collects follows a circuitous path before it is entered into the appropriate AFS national database. Most ASIs today collect data during an inspection or investigation using brief notes written down on a notepad. When they return to the office they fill out the appropriate form(s) referring to the written notes from their note pads and their memory. The data from these forms is then entered into a local database at the office, often by a data entry clerk. This is a time consuming process that is prone to data entry errors of omission and commission. Time and money would be saved and data integrity would be improved if the number of times the data were handled was minimized. At some time in the future it is planned that the handling of the data would occur once using a single point entry job aid like the Inspectors Field Kit (IFK). Unfortunately this will not occur in the near future for all AFS offices. In the mean time, an optical character recognition application would provide the means to reduce the number of times the data were handled. With the help of it, data can be input into the computer by scanning the raw data directly from the initial form. This study was undertaken to find out how accurate this technology can be and what configuration(s) of software and hardware should be used to obtain the best results. The process and the results of the study are discussed below.

Various Optical Character Recognition software products were investigated for this activity. We identified 36 different OCR packages that were currently available. Features such as handwriting recognition, form removal, image enhancement options, and de-skew capability were identified as minimal OCR capabilities. In order to be compatible with the IFK we also looked for the ability to support industry standard programming languages (Visual Basic and C) within the Microsoft Windows operating environment. This would allow an OCR application to be tightly integrated into existing, as well as future, AFS systems. These requirements reduced the number of potential products to 12. Many of these had features that were not applicable to the proposed AFS office environment such as form creation utilities, stand alone receive and send FAX capability, batch scanning and classification algorithms, and graphic editing capabilities. The cost of these additional features was not deemed necessary just to get the basic required OCR capabilities. After reviewing product information and trade journal reviews, OMNItools by Nestor Products was purchased and evaluated.

As with all technology assessment activities, this review of products is current as of March, 1995. The introduction of new technologies is continuous and a better product may be available in the near future. We will continue to remain cognizant of these new systems as they are introduced.

*OmniTools*

OmniTools, developed by Nestor Incorporated, accurately recognizes hand-written and machine-printed characters from scanned or faxed images. In addition to character recognition, the system identifies documents, resizes and straightens incoming faxes, removes preprinted forms, automatically detects hand-printed and machine-printed words, reads optical mark (check box) entries, and provides several output options including alternate choice characters. It provides an Application Program Interface (API) for industry standard programming languages, such as Visual Basic, and also allows handwriting recognition solutions to be developed from Access, Excel, Foxpro, Lotus 123, and Paradox.

### 3.2.1 Recognition Process

The process of handwriting recognition using this product includes five steps: (1) preparing an image file, (2) defining a zone definition form, (3) performing the actual recognition, (4) displaying the results and (5) verifying the results. Except for the last, all of the steps can be done with the OMNItools software.

#### 3.2.1.1 Preparation of Image Files

Since OMNItools cannot prepare image files, a basic scanning product was used to create the image file. This file contains the image of the hand-writing and form that will be recognized. An image can be captured by a camera, a scanner, or some other devices. All the image files used in this study were created using the Hewlett-Packard ScanJet IIc scanner and the Deskscan II software<sup>1</sup>. Using this hardware and software combination, three attributes of the resulting image could be modified: image file format, brightness, and resolution. These attributes are commonly available to most scanners, and are discussed in detail below.

##### *Image file format*

OMNItools accepts either Paintbrush or Bitmap format files. Preliminary testing indicated that there was no difference in recognition accuracy between these two file types. Since the size of a Paintbrush file is usually four to five times smaller than the size of a Bitmap file, the image files were stored in a PaintBrush file format. The number of colors used in a PaintBrush file can also be set. Two color (black and white) PaintBrush files were used for all the tests in this study. The reason for this decision is that OMNItools has difficulty interpreting PaintBrush files that contain more than two colors.

##### *Brightness*

The Brightness attribute controls the contrast of an image. It is similar to the brightness control used in a photocopier. The darker you set the brightness attribute, the more details you can see. The range of the brightness scale for a ScanJet IIc scanner is from 0 (darkest) to 255 (lightest). By trial and error, two values, 80 and 150, were chosen to be used in this study. When the brightness is set to a value of 80, the scanned image is clear and sharp for both dark and light color lines. When the brightness value is set to 150, dark color lines appear clearly, while light color lines are not visible.

##### *Resolution*

The resolution is determined by the number of dots per inch (dpi) used to represent an image. In DeskScan II, the dpi setting can be set as low as 12 dpi or as high as 1200 dpi. A setting of 100 dpi resolution was used in the beginning. It was quickly determined that this value was too low because the image quality was very poor. A setting of 300 dpi was found to be the lowest setting that produced a high quality image for character recognition in the image file.

The density of data on the original form is also very important. The data density cannot contain too much data when the image is processed. How much is too much was determined empirically. When the form's data density was too high, an error message "Image is too large and complex" would be displayed. This phenomena was discovered during the initial familiarization period. This situation did not occur during the actual evaluation.

It warrants repeating that the brightness and the resolution attributes discussed above are specific to the scanner. They are not part of the OMNItools. Readers must keep this point in mind when these scanner settings are discussed in context of the OMNItools attributes.

### *3.2.1.2 Form Definition*

A zone definition form (ZDF) file contains information of how OMNItools should recognize the image. The specific area or zone on the form that will contain data must be identified. You can also specify more information about each zone and about the whole form so that the software can carry out a more accurate recognition. There are three kinds of zones which can be defined in a ZDF file: registration zone, data zone, and optical mark recognition (OMR) zone.

#### *Registration zone*

This zone defines static information that can be deleted from the scanned image using a feature called Form Removal. Using a common tax form as an example, OMNItools would be able to remove those printed boxes, lines, and characters from the tax form as the scanned image was being processed. It would read the tax form as if it only contained the hand-writing of the author. To use Form Removal, registration zones have to be defined and two forms must be supplied: one blank form (called Master Form) and one form filled with data (Data Form). The registration marks are used as anchors between the Master Form and the Data Form so that the static data can be removed accurately.

Also, through trial and error it was found that 1)Form Removal worked best if the registration marks were some simple shapes like small, filled-in squares and 2)Locating the registration marks close together at the top third of the page provided the most accurate combination for the Form Removal feature to function properly. Locating these marks was not an easy task. It was discovered that characters or complex graphics cannot be used as registration marks. This would result in an error saying "Can't find the registration mark".

#### *Define data zones*

Data zones are areas which contain the hand writing that needs to be recognized. A single form can contain multiple data zones. Several attributes can be defined for each data zone, each of them intended to specify the number/type of characteristics within a data zone which would result in a higher rate of recognition accuracy. The attribute options available are:

I) Hand print / Machine print.

Specifies whether the zone contains hand-writing, machine-print characters, or both.

II) Characters Per Inch (CPI)

A data string typically has a constant letter spacing. If the number of characters per inch is known in advance, it can be specified so that the software will locate each character more accurately.

III) Punctuation Marks

Some data strings may or may not contain punctuation marks. Setting attribute "Containing Punctuation" to "none" will reduce the possibility of recognizing some characters as punctuation marks if no punctuation exists.

#### IV) Single Word, Single/Multiple Lines

The data format may be in one word, one line, or multiple lines. This option may help to eliminate recognizing extra spaces and recognizing one character as two.

#### V) Checking Context

If this is set, OMNItools uses an expert system for grammar in an attempt to guess the next character based on the context of the words if there is any uncertainty about that specific character. For instance, if the software is not sure whether the character is a 'v' or 'u' following a 'q', it would identify the character to be a 'u' because of higher grammatical probability.

#### VI) Define Dictionary.

A Dictionary can be used (or defined) to restrict the word for a specific zone. For instance, suppose a data zone is restricted to a dictionary that is defined as containing only two words ("MALE" and "FEMALE"). If, for example, a word "MALA" (or anything similar) was recognized, the word will be changed to "MALE" because of the dictionary constraint.

#### VII) Character constraint

It is usually known in advance what type of characters will appear in a data zone. For example, A-Z, and/or 0-9, or some unique combination are valid ranges.

### *Optical Mark Recognition (OMR) zones*

These zones are areas on the form designated for check boxes. It can be chosen to be either a single radio box or a multiple choice group.

### *Form level information*

There are some attributes which would affect the whole form. These options are:

#### I) Form Removal - ON/OFF

If this option is set, the static data will be removed from the image.

#### II) Remove long lines - ON/OFF

If this options is set, all the long lines will be removed.

#### III) Restore/de-skew image - ON/ OFF

If this option is set, OMNItools will try to restore image by de-skewing some lines that may have been skewed during the process of capturing the image from the source.

#### IV) Drop-out ink - ON/OF

This option tells OMNItools whether the image to be recognized contains drop-out ink or not.

#### V) Result file format - ON/OFF

Result file format can be text, text with quotes, or ZRF (file format defined by OMNItools). If the results are going to be verified using the OMNItools, the result file format has to be in Zone Recognition File (ZRF) format.

### *3.2.1.3 Recognition*

The actual recognition can be done by specifying the image file and the ZDF file. It usually takes less than 10 seconds to finish one recognition with about 100 characters using a Pentium-90 machine.

### *3.2.1.4 Results Display*

OMNItools provides a tool to view the ZRF file. It can display the results of all the data and OMR zones in a scrollable window. It can be chosen to show how accurate the recognition was for each character. Threshold confidence levels can be set such that it will only show the recognized character if the confidence level is higher than the specified value. Using this tool, results can also be stored in a plain text file or copied to other Windows' application.

### *3.2.1.5 Verification*

The verification tool allows users to see the recognition and the original data at the same time. This allows the users to compare the results visually and correct any mistakes made by the software. As mentioned before, the results have to be stored in ZRF file in order to use this tool. The modified results can also be stored in the same ZRF file.

## **3.2.2 Methodology**

### *3.2.2.1 Data Preparation*

A modified version of the standard AFS form, Program Tracking and Reporting System (PTRS), was used for all the tests. This form was created using a software application called VISIO. There are a number of modifications made to the basic form in order to be suitable to be tested. Four registration zones were defined. Data fields were enlarged to have a density of 6 CPI. Letters within any check box were removed to avoid any confusion between these letters and the actual hand-writing. The gray scale of boxes that surrounded the data fields were set to be the lightest shade available in the VISIO application. This was done to minimize the interference with the recognition process. The modified PTRS form is shown in the Appendix.

### *3.2.2.2 Data Collection*

Ten Galaxy Scientific Corporation employees participated in this study. A sample form and a blank form were given to each participant. They were instructed to copy the information from the sample form to the blank for in their own handwriting. The sample form contains five class of data that included every recognizable character:

- 1) Uppercase : three sets of upper case alphabets (A-Z)
- 2) Lowercase : three sets of lower case alphabets (a-z)
- 3) Digits : five sets of digits (0-9)
- 4) Special : three sets of special characters ("\$( )+/-")
- 5) Checkmark : thirty-six check mark zones

There are a number of attributes can be changed in the ZDF file that were discussed in previous section. Some of these attributes remained fixed for the study while others were varied. The following section lists the fixed and variable attributers.

Fixed attributes:

- I) Hand print / Machine print.

Handprint was used throughout the entire study.

- II) Punctuation

No data will contain any punctuation.

### III) Single line

All data was regarded as single line data.

### IV) No context checking

The sample characters were listed alphabetically, therefore context was not used.

### V) No dictionary defined

For the same reason as above, no dictionary was defined.

### VI) No drop-out ink

No drop-out ink was used.

### VII) Result file format

Text file format was used.

Variable attributes:

#### I) Form Removal

The options tested were On or Off. The static data was removed from the image if "On" was selected.

#### II) Remove long lines

The options tested were On or Off. If " On" was selected then all the long lines were removed.

#### III) Restore/de-skew image

The options tested were On or Off. This attribute can only be used when Form Removal is "Off", otherwise the error message "Can't find the registration mark" would occur.

#### VI) Character constraint

This attribute only applies for the data zone. There are two kinds of constraints used in the tests: restricted constraint and relax constraint. For the restricted constraint option, the data zone was restricted to one of three settings:

- alphabetic characters defined to be from A and Z;
- digits defined to be from 0 and 9;
- special characters defined to be anything (A-Z,0-9,\$()+-/).

For relax constraint option, every data zone was defined to recognize all characters.

#### V) Characters per inch (CPI)

This attribute only applies to the data zone. It can be set to any positive value. The data form was originally designed for a character spacing of 6 CPI. Therefore this option was set to either 6 CPI or 0 CPI for these tests. The 0 CPI option means that the characters per inch attribute is undefined. In other words, the software has to locate the characters by itself.

#### VI) Brightness of the image

The options tested were 80 or 150.

There are a total of 48 possible combinations for above attributes. [Table 3.1](#) illustrates the options more clearly:

### Table 3.1 Options

<b>Attributes</b>	<b>Options</b>	
Characters per inch	0 (Undefined)	6
Form Removal	Yes	No
Remove Long Lines	Yes	No
Restore/de-skew image	Yes	No
Character Constraint (A-Z or 0-9)	Restricted (all characters)	Relaxed
Scanner Brightness	80	150

Ten sets of hand writing were collected. Each set of data was recognized using all 48 configurations mentioned above. The results were stored in text file format and printed out. The printout were counted manually to determine the number of correctly recognized characters per set of data.

### 3.2.3 Results & Analysis

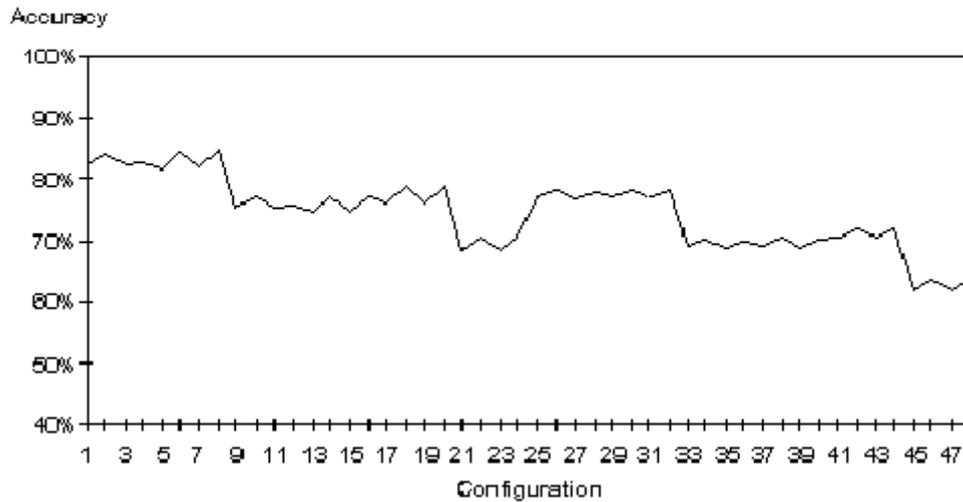
For each configuration that represented the 48 unique combinations of variables, an average percentage of accuracy was calculated across the ten participants. The data for each variable attribute was divided into two groups (since each attribute has two options). A line graph was plotted using these two groups. The difference between these two lines indicates how much the specific attribute affects the recognition accuracy.

Since data zones and OMR zones have different attributes, their results were analyzed separately. The results were illustrated with the graphs. It needs to be emphasized for the reader that each graph represents a different set of configurations of variables to illustrate the effects of each attribute. For example, Configuration 1 in [Figure 3.1](#) may not be the same as the Configuration 1 in Figure 3.2. Detailed information for each graph indicating configurations and actual values can be found in the Appendix.

#### 3.2.3.1 Data Zones Average results

Figure 3.1 shows the average results for each configuration. The table shows the corresponding statistical values. Descriptions for each configuration are in the Appendix. There are several rises and falls on the graph. They are caused by different variable attributes. The effects of each attribute will be discussed individually.

Average	Standard Deviation	Minimum	Maximum
74.28%	5.85%	61.88%	84.51%

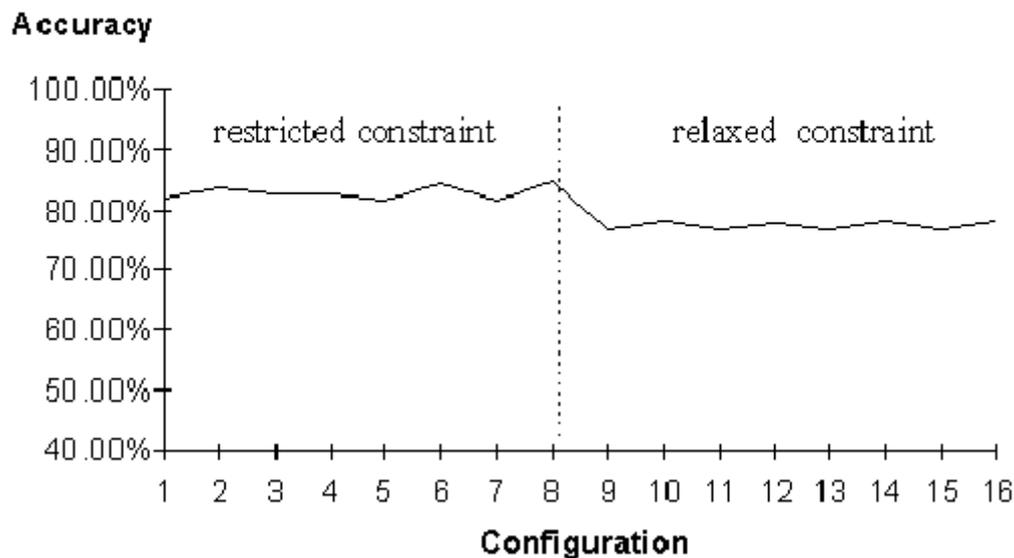


**Figure 3.1 Average results for each configuration**

*Character constraints*

Figure 3.2 shows how the attribute Character Constraint affects the recognition accuracy. The first eight configurations have a restricted constraint while the last eight configurations have a relax constraint. There is a drop in accuracy (7.06%) when the constraint is changed from restricted to relax. This is quite reasonable because there are a number of letters which are easily recognized as digits and vice versa (e.g., 5 & S, 1 & l, 9 and q, etc.). It is also found that the trend appears to be the same for the brightness variable and the form removal attribute.

Constraint	Restricted	Relax	Difference
Average	82.85%	75.79%	7.06%
Std Dev.	1.12%	1.16%	-

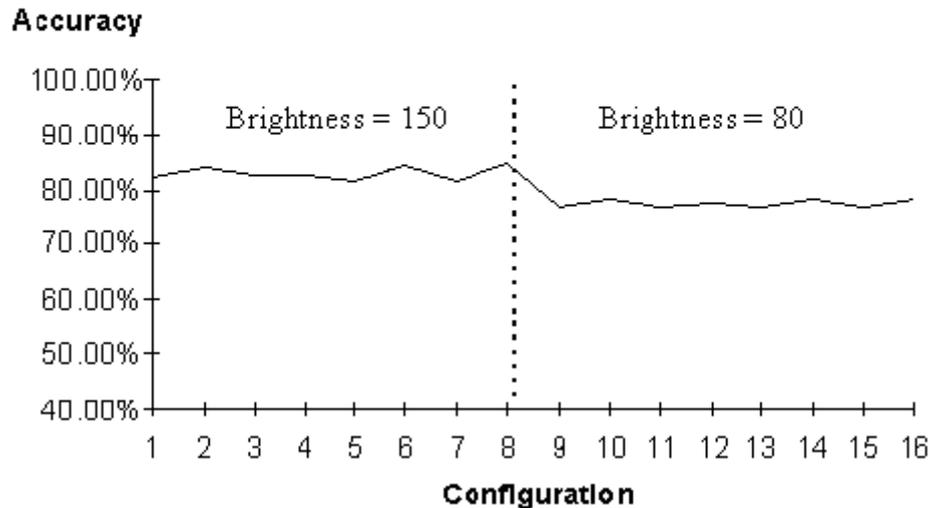


**Figure 3.2 Configurations with brightness = 150 and no form removal applied**

### Brightness

Figure 3.3 shows the results of restricted constraint without form removal. It again shows that there is a decrease (5.54%) in accuracy in the middle of the graph. That is the result of a change of the brightness attribute from 150 to 80. Similar trends were found using different combinations of character constraint and form removal attributes.

Brightness	150	80	Difference
Average	82.85%	77.31%	5.54%
Std. Dev.	1.21%	0.65%	-



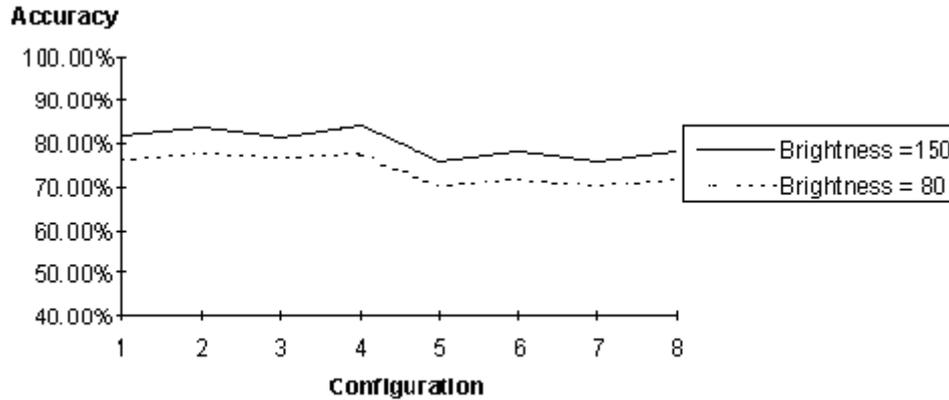
**Figure 3.3 Configurations with restricted constraint and no form removal applied**

### Form removal

Figure 3.4 shows the results of configurations with restricted constraint. Two series of data are shown on the graph. One uses Brightness = 150 and the other uses Brightness = 80. Both are showing the same distribution. The respective decreases (5.33% and 6.31%) in the middle of the graph are caused by the form removal feature. It was believed that the removal of the form would improve the recognition accuracy. The results were opposite from what was expected and there is no obvious explanations for this.

Brightness = 150			
Form Removal	No	Yes	Difference
Average	82.91%	77.38%	5.33%
Std. Dev.	1.39%	1.39%	-

Brightness = 80			
Form Removal	No	Yes	Difference
Average	77.38%	71.07%	6.31%
Std. Dev.	0.71%	0.77%	-



**Figure 3.4 Configurations with restricted constraint**

Character constraints, brightness and form removal were found to be the only attributes that affect the recognition accuracy. It is also found that defining the characters per inch attribute would help improving the recognition accuracy a little (as shown in [Table 3.2](#) below). The de-skew and long line removal attributes do not affect the recognition accuracy at all.

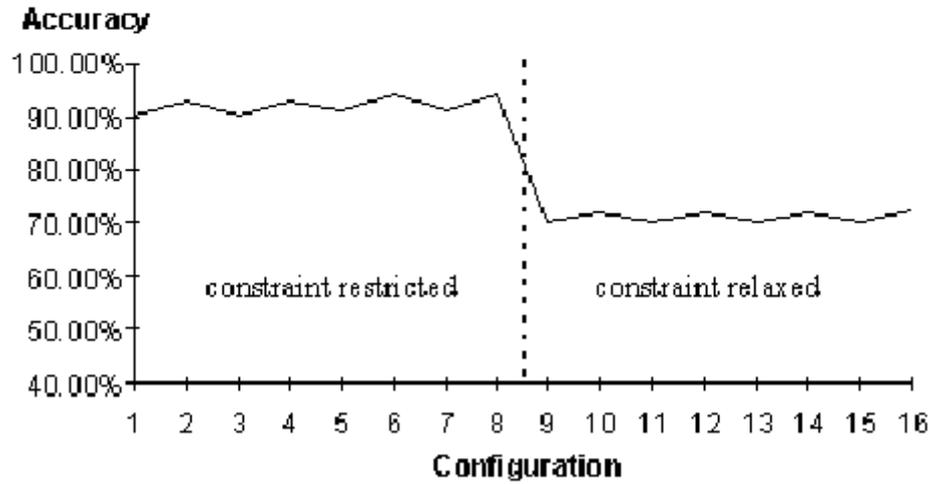
**Table 3.2 Average and Standard Deviation**

CPI	6	0	Difference
Average	75.11%	73.45%	1.66%
Std. Dev.	5.92%	5.79%	-

*Digits with different character constraint*

**Figure 3.5** shows the results for digits class only. It uses brightness = 150 without form removal. The accuracy drops dramatically (20.95%) when the constraint is changed from restricted to relax. The change is so big because there are only 10 possibilities (0-9) for restricted constraint and there are 36 possibilities (0-9,A-Z) for relax constraint. The other attributes do not affect the accuracy of digits class at all.

Constraint	Restricted	Relax	Difference
Average	92.15%	71.20%	20.95%
Std. Dev.	1.77%	1.19%	-

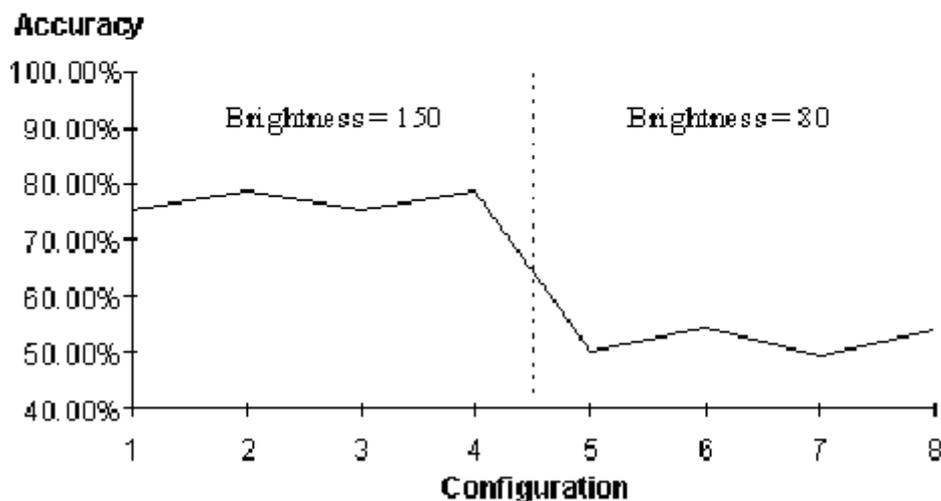


**Figure 3.5 Digits class with brightness = 150 and no form removal applied**

*Special characters with different brightness*

The only attribute that affected the accuracy for special characters class was Brightness. [Figure 3.6](#) shows the results of special character recognition without form removal and de-skew. The recognition accuracy falls (25%) when the brightness is changed from 150 to 80. This behavior is difficult to explain.

Brightness	150	80	Difference
Average	76.94%	51.94%	25%
Std. Dev.	2.25%	2.59%	-

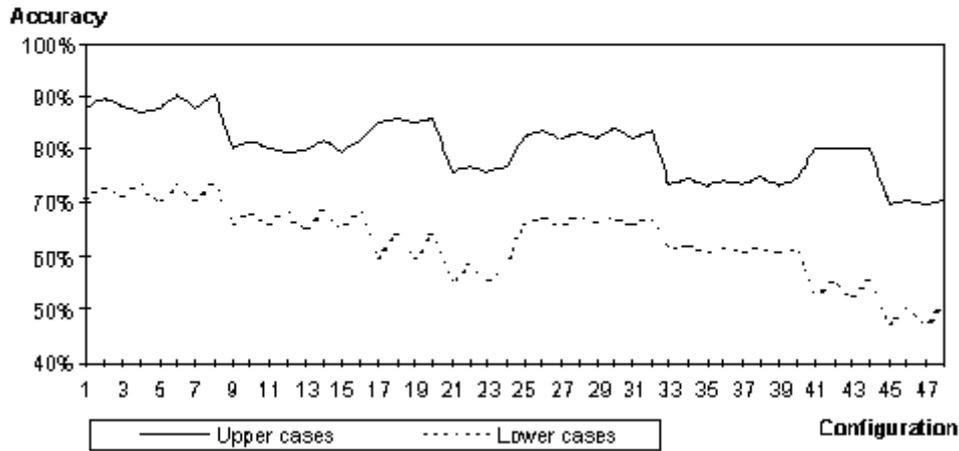


**Figure 3.6 Special character class without form removal and deskew**

### Upper and lower cases characters

**Figure 3.7** shows the recognition accuracy results of upper cases and lower cases. It can be observed that the accuracy of upper case characters was much better than that of lower cases. One of the reasons may be that some of the lower case hand writing characters are very similar in shape to each other. For example, e & a, g & q, r & v, n & h, etc.

Class	Upper cases	Lower cases	Difference	Overall excluding lower cases
Average	83.73 %	62.86%	20.87%	70.95%
Std. Dev.	3.99%	7.09%	-	-

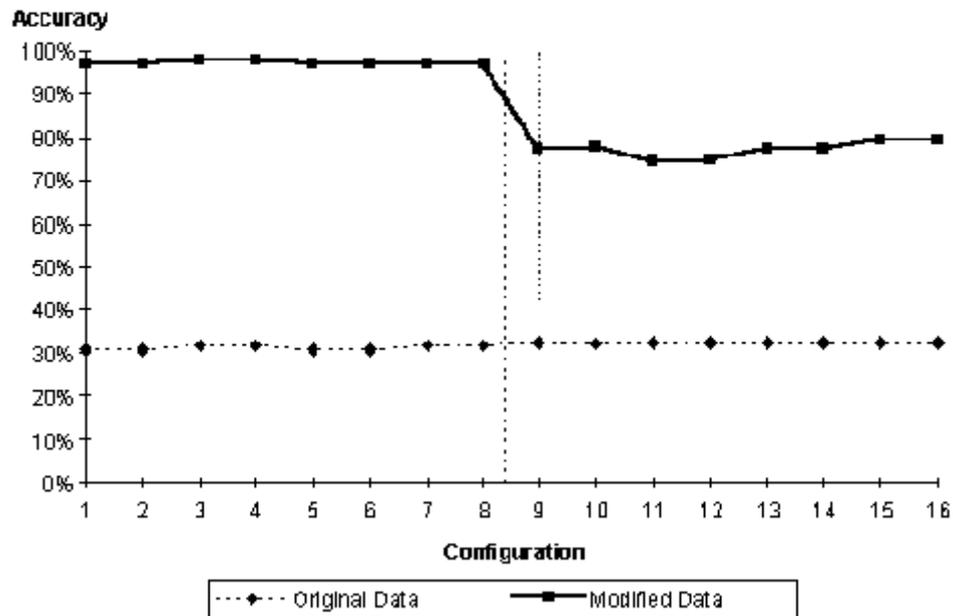


**Figure 3.7 Comparison of upper cases and lower cases performance**

### OMR zones

**Figure 3.8** shows the results for OMR zones. The results are quite bad. The reason is that OMNItools was not able to discern if an OMR zone is completely empty. Considering this observation, it assumed that all the uncertain results are actually unmarked. With this assumption, the results improved significantly. The modified results are shown on the same figure. The drop in the middle is caused by enabling the form removal attribute. Again this decrease in recognition accuracy when Form Removal is activated was not expected.

	Original Results	Modified Results	Difference
Average	31.65 %	87.26%	55.61%



**Figure 3.8 Results for OMR Zones**

### *Optical Character Recognition Suggestions*

OMNItools is an acceptable hand writing recognition program that achieved approximately 85% recognition accuracy during our evaluations. However, careful design of source data and proper choice of attributes are very important to obtain the best possible results. The following design recommendations and usage for (1) source form design, (2) source form filling, (3) scanner settings, and (4) OMNItools settings are suggestions to maximize the recognition accuracy based upon the results of this study.

Design Recommendation:

1. Source form design
2. Source form tilling
3. Scanner setting
4. Omni tools setting

### *Source Form Design*

1. The source form has to be designed carefully. Borders should be used to surround each character of the input text field. This will control the size and the density of characters (CPI) when data is entered on the form. Either rectangle boxes or comb fields would be a good choice. These boxes or comb fields should also be printed in some lightest shade possible. This will allow the boxes or comb fields to be dropped out easily during the image process.

### *Source Form Tilling*

2. The form should be filled out using black ink pen. It is also suggested to use all capital letters.

The form should be designed to carefully organize the density of data otherwise OMNItools may not be able to carry out the recognition.

### *Scanner Setting*

3. The image of the source form should be in black and white only. The resolution of the scanner should be at least 300 dpi. The brightness should be chosen such that the boxes or comb fields (drawn in the lightest shade possible) are not recognized during the image process. Different scanners will require some experimenting in order to find the best value of these (or other) available attributes.

### *Omni Tools Setting*

4. When defining the zone definition form, form removal is not suggested to use. Effort should be put on arranging the zones such that each area contains only either alphabets, or digits, or a small range of characters. It is also helpful to define the characters per inch for each zone. The results of the OMR zone should be modified by replacing the uncertain results as unchecked.

## **3.3 Personal Digital Assistants**

The Personal Digital Assistant (PDA) industry is in a state of transition. The first generation of these devices were greeted with great expectations. They were to provide personal electronic-based tools designed to improve the productivity of its owner in a pocket-sized package. Unfortunately these expectations greatly outpaced reality. The root of the problem was this product was developed in a vacuum then its manufacturers went in search of a consumer market. These first generation devices attempted to be all things to all users. As it turned out, very few consumers purchased these products and those that did were disappointed with their performance.

This lack luster performance by PDA sales has caused concern among the manufacturers and the software providers for these products. New processors and operating systems that were planned for release this year have been delayed indefinitely. Some in the industry have gone so far as to declare the PDA concept as dead. Based upon our research we feel this is too extreme. There is a market for these devices but they must take a user-centered approach when developing the new generation of these systems.

The two key features that would make a PDA a useful tool for an AFS ASI are a PDA operating system that is compatible with their desktop computers (e.g., Windows compatible) and communications connectivity. Unfortunately both of these capabilities are either not available on today's PDAs or are very limited. Because of these reasons we did not pursue further investigation of PDA for ASI use at this time. [Table 3.3](#) contains the specification of several PDAs that we investigated.

These units are roughly seven inches by five inches, less than an inch thick, and weigh about one pound. They utilize a low power processor, up to 4 MB RAM, one Type II PCMCIA slot and a three inch by four inch monochrome LCD display. The PDAs use either a pen-based DOS or a proprietary pen-based operating system. Handwriting recognition is only one element of a pen-based operating system. The specific user interface metaphors are different but overall, they all utilize the pointing ability of the pen for navigating through the operating system or interacting with an application. They also capture graphic images by storing "electronic ink"

As this research effort came to a close in March 1995, a second generation of PDAs have started to emerge. The early press releases describing these new PDAs claim to have addressed the two features that would make these units useful for an ASI. We will be continuing to keep abreast of these products through Task Order 03.

**Table 3.3** PDA Specifications

	<b>PDA #1</b>	<b>PDA #2</b>	<b>PDA #3</b>	<b>PDA #4</b>	<b>PDA #5</b>
<b>Processor</b> (x86 compatible)	Casio Custom 68349/16 MHz	ARM 610/20 MHz 68349/16 Mhz	Motorola Dragon MHz	Motorola Dragon	<a href="#">NEC</a> VG230/16
<b>HDD</b> <b>Storage</b>	PCMCIA memory card	PCMCIA memory card	PCMCIA memory card	PCMCIA memory card	PCMCIA memory card
<b>RAM</b>	1MB (4 MB ROM)	1MB (4 MB ROM)	1MB (4 MB ROM)	512 KB (4 MB ROM)	3 MB 6 MB Mask
<b>Desktop</b> <b>Connect</b>	PC (option) Connectivity (opt)	Mac & Windows Connectivity (opt)	PC (option) Connectivity pack	Mac & Windows	Serial LapLink
<b>Display</b>	3.1" x 4" 320 x 256 pixels	3" x 4" 336 x 240 pixels	3.0" x 4.5" 480 x 320 pixels	3.0" x 4.5" 480 x 320 pixels	7.4" diag 640x400 pix
<b>Battery</b>	Three AA bat., AC/DC	NiCad, AC/DC	NiCad, AC/DC	Six AAA bat., bat.,	Six AA AC/DC
<b>Operating</b> <b>Env.</b>	GEOS, PenRight!	Newton Intelligence	Magic Cap	Magic Cap	GEOS
<b>Size,</b> <b>Weight</b>	6.8"x4.2"x1.0" 0.95 lbs	8.0"x4.0"x1.25" 1.28 lbs	7.5"x5.75"x1.2" 1.7 lbs	7.5"x5.2"x1.0" 1.2 lbs	9.2"x6.4"x 1.4" 2.4 lbs
<b>Options</b>	Message card, fax modem, printer	Message card, printer connection, flash storage.	Message card, printer connection, flash storage.	Pager card, Li-Ion Bat.	LapLink, head set, memory card.

Voice recognition is being investigated as a viable means of allowing ASIs to interact with the AFS database systems. Interaction could be in the form of allowing ASIs to use voice not only to enter data into the system but to also control other applications on their desktop computers. Speech recognition systems can be either speaker-dependent or speaker-independent and either continuous-speech or discrete-speech. Most voice recognition systems today use the speaker-dependent, discrete-speech recognition technology. The effort by most manufactures of voice recognition systems is directed to developing a speaker-independent, continuous speech product. In theory, speaker-independent systems would recognize speech equally well for all users and allow for users to speak in natural, continuous speech. In reality, recognition accuracy of current systems is less than perfect and typically deemed unacceptable for most uses. This less than optimal recognition accuracy is due primarily to the difficulty in accounting for the many variations of the American English dialect. On the other hand, speaker-dependent, discrete-speech systems can achieve optimal

recognition accuracy for one user at a time. This is due to the fact that discrete-speech systems requires that users speak with a pause between words and perform a series of exercises to develop a voice template for that specific user. The current effort has concentrated on the latest products that have a quasi-speaker-independent capability which provides the option to increase the recognition accuracy with a brief enrollment exercise performed by the user.

Two important factors were being used as the criteria for evaluating these software packages. First, the appropriate package had to be Personal Computing Manufacturing Community International Association (PCMCIA) compatible. This feature will allow Voice Recognition Software to run on a Notebook Computer, thus enabling an ASI to use the software while he/she is out in the field. Second, the appropriate package must support industry standard programming languages (Visual Basic and C), which will allow voice recognition to be tightly integrated into existing as well as future AFS systems.

The following is a brief summary of several voice recognition software packages that were investigated.

### **3.4.1 DragonDictate from Dragon Systems**

DragonDictate uses the speaker-independent, discrete speech recognition technology and features a large active vocabulary which users can totally customize with their own words. A unique 110,000-word pronunciation dictionary with acoustic models makes adding words easy and ensures immediate recognition. DragonDictate's special vocabulary optimizer automatically personalizes your vocabulary while its dynamic adaptation capability adjusts to your voice and work environment. In addition, it allows you to control various applications by voice.

The major drawback to the DragonDictate voice recognition software is that it is not PCMCIA compatible. However, it does have a C language Application Programming Interface (API).

### **3.4.2 Kurzweil Voice for Windows from Kurzweil Applied Intelligence, Inc.**

Kurzweil Voice enables users to create, test, and enter data simply by speaking. It also allows navigation, which drives the Windows Operating System and Windows-based applications on a command and control basis. Kurzweil Voice incorporates a new version of Kurzweil Artificial Intelligence's (AI) large vocabulary, speaker-independent, discrete speech recognition technology. It also has on-line knowledge, including acoustic recognition models and spellings, for a total of 200,000 words.

Although Kurzweil Voice is impressive, it does not have a PCMCIA interface. It neither has a C language nor a Visual Basic API.

### **3.4.3 Custom Voice/ICSS from A&G Graphics Interface**

Custom Voice/ICSS uses a speaker-independent, continuous speech system. It provides a simple high-level interface to speech recognition via standard Visual Basic programming tools. Custom voice is geared towards the developer. It allows a developer to create customized applications quickly, using industry standard development tools.

Although the system has a Visual Basic API, it only has a 1,000 word vocabulary and it is not PCMCIA compatible.

### **3.4.4 IBM VoiceType Dictation for Windows from IBM:**

This is a discrete, speaker-dependent voice recognition system. It allows users to create text quickly and efficiently simply by talking to a desktop personal computer, notebook or subnotebook PC. The software gives users a basic 30,000 word vocabulary, as well as specialized language models for

specific professions ( including radiology, surgery, and law ) to speed the accurate conversion of words to text. VoiceType Dictation creates a model based on each user's voice, which allows the system to accurately convert speech to text as quickly as 70 to 100 words a minute.

The IBM VoiceType Dictation system was purchased for evaluation because it is PCMCIA compatible and it has a Visual Basic and C language API. The system was evaluated and the results of the evaluation are as follows.

The first effort with this system was to perform the enrollment procedures. This generates a voice template for each individual user that the application uses to aid in recognizing speech from a particular individual. This also provides an opportunity for the user to become familiar with the capabilities of this system. Once this was completed, testing began on the recognition accuracy and speed. Finally, the Speech Software Development Kit (SDK) was investigated to figure out how to incorporate this technology into existing application in the most unobtrusive fashion.

#### *3.4.4.1 Enrollment Process*

The enrollment process for the dictation system is long and thorough. Enrollment is a two part process: your dictation and the computer's processing of your voice information. During enrollment, VoiceType gives you a set of sentences to dictate. The system already knows these sentences, so the pronunciation of each word assists the system to learn how these words sound in the user's voice. It does not appear to be too burdensome to request that a user go through this process in order to achieve the highest level of voice recognition. In general, recognition is reasonably quick and highly accurate. In Paced/Command mode, the recognition engine is usually in the 97% - 99% accuracy range and is very quick. This is due mainly to the use of a smaller vocabulary and the simple sound matching processing that is done to recognize words. In Dictation mode, the recognition engine is considerably slower. This engine uses a language model to narrow down the possible word options and better interpret what is being said; not only on the actual word sound, but on the context of the sentence. This helps reach higher levels of recognition accuracy than can be achieved through sound matching alone.

However, the recognition is not flawless. The recognition engine had the most trouble with words containing multiple syllables. Occasionally, the recognition engine would recognize a single, multiple syllable word as multiple words. This would cause the recognition can get way off-track using Dictation mode. Since the engine attempts to use the context of what is being said, a stray word or severely mis-recognized word can totally change the meaning of a sentence. Thus, the context is incorrect and recognition engine will briefly cascade off into the wrong direction. Fortunately, this was not a frequent problem.

Background noise was not a serious problem. Extraneous noises will affect recognition, but there are solutions to minimize its effect. One option is for the user to create several training sessions. One training session could be in the quiet environment of an office and another for a noisy outdoor setting. It was noted that one item that would really help in speaking to the recognition engine is an on/off switch. A hardware push button could be used to activate the microphone only when this button is depressed. This will help in eliminating extraneous noise and vocabulary that might be accidentally spoken by the user.

When there is an error in recognition while dictating, it can be somewhat tedious to correct the engine. Fortunately, there are programming aids that can be created to assist the user in the correction process. The effort put forth in enrollment and error correction does pay off in the long run in recognition accuracy.

Due to complicated modeling that is being done internally, the speech recognition engine uses a large amount of memory (16MB of RAM) and disk space. The larger the recognition vocabulary, the larger the storage requirements. In addition, recognition is fairly hard disk drive intensive. This may come into play in application designed for mobile computers where battery life is a factor.

One final point should be noted. From discussions with IBM technical support, it was discovered that the system does have a speaker independent model that can be used for simple commands and minor dictation. This type of speaker independent model is used in the sample programs that came with the system. Sample games provided called States and Weather were used to evaluate this feature. The independent models used in these programs were crude but functional. They worked, but their accuracy percentage is very low; around 60-70 percent. It does not appear that there is any way to use a speaker independent model, even on a small scale, and bypass the user having to go through the long enrollment process. Anyway, it appears that IBM does not want developers to use this independent model. They will not give any information on how to access the independent model through the SDK.

#### *3.4.4.2 Speech Software Development Kit (SDK)*

The SDK is very thorough and very complex. We were only able to scratch the surface of all the functions and capabilities that are accessible through it. There are several good demonstration programs included in the package. We relied heavily on these to get an initial demonstration program operating. One feature that was not known earlier was that the SDK will only work in a 32-bit environment. That means Windows NT or the WIN32S add-on to Windows 3.1 is required. We had trouble creating a dynamic linked library (DLL) with the speech API that Visual Basic could handle. It was discovered that VB cannot handle the 32-bit interface required for DLLs using the speech API. Instead an executable file called TALK was created that was run once the target application was started. This program recognized all words and passed messages concerning recognition to the target application.

When defining command vocabularies for the user to specify fields to input data, the engine does not allow for multiple words in a command. In general, any word in the 'Text' vocabulary can be recognized as a command. The developer must then manually keep track of words said by the user and interpret a given series of words as needed. There are procedures to add words to the vocabulary along with proper pronunciation. However, this process is fairly complicated thus was not deeply pursued.

The engine has the capability to replay, any recognized word, in an audio format. In a sense, the user can speak a particular command and the engine can replay what it recognized. This can be used as a verification mechanism for the user to know that his words were processed properly.

#### *3.4.4.3 PENS Integration*

The task of integrating the engine into the PENS software was a complex one. Due the nature on the engine, it will not be as simple as dropping a special control into the project in order to integrate speech. There will some intruding code that will be necessary to process and interpret commands and actions received from the speech engine. Because of this, there will be an additional level of complexity added to the software. This may cause some difficulties with programs that are already very complex.

In order to accommodate the existing PENS software, a command structure must be developed that will allow the user to easily and intuitively set the software's focus on a specific field for input. In addition, the structure must allow the user to easily and quickly input numbers, letters, or dictated text.

The overlying software structure consisted of a series of message levels such that recognized words are passed through different levels of functionality within the PENS software. The first level is the upper level tab navigation. Each form is made up of several tabbed folders. All command words are first passed to the main tab folder for the current data entry form in use. If a command word for tab control is recognized, then that causes a change in the currently active tab folder. Otherwise, if the command word is recognized as a valid data entry section for the currently active tab folder, then that data section is then given the focus. Code for this data section would then check the command

words to see if it was attempting to recognize a particular field within this section. Once a data entry field is recognized through a command word, it is then given the focus. At this point, all commands or dictated text are passed to this control for data input.

All messages are thus passed down this chain until it is recognized as a command or field name, or until it is used as input into the active field. This cascading message loop was implemented in a sample PENS application that was developed during this evaluation of the speech software. On this small scale, it appears that this approach will work and is fairly foolproof. It appears that speech recognition would be fully integrated into PENS. However, it will require additional work considering the complexity and sheer volume of forms and controls in the PENS software.

#### *3.4.4.4 Conclusions on IBM VoiceType Dictation System*

The IBM VoiceType Dictation system is at the cutting edge of recognition based upon the initial requirements for this type of system. It can provide fast, accurate speech recognition for an data entry and system control application. However, much work still remains to be done. This system will add a considerable amount of computational overhead to a given application. It also requires a large amount of memory and disk space. On the other hand, it can really speed user input; particularly for users that must input large amounts of information or have difficulties with current 'standard' input devices or with typing. Recognition of dictated text by the engine is probably faster and more accurate than what 90% of people can type. If this software is to be used in an application, the primary reason should be to take advantage of its dictation capabilities. One needs to seriously weigh the benefits of this package with the need for this product and the effort that is willing to be given to incorporate it into an application. The demands that this product would put on some mobile computing application might be too great at this time. We do think though that this product is currently capable of adding a substantial level of usability to several applications presently being developed by the Performance Enhancement System program.

### **3.5 Conclusions and Recommendation**

The three technology areas that were investigated all demonstrated that they each have a strong potential to enhance the Performance Enhancement Program. In a follow-on program we are planning to take each of these technologies and integrate them into the Performance Enhancement System program software and perform a series of preliminary evaluations.

# Chapter Four

## Coordinated Development and Evaluation of Database Design for Future Systems

### 4.1 Summary

The research team considered an improved database management system that is tailored to the needs and responsibilities of the Flight Standards Service (AFS) Aviation Safety Inspectors (ASI). The result of this effort was a prototype interface design that provides an easy means for interacting with the various AFS database systems. The research team designed the prototype interfaces using the same user-centered design methods and criteria described in previous sections. A series of prototype and evaluation phases have culminated into a recommendation for an improved database management system.

### 4.2 Requirements Definition

After consultations with various ASIs and other information system contractors, a general set of guidelines were developed for this concept. First the new database interface had to be reconfigurable. The local system manager needed to be given some latitude to decide which applications and database systems will be presented for that Flight Standards District Office (FSDO) and how they will be grouped. Second, the interface was to be a relatively small window that could normally stay on top of all other windows on the display. Third, the interface was to be able to remember its last position on the display and the last application or database system that was used. Fourth, the interface was to use many of the Microsoft Windows user-interface conventions for ease of use and minimal training. Finally, the interface was to be standardized at all AFS offices so that any ASI could use any computer at any location and interact with a similarly configured interface.

#### 4.2.1 Design Concepts

There were several options considered in meeting these guidelines:

##### *Utilizing Program Manager*

The first concept considered was just to use the existing Program Manager from the Windows operating system. One advantage was that all Windows users are familiar with this application. Other advantages were a shortened development time (since this is a simple modification of an existing program), and the need for little or no system maintenance. The disadvantages were that Program Manager must be shared with all other Windows applications, and the interface configuration could be easily modified by any user (though some safeguards could be put in place to minimize this problem.)

##### *Developing a Program Manager-like Interface*

The second concept was to create a new Program Manager-like interface that would be customized to the AFS needs and yet resemble Program Manager in look and functionality. The advantages were that this interface would act similarly to the existing Program Manager and be fully customizable with the ability to access new bitmaps, icons, colors, etc. Also, advanced features not available in Program Manager such as nested folders would be supported. The primary disadvantage with this approach was that it would require a much longer development time than the other concepts

to capture not only all the existing Program Manager functions but all the unique AFS functions as well.

### *Toolbar Approach*

The third concept evaluated was a dedicated small graphical application used to launch specific applications or databases. A tool bar approach could be called up quickly via a hot key to display the available applications and databases on one side of the display. The advantages were that this would be a small unobtrusive window that could ride on top of other windows and give quick access to all other available resources. The disadvantages would be lengthy development time, depending on the number of functions that are contained in the final product (though not nearly as long as the previous concept), and limited room for additional functionality due to restricted window size.

## **4.2.2 FSEO Prototype**

The selected approach for the Flight Standards Electronic Office (FSEO) prototype was the toolbar approach due to its flexibility and moderate development requirements. With this approach, the FSEO prototype was divided into two basic components; the login screen and the base application.

### *Login Screen*

The first component is the login screen which is designed to handle user identification and password access to all national AFS databases. An example of the login screen is shown in [Figure 1](#). Upon activation of the login screen, a video clip of various FAA logos is displayed in the upper right corner. If desired, the video can be stopped by clicking once on the video with the mouse. The user accesses FSEO by entering his or her initials along with a password. When ID recognition occurs, the text fields in the lower left corner show the stored information about the user ID. After a user enters a correct ID and password, the option to change the password for that ID is enabled. The same identification can be used by all national databases and other applications launched with FSEO. This would eliminate the need for a separate user ID and password for each national database that the ASI was authorized to use. Also, with a user identification, the records stored by each inspector can be easily distinguished.



**Figure 4.1 FSEO Login Screen**

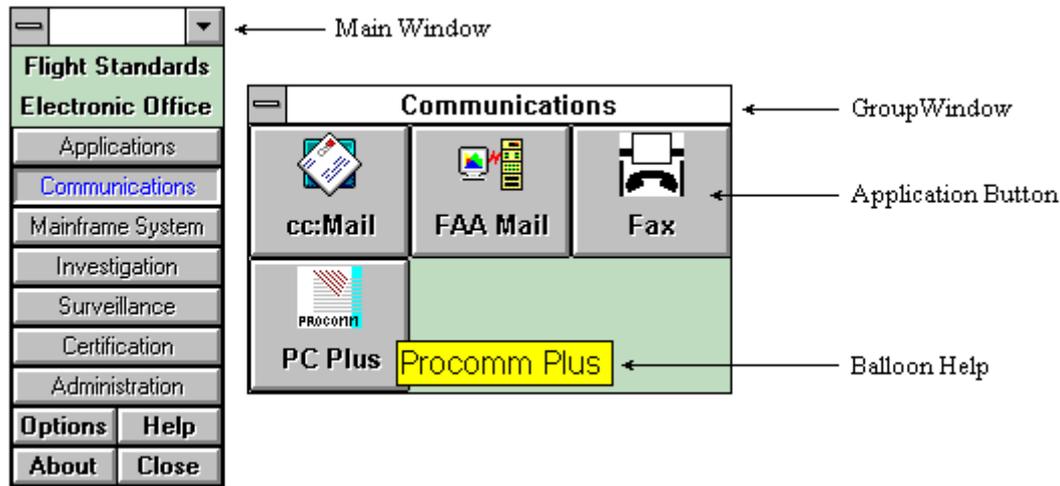
### *Base Application*

The second component is the base application and is designed to activate desktop software and utilities. The base application is further divided into a main window and a group window. The main window contains a series of buttons each associated with a group window. The main window contains additional buttons connecting the user with features such as options and help. When a user selects a group button, the appropriate group window is displayed and becomes active. This window presents a series of application buttons. Each application button consists of an icon with a caption below the icon that identifies a particular database system or software application. Along with the caption, a balloon help feature provides a more descriptive statement about the application. The user then selects an application button to launch that application. [Figure 4.1](#) shows the main window along with an associated group window.

An "always on top" feature is provided with FSEO. The "always on top" state keeps FSEO visible and accessible to the user while running other applications. The only time the FSEO window is minimized is by the direct action of the user. The user then can expand the FSEO window back to full size with the FSEO hot key.

### *Balloon Help*

The balloon help feature activates when the user positions the cursor over an application button. At this time, a window appears adjacent to the button of interest containing descriptive text about the application button. The balloon help text can be any type of desired description, but generally the balloon help is designed to be an expansion of the abbreviation or acronym in the caption. The balloon help is time delayed in order to prevent interference when a user quickly searches for a button to select. The balloon help feature is shown in [Figure 4.2](#).



**Figure 4.2 FSEO Base Application**

### *Option Utility*

Another feature of FSEO is the option utility. The option utility allows a system administrator to perform two operations within FSEO. The first operation adds a new user identification. A new user identification includes information such as name, initials, office and password. The second operation modifies the structure of FSEO. The system administrator can create or modify groups, buttons, icons and balloon help descriptions.

### *Help Documentation*

The help documentation will contain information related to the operation of FSEO. The help documentation provides instructions and explanations for the FSEO components. When pressed, the F1 key launches the context sensitive help. A context sensitive help connects the current component of the program with an equivalent help topic.

### **4.2.3 User Evaluation**

This prototype concepts was presented to six ASIs for comment and review. All agreed that this concept would be a better approach to their interactions with the many applications and databases that they use on a daily basis. Several commented that their own FSDO has implemented a similar type of common user interface application for their specific FSDO. Each agreed though that it would be advantageous if AFS adopted a agency-wide interface standard. The major disadvantage that was cited was how FSDO would interact with the database security procedures that are currently in place. Each database systems currently requires that each ASI have a unique user ID and password. A single point entry system such as FSEO would be a significant departure from current procedures.

### **4.2.4 Summary**

Overall, the purpose of FSEO is to provide a front end for FAA applications utilizing a standard toolbar approach in a Windows environment. FSEO also aids the user by incorporating application identification and documentation for help. The goal for the FSEO project was to produce a fully developed software package that interacts with the national AFS databases and launches applications from an organized set of groups and buttons. As AFS continues to modify and incorporate new technologies and improved data handling procedures, a concept such as FSEO should receive more

support from the AFS community.

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## **Work Order 3 Final Report (1995)**

### **A Human Factors Study to Explore and Support the Application of Advanced Technologies for Communication and Information Access within the Flight Standards Service**

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(unpublished report, 1995)

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## **1.1 Activity 1. Identify, Procure, and Test Advanced Technology Communications for FAA Safety Data Transmittal**

The intent of this subtask is to identify cellular and other wireless communications devices that could enhance the data collection performance and reference data access for the Aviation Safety Inspectors (ASI). The research team has evaluated various products and services that could have an application for AFS operations. Several products and services were procured and underwent testing.

Advanced communications technologies hold tremendous promise to better meet the information needs of the ASIs. The ability to remain connected to, or gain access to, the computer and database resources of the District Office through wireless connectivity have the potential to improve the efficiency of the ASI in accessing data to expedite the completion of an inspection or investigation.

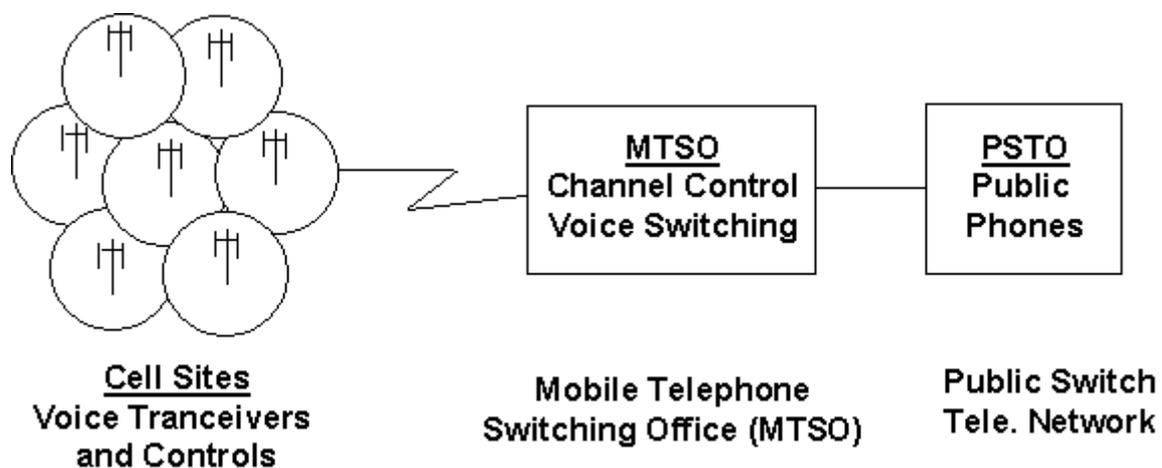
The communication technologies that are available today consist of cellular, packetized radio, spread spectrum radio, infrared transmission, and wireless LANs. These technologies have been divided into two categories: (1) Long Distance Data Communication, and (2) Short Distance Data Communication. Each technology was researched and analyzed for appropriate application to ASI needs. Recommending a wireless data service for the AFS will be based upon such criteria as service availability, coverage, roaming capability, transmission speed, network capacity, air-link confidentiality, interoperability, and available hardware and software. However, most wireless data communication services available today are still in their early stages and will require more time to mature and expand coverage. The following is a series of descriptions of each of these communication technologies and what applications show promise to improve ASI performance. For those technologies that were deemed promising, a description of the subsequent evaluations are included.

## 1.2 Long Distance Data Communication

The communication technologies listed in this section represent services that allow a mobile user to roam regionwide and nationwide and still be able to connect to remote host systems for the purpose of receiving and transmitting data and reference information. Each of these services are still relatively new and major changes in this segment of the communications industry are expected over the next few years.

### 1.2.1 Circuit-Switched Cellular

The circuit-switched cellular network for voice transmission is the most widespread wireless communication service today. Approximately 95% of the U.S. population is covered by this cellular service. The current cellular network, the Advanced Mobile Phone System (AMPS), provides the backbone for voice and data-over-cellular service using circuit-switched and CDPD technologies (see Section 3.1.1.2 for CDPD review). The AMPS is essentially an extension of the existing landline phone system, referred to as the Public Switch Telephone Network (PSTN). The difference is that a Mobile Telephone Switching Office (MTSO) is used to keep track and maintain communications with the mobile cellular users. The AMPS consists of a patchwork of overlapping radio sectors, called "cells", each containing a transmitter/receiver antenna. When a voice call is placed, a dedicated connection, or "circuit", is used as the connection between the two end-points of the call. If one of the end points is moving during the call and passes from one cell site to another, the call is "handed-off" to the new cell site by the MTSO. At the completion of the call, the connection is then terminated. [Figure 1.1-1](#) provides an illustration of the network architecture.



**Figure 1.1-1 Circuit-Switched Cellular Network**

Transmitting data-over-cellular uses the same process. Once the circuit-switched connection is made, all data is transmitted during one continuous session. There are a few problems though. AMPS, as it exists today, was designed for voice communications, not data transfer. Connection problems and interference that go unnoticed or are ignored during voice communications have a profound impact on data communications. Man-made and natural structures such as buildings, tunnels, trees, hills, and valleys can block or cause interference with the signal (e.g., pops, crackles, hissing, etc.). Channel interference resulting from either a long distances between the mobile user and the transmission tower and/or heavy cellular phone traffic (e.g., during rush hours and lunch hour) can degrade the quality of the connection and make a data connection more difficult to maintain. Cellular hand-offs that cause transmission delays will also result in lost data. Nearby [RF](#) transmitters or electrical equipment can also cause interference in the cellular signal. To mitigate these problems, enhanced protocols and software are being introduced as data-over-cellular becomes

more popular.

A data-over-cellular connection requires several hardware and software components. In addition to the digital cellular phone and a notebook computer, a modem and a data interface device are required. The selection of a modem provides the option of choosing different protocols. These protocols are (1) data modulation schemes that determine the data transfer rate (e.g., 1,200 to 14,400 bps), (2) error correction capability to detect and correct data transmission errors (e.g., V.42/LAPM and MNP10), and (3) data compression algorithms that allows for automatic compression of data to increase effective data transmission (e.g., MNP5 and V.42bis). Some protocols are "two-sided" and require the protocols to be present on both ends of the transmission. "One-sided" protocols only require the protocol to be resident on one end of the connection. Some of the data modulation schemes also have the capability to shift the data transmission rate up or down depending on the quality of the connection. One problem that exists today, but will most likely be resolved in the near future, is that there is no standards for the electrical connection for cellular phones. Therefore, the selection of a modem requires some attention to the issue of hardware compatibility. As with any new technology, new protocols are being developed to enhance the data transmission quality and these will be evaluated as they become available.

The other unique component for this data-over-cellular connection is a data interface device. Cellular phones expect to respond to dial tones and ring indicators. The data interface device generates these dial tones and ring indicators since cellular phones and modems do not perform these functions. This device connects the cellular phone to the modem to allow the modem to autodial and autoanswer through the phone.

As data-over-cellular service continues to become more popular, manufactures are beginning to recognize that a simpler hardware solution is needed. Hardware solutions that combine two or more of these components into a single device are beginning to be offered. One example is a Personal Computer Memory Card International Association (PCMCIA) card that contains both the modem and data interface circuitry. The PCMCIA card plugs into the PCMCIA slot in a notebook computer and a standard cellular phone then attaches to the PCMCIA card. Specific software drivers are then required to properly manipulate the data for display to the user. One potential problem with this option is the issue of standardization of hardware. Not all PCMCIA cards are compatible with all notebook computers. Also, some notebook computers have a high radio frequency (RF) emission that interferes with the cellular transmission and reception.

Another example is the "Air Communicator" phone. This product combines the modem, data interface device, and the cellular phone into a single unit. The unit is a little larger than a standard cellular phone but is much more convenient than keeping track of three different devices. This device was purchased and evaluated for its ability to send data files over circuit-switched cellular.

### 1.2.1.1 Air Communicator Evaluation

#### *Testing Procedures*

The main purpose of these tests was to determine the data transfer rate using Air Communicator system. Files of different sizes were created and used in the evaluation (e.g., 4KB, 8KB, 20KB, 50KB, 100KB, 200KB and 500KB). These files were transferred from a notebook computer to the server using the Lotus cc:Mail Mobile software. These files were also transferred in the opposite direction from the server to the notebook computer. A file transmission process basically consists of two steps. Step one consists of setting up the modem connection (the startup time). Step two is the actual file transmission (file transfer time). Transmission time were recorded for both steps. Five transmissions were done for each file and for each direction.

#### *Observations*

The maximum throughput of Air Communicator is 57600 bit per second (bps) when V.42vis

compression protocol and MNP error correction protocol is used. However, it was discovered that only LAPM error correction protocol can be used with the Lotus cc:Mail application. The maximum throughput using this protocol is 14,400 bps.

Air Communicator has two indicators to present the status of the phone line. One indicator measures the strength of the signal and the other indicates the quality of the line. The strength of the signal is identified as being low, weak, and strong. The quality of the line can be identified as either critical, low, medium, and good.

We initially attempted to connect to the server using a cellular connection at 12,000 and 14,400 bps. We were unsuccessful in these attempts. We then tested the Air Communicator by connecting it to a telephone line directly (a wired connection), we found we could transfer data in 14,400bps without a problem. This indicated a limitation of the cellular connection. We then tried using a cellular connection at 9,600 bps instead. Though we were able to successfully transfer data at this rate, the connection was not stable. We often received a "Data Connection Loss" error message during our data transfer tests.. Even though the line strength was strong and line quality was medium, the connection was still dropped intermittently. Moreover, the error rate using 9600 bps was high. It was usually around 25% but occasionally went as high as 60%. The Air Communicator is designed to be able to switch to lower data rates if the signal strength is weak or the quality is low. However, it did not do this when the transmission rate was set at 9600 bps. Even though the error rate was typically around 25%, there is an associated overhead when recovering from errors, so the effective data transmission rate was much lower. We estimated the net transfer rate to be equivalent to a 4800 bps data transmission rate.

When the data transmission was set at 7200 bps or 4800 bps, the connection was very stable and seldom broke. The error rate using these rates was less than 10%. The Air Communicator also worked well even if the signal and quality of the line were low at these transmission rates. It would also automatically switch to lower or higher speed accordingly as the signal strength increased or decreased.

## *Results*

The results are illustrated by graphs below. The [Figure 1.1-2](#) presents the file transfer times against the sizes of file transferred. The transfer time was in linear proportion to the file size for each direction (to or from the server). The average transfer rate was about 100KB per 4 minutes. [Figure 1.1-3](#) shows the startup time for each transmission. The startup time was almost constant (about 36 seconds) for each case.

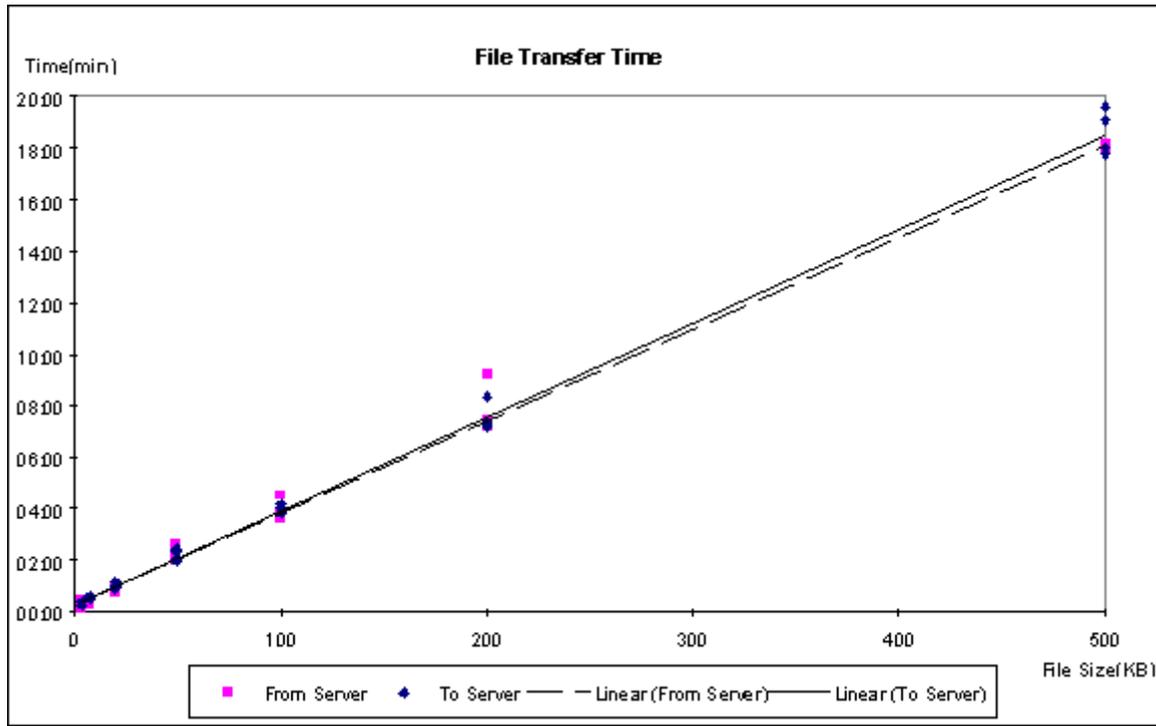


Figure 1.1-2. File Transfer Times

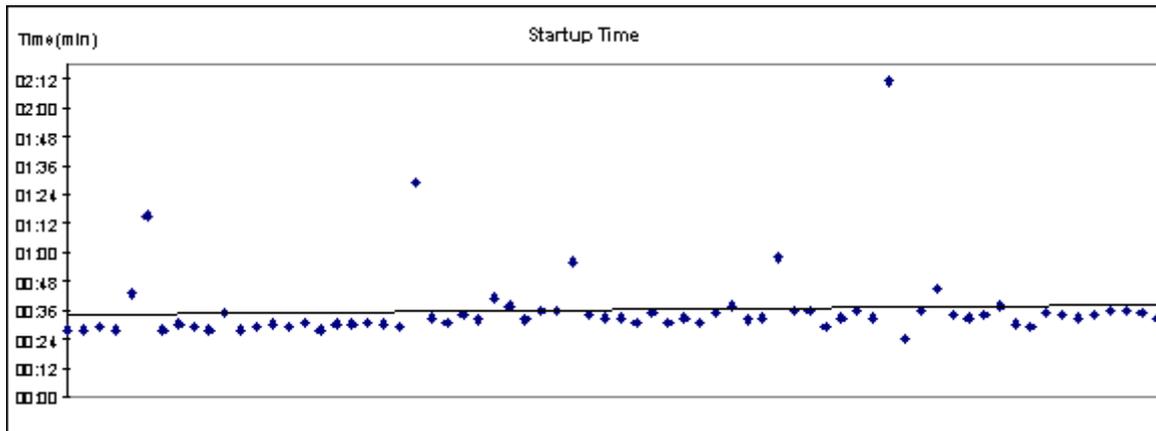


Figure 1.1-3. Start-up Times

To test the unit in a different environment we also tried to use Air Communicator to connect to an Internet site. Depending on the strength and quality of the line, we could sometimes make connections using 14,400 bps. But it was not very stable in 14,400 bps. It usually switched to 12,000 bps and then to 9,600 bps to reduce data transmission errors. One thing good about connecting to this Internet site was that we could set up the line to make use of the MNP correction and the compression protocol. We did some file transfers and the results are listed in [Table 1.1-1](#) below. It took less than a minute to transfer a 100K size text file if the file could be compressed to half of the original size (this is usually possible for a text file). For example, it took about two and a half minutes to transfer a 100K file.

Table 1.1-1. File Transfer Data Using the Internet

File Size	Compressed size of original	Total time	Time per 100KB	File Type	Direction
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125K	90%	0:01:40	0:01:20	Binary	From server
109K	33%	0:00:50	0:00:46	Text	From server
100KB	90%	0:02:33	0:02:33	Binary	From server
113K	50%	0:00:55	0:00:49	Text	To server
100KB	100%	0:02:16	0:02:16	Binary	To server

### *Conclusion*

The performance of the Air Communicator was acceptable to be used as a mobile communication tool. It has fair data transfer rates that are good enough to transfer small files (approximately 100K) between a mobile user and a server. For sending data files and small text files as . The key advantage of this unit is that the modem and interface unit are contained in the phone itself. The key disadvantage of this system is the lack of data security with analog circuit-switched technology. Unlike other wireless communications systems that will be covered later in this report, there is no data encryption inherent with this technology. This may get resolved as the carriers begin to offer digital circuit switched services. It is our understanding that data encryption will be available when these services are deployed. We will keep abreast of this technology as it evolves.

### **1.2.2 Cellular Digital Packet Data (CDPD)**

Cellular Digital Packet Data (CDPD) lets users send high-speed bursts of data, called "packets" over the existing AMPS network. The CDPD network is designed to be transparent with respect to the activities of the AMPS network. Unlike circuit-switched cellular which uses a modem-to-modem communications architecture, CDPD uses a network-to-network communications architecture. A Mobile Data Base Station (MDBS) is added to existing cellular sites which uses the same antenna that the AMPS transmitter and receiver uses. [Figure 1.1-4](#) illustrates the CDPD network architecture. The boxes in bold are the components that are added to the existing circuit-switched cellular network.

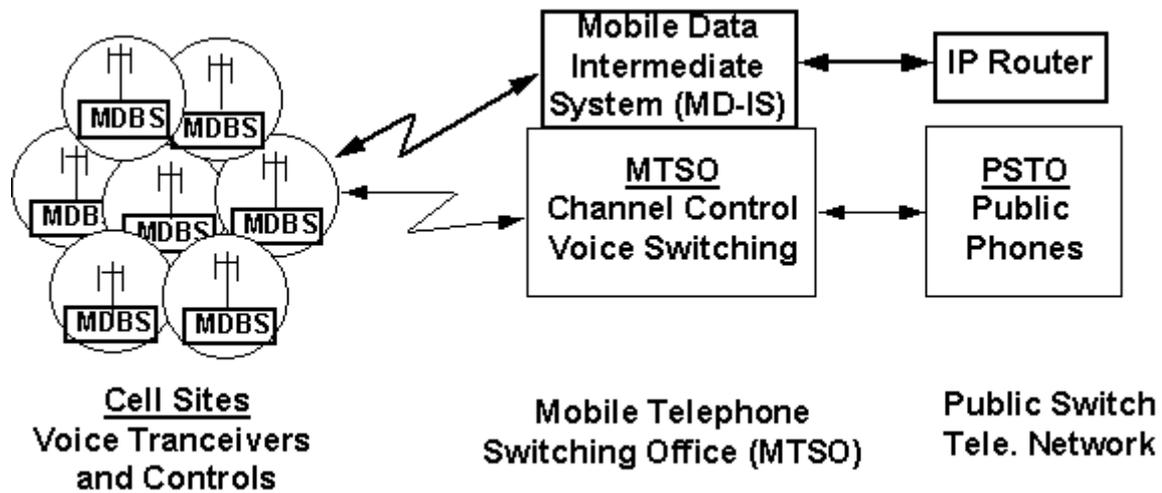


Figure 1.1-4. CDPD Network Architecture

When a CDPD call is requested by a mobile user, the MDBS uses a scanning receiver to scan all of the AMPS channels to detect the presence of circuit-switched traffic based upon signal strength. If two channels are idle (one to transmit and one to receive), the MDBS establishes an air-link between itself and the mobile user. Research has established that 30% or more of a channel's airtime is spent idle without transmitting voice traffic. Its during these idle times that the MDBS establishes and conducts the digital-data transmissions. To keep conflicts between the circuit-switched and CDPD networks from occurring, voice circuit-switched connections have a higher priority than CDPD connections to use the AMPS channels. If during the transmission of data the MDBS senses that a circuit-switched message is about to request the channel it is currently using, it will disconnect the digital-data link and establish another link on another channel. This technique is referred to as "channel hopping." [Figure 1.1-5](#) illustrates the concept.

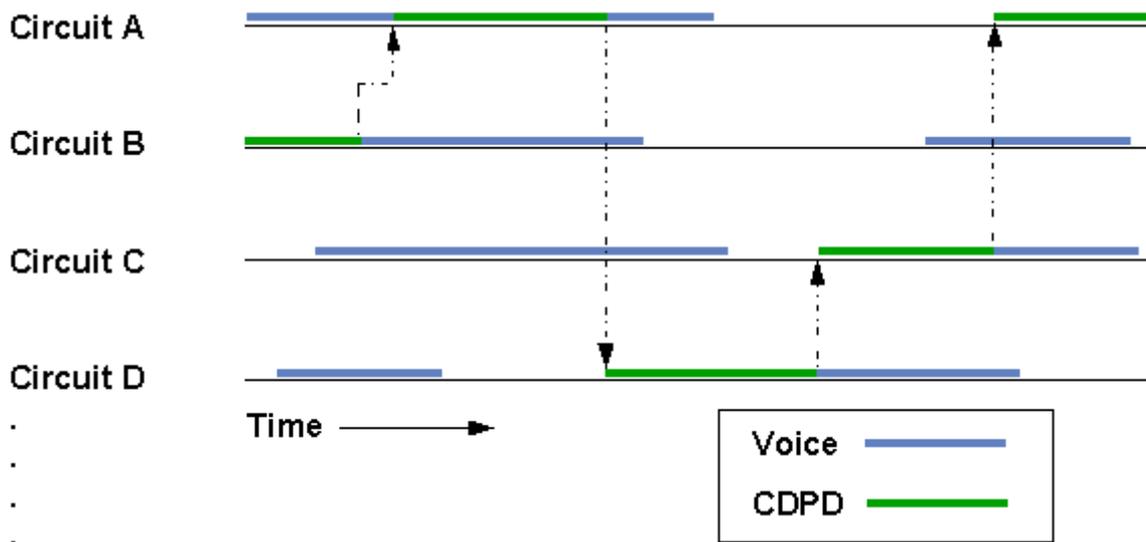


Figure 1.1-5. CDPD Frequency Hopping Illustration.

CDPD technology uses a packet-switched architecture to send data. It does not establish a circuit-switched cellular connection between two points as AMPS does. CDPD breaks up the data into small "packets" and uses destination information in a header to route these data packets throughout the network. It is these packets that channel hop throughout the network and then are reassembled at the destination to form the original contiguous data file. It is apparent from this description that not every packet of a data transferred will be routed to same way to reach the same final destination.

The end systems that use the CDPD network are referred to as the Mobile-End System (M-ES) and the Fixed-End System (F-ES). The M-ES is a portable computing device, such as a notebook computer, that can roam from cell site to cell site and communicate with the CDPD network via the MDBS. The F-ES usually is comprised of a server or host system that is directly wired into the CDPD network. The F-ES is not required to be aware, in any manner, of the mobility issues associated with the M-ESs they communicate with. Existing standard protocols in F-ESs will transparently interact with CDPD mobile subscribers, meaning that existing application systems and land-based networks need not be modified to communicate with M-ESs.

The CDPD network is designed to accommodate a raw data rate of 19,200 bps. In practice, the net data throughput is typically between 10,000 and 12,000 bps. The reason for this decrease in throughput is the large amount of control and destination information contained in the header within each data packet. It is this information that allows the receiving end-system to collect all the packets and reassemble them into the original data file.

Currently, approximately 12 metropolitan cities have a commercial CDPD network functioning. By all accounts, 1995 will be a very important year for CDPD. The current plans are to add the CDPD infrastructure for many more cities by the end of 1995 and have these new cities on-line and operational by early 1996. CDPD will be able to expand quicker than any other type of wireless system since they are building on top of a 95% coverage base established by circuit-switched cellular.

The research team initially established a working relationship with two wireless communication service providers to test their systems. These companies are Bell South Cellular and AirTouch Cellular Data Group. Based upon the success of our initial evaluation below we have recently established relationships with three additional carriers and will pursue continued testing during the follow-on contract.

### **1.2.2.1 Modification of Existing Software for the CDPD Network**

The ultimate goal of this effort is to determine if this CDPD technology can be integrated into the PENS application to permit the ASIs to access AFS information at remote locations. The concept is for an ASI to be supplied with a small notebook computer equipped with a wireless modem containing a minimum of client-based software and local databases. When specific information is needed to complete an investigation, inspection, etc., the ASI will be able to query the databases on the server at either the local FSDO office or a national database and download the desired information.

In order to use the Performance Enhancement System (PENS) application with these CDPD services we were required to make several changes to the software and the database architecture. This was required because wireless networks utilize a slower data transfer rate than the conventional wired networks. The existing PENS software needed to be modified in order to efficiently utilize the wireless technology. In addition, users of these wireless networks are charged on a per-packet basis. Therefore an effort was made to transmit the minimal amount of data required to meet the end users needs. For this evaluation, one component of the PENS software was selected for modification, the Inspector's Field Kit (IFK). The IFK is an ideal candidate for this evaluation because it will provide ASIs with the capability to remotely access centralized database systems at their local district offices while they are doing inspections in the field.

The Client/Server environment was selected as the database environment for the Fieldkit software for two main reasons. First, the Flight Standard Service (AFS) has indicated that they will be moving to this database environment in the near future and second, the Client/Server environment is ideal for wireless data communication. In a Client/Server environment, processing is split between powerful servers and desktop or notebook client computers. A powerful computer usually functions as the database server, referred to as the back-end of the system (F-ES for CDPD applications), which services the requests of the client computers. These client computers, referred to as the front-

end of the system (M-ES for CDPD applications), typically are less powerful computers running a Windows-based system, that make requests to the server. Client/Server technology inherently reduces network traffic which is a major advantage when dealing with wireless networks given their limited network bandwidth. For example, when a client application makes a request to the server, the server processes that request then sends back only the data that was requested to the client. This is in contrast to a traditional file system which moves large blocks of information over the network to the desktop system for processing.

The Fieldkit software was originally developed using Microsoft (MS) Visual Basic that accesses data stored in the Paradox 3.5 database system. The following tools were used to set up the Client/Server environment and for modifying the Inspector's Fieldkit software.

- MS Windows NT Server Operating System, Version 3.5
- MS SQL Server Database, Version 4.21
- MS SQL ODBC Drivers
- MS SQL Server Programmers Toolkit for Visual Basic

MS Windows NT runs on the server machine as the Operating System. MS SQL Server functions as the Database Management System (DBMS) running on the server. MS SQL Other Data Base Commands (ODBC) drivers provides the IFK software high level access to the database server. The SQL Server Programmers Toolkit is an Application Programming Interface (API) which provides the IFK software with a low level access to SQL Server. Although access to SQL Server from the Programmer's Toolkit is faster than ODBC, an application developed using this software cannot access another Client/Server DBMS such as Oracle or Sybase, without modification to the application. Whereas an application developed using ODBC provides slower access to the server, but it provides the portability needed to run an application across DBMS. (NOTE: The AFS has recently made a decision to use MS SQL Server as their standard database so the ODBC interface will not be used in future software configurations.)

Because of the limited bandwidth of the CDPD Network, only database tables that are updatable by IFK software were migrated to the MS SQL Server. These tables were migrated in their current format. No modification was made at this time to modify the structure of these database tables. The other tables were look-up tables that are used by search functions in the software. These look-up tables are rarely changed so there was no need to have this data transferred over the network. There the look-up tables remained as Paradox database tables and they reside on the local hard drive of the machine that the application is running on.

In addition, a CD-ROM from Summit Aviation Publications, containing FAR and Handbook data, were placed in the CD-ROM drive on the server. This was done to test response times for FAR and Handbook searches. It is important to note that we are not advocating this particular product as the best choice. There are other CD-ROM products that contain the FARs and related information that can also be used.

### **1.2.2.2 Bell South Cellular**

Bell South Cellular has established a CDPD laboratory in the Atlanta area and have agreed to participate with us in a series of studies to determine how this technology might be utilized by an Aviation Safety Inspector (ASI). The initial evaluation consisted of a series of tests to establish a baseline performance of data transfer times and reliability of the CDPD network system. Two portable computers were used to emulate the F-ES and the M-ES. To establish the connection between the notebook computers and the modems, a Transmission Control Protocol/Internet Protocol (TCP/IP) software stack was required.

One important fact that was uncovered in this initial stage is that not all TCP/IP stacks are compatible with all CDPD modems. Also, not all TCP/IP stacks are compatible with other TCP/IP stacks. We spent a fair amount of time and effort to determine what hardware and software were compatible. Hopefully a standard will emerge in the near future to make the selection of CDPD

components a simpler task.

Learning the proper configuration of the software also took much time. Once we were able to establish communications between the F-ES and M-ES we then attempted to transfer files. These initial tests were successful but disappointing due to very slow transmission rates of 300 to 600 bps. This was not the 19,200 bps that we expected. What we determined was that the CDPD modem that we were provided with used a half-duplex communications protocol and that the TCP/IP stack was not tailored to operate in the CDPD environment.

Not long after these initial tests we begin to see advertisements in the trade journals of TCP/IP stacks tailored for the CDPD environment and other CDPD modems . We continued to research these new products and finally selected a new TCP/IP stack and a modem that can highly recommended. We purchased these components and were able to achieve the desired transfer rates.

We continued to use this laboratory to test new versions of our software and plan to continue our working agreement with Bell South through the follow-on contract.

### **1.2.2.3 AirTouch Cellular Data Group**

The research team made contact with the AirTouch Cellular Data Group and established a non-disclosure agreement. This effort provided the research team an opportunity to travel to San Diego, CA to perform a series of field studies in an actual CDPD regional network. San Diego was been used by AirTouch as an evaluation site because it provides a broad array of terrain features to test the strength and penetration of the CDPD connections in a metropolitan location.

To evaluate this concept a three phase process was established. Phase One, now completed, was designed to determine transfer times, data integrity, and connectivity issues (both hardware and software). A modified version of the PENS Inspectors Field Kit (IFK) software was used as a front-end client application that ran on a mobile notebook computer. A Microsoft SQL Server database ran on a Windows NT server that was accessed over an AirTouch Cellular CDPD network by the mobile notebook computer located in the San Diego, CA area. This phase produced promising results that included a list of lessons learned (see below). Phase Two is planned to integrate a more complete version of the PENS software on the mobile notebook computer and a subset of the FAA references on the server database. The server, the supporting communications hardware, and the database will be located at a FSDO. This will allow several ASIs the opportunity to use this wireless job-aid during actual investigations and inspections. The ASIs will be able to download work programs, upload completed forms, and request existing and/or ad-hoc searches to be run over a wired and wireless network. Phase Three will involve a broader integration effort to include actual national database systems that will allow ASIs to access real data at the local and national level databases. Actual inspection data are planned to be uploaded and downloaded during this phase at several district offices.

The following is a summary of Phase I data transfer tests between April 10-12, 1995 in the San Diego, CA area. The AirTouch Cellular personnel provided technical assistance and the access to the local CDPD network. The F-ES computer was directly connected into the MD-IS at AirTouch's San Francisco Office. The M-ES was connected to a CDPD modem was used to access the CDPD network. This unit was operated in the San Diego area. Both client and server systems used the same TCP/IP stack to communicate across the CDPD network.

#### *Evaluation Activity*

An IBM Thinkpad 510 sub-notebook computer was configured at the GSC office in Atlanta prior to the Galaxy Scientific staff arriving in San Diego. The first day of the evaluation we met with two AirTouch representatives and gave both of them a briefing of the Performance Enhancement System (PENS) for the AFS and demonstrated the software that we were prepared to test. We reviewed city maps to verify that the airports that we wanted to test at were within operational cells in the San

Diego CDPD system. Since this CDPD system was still in the pre-operational testing phase not all locations were operational during our testing. We modified our plans and re-mapped our route for the next day based upon this information. Final preparations were made that first day and all components were operating properly. We collected several documents that described these techniques and planned to use them in the second phase of our evaluations.

The second day the GSC and AirTouch personnel travelled to three different airports in the San Diego area; Montgomery Field, Brown Field, and Lindbergh Airport. At each airport the system was tested at specific locations on the airfield likely to be frequented by ASIs (e.g., Fixed-Base Operator facilities, hangers, and terminal buildings). At each of these locations a connection was made to the CDPD network and collected several parameters that were of interest to AirTouch. We then uploaded and downloaded files from several different sites (two servers in San Francisco, and one server in Seattle) to collect transmission times and transmission errors. We also exercised a program that searched for key words in the FARs contained in our server in San Francisco and downloaded the sections associated with these key words. A few problems were encountered during the day but, overall, we were able to attain our goals for our first evaluation of this technology. [Table 1.1-2](#) contains the information concerning data transfer integrity and transfer times.

The third day was spent at the San Diego FSDO briefing the ASIs there on the overall PENS program and specifically our CDPD testing. The office personnel that attended the briefing were interested in our activities and gladly agreed to assist us with the next phase of our work. We spoke at length with the acting FSDO manager and the network administrator and reviewed the hardware and software configurations with them in detail.

### *Lessons Learned*

The initial conversion of the IFK Software was done using ODBC. This effort required very little change to the existing application. The existing structure of the program was maintained and the only change made was replacing the Paradox Database access calls with ODBC access calls. Although this effort allowed the research team to verify that the IFK software can run in a wireless environment (proof of concept), the performance was too slow. The application was able to connect to the MS SQL Database Server and was able to return data from the server, but it was very slow in doing so.

Because of the slow response time experienced with the initial conversion, the IFK Application was converted using the MS SQL Server Programmers Toolkit. This effort required extensive programming changes. The access calls to the database had to be changed to meet the Programmers Toolkit's protocol. The manner in which the application process data returned from the database had to be changed. The initial version of the IFK program used a Visual Basic Object called Dynaset. This Dynaset object automatically handles the processing of data returned from the server. On the other hand, the Programmer's Toolkit requires that the programmer handles the processing of the data returned from the database. This requires more lines of code than was required in the original version.

In addition to these changes, the IFK software was also modified to provide integrated access to the information on the Summit Aviation Publication CD-ROM located on the server. This feature allows an ASI to access regulatory data without exiting the IFK software. The software was extensively tested later at the Bell South laboratory and it was successful. The performance was in-line with those expected over the CDPD network.

One final hardware problem that was uncovered is that there are two different serial port chip sets that are used in notebook computers. The UART 8250 has a maximum data transfer rate of 9600 bps and is not compatible with a CDPD network. The UART 16550AF is the required chip set and is able to accommodate the 19,200 bps data rates.

This effort clearly demonstrated that existing software can be successfully modified to run over the CDPD network. It also demonstrated that ASIs can use the IFK software in the field to remotely

access centralized database system nationwide when they have access to a CDPD network.

The major drawback to this concept is that the deployment of new CDPD networks in the United States is progressing slower than expected. The wireless data transmission industry is at its inception and it looks like it will be a year or two before it begins to mature for nationwide service. We intend to complete the second and third phase of the investigation and continue to make contacts with the various CDPD providers to ensure compatibility with all their CDPD networks.

**Table 1.1-2 CDPD File Transmission Information**

**Montgomery Field**

Location: Gibbs Flying Service FBO and adjacent hanger.

Date: April 11, 1995

1. Search FAR task response times using GSC server with Reflection v4.01

Time

Key word search - "aviation" 60 sec

Retrieve text (6 line x 120 char/line) 20 sec

2. FTP download from Airtouch Server with Reflection v4.01

File    File Size(Bytes)    Time

adspg.txt    4797    13 sec

cdemo9.gif    9129    27 sec

cdemo2.gif    19107    65 sec

cdemo4.gif    41411    189 sec (See Note 1)

3. FTP download from WRQ Server using Reflection v5.0

File    File Size(Bytes)    Time

adspg.txt    4797    25 sec

cdemo2.gif    19107    61 sec

4. Comments

General. The signal strength and transfer times were identical for both the Gibbs Flying Service FBO and the hanger on the field.

The following day we were briefing the FAA personnel at the San Diego FSDO and we attempted to demonstrate the CDPD communications. We recorded an RSSI of -71 dB. We were able to Ping the WRQ Server but were not able to transfer files with our server (the ICMP protocol is used for ping and the TCP/IP protocol used for FTP, Winsocket, etc.). We were located within a concrete and steel building in a central conference room. When we moved to an outside window office we were able to transfer files but the times to transfer these files were noticeably longer. I thought that we would be able to transfer files in the conference room based upon the RSSI value that we initially recorded. This was not the case.

**Table 1.1-2 CDPD File Transmission Information (con't)**

**Brown Field**

Location: Kome Flight Service.

Date: April 11, 1995

1. Search FAR task response times using GSC server with Reflection v4.01

Time

Key word search - "aviation" 109 sec

Retrieve text (6 line x 120 char/line) 38 sec

2. FTP download from Airtouch Server with Reflection v4.01

File    File Size(Bytes)    Time

adspg.txt 4797 28 sec

cdemo9.gif 9129 62 sec

cdemo2.gif 19107 See Note 1

cdemo4.gif 41411 (Not attempted)

3. FTP download from WRQ Server using Reflection v5.0

File    File Size(Bytes)    Time

adspg.txt 4797 (Not attempted)

cdemo2.gif 19107 (Not attempted)

4. Comments

Note 1. At this site the CDPD connection was not stable. This resulted in the attempted download of the file cdemo2.gif to be aborted twice. At this point the connection became so unstable that no further transfer attempts were made. We checked the connection using the Ping utility and found that between 30% - 70% of these attempts were successful over a five minute period. We also noted that only channels 595 and 637 provided an RSSI level of around 50-60 dB. The pings that were successful had a noticeably longer response time (500-600ms was normal with longer times being 1200 - 1500 ms).

**Table 1.1-2 CDPD File Transmission Information (con't)**

**Lindbergh Airport**

Location: Delta Airlines Gate #23

Date: April 11, 1995

1. Search FAR task response times using GSC server with Reflection v4.01

Time

Key word search - "aviation" 78 sec

Retrieve text (6 line x 120 char/line) 38 sec

2. FTP download from Airtouch Server with Reflection v4.01

File    File Size(Bytes)    Time

adspg.txt 4797 18 sec

cdemo9.gif 9129 66 sec (See Note #1)

cdemo9.gif (second attempt) 9129 67 sec (See Note #2)

cdemo2.gif 19107 127 sec (See Note #3)

cdemo4.gif 41411 (Not attempted)

3. FTP download from WRQ Server using Reflection v5.0

<u>File</u>	<u>File Size(Bytes)</u>	<u>Time</u>
pres16.txt	4578	5 sec
pres25.txt	10725	15 sec
pres28.txt	18889	26 sec

4. FTP download from Microsoft Server using Microsoft TCP/IP v1.01

<u>File</u>	<u>File Size(Bytes)</u>	<u>Time</u>
dirmap.txt	4375	5 sec
msnerp.txt	22641	38 sec

5. FTP upload to Airtouch Server

<u>File</u>	<u>File Size(Bytes)</u>	<u>Time</u>
adspg.txt	4797	10 sec
cdemo2.gif	19107	29 sec

6. Comments

Note #1. This transfer took longer than expected. When the diagnostics function was run the following were recorded:

12 checksum errors

1 Destination error

5 Re-transmit errors

Note #2. The same file was transferred and when the diagnostics were run again the following was recorded

10 checksum errors

0 Destination error

1 Re-transmit errors

Note #3. When this file was transferred the following errors were recorded.

10 checksum errors

0 Destination error

1 Re-transmit errors

We then logged into the WRQ server and downloaded the files listed in Section 3. There were no errors and the transfer times were noticeably shorter.

For an additional test, we logged into the Microsoft server in Seattle and downloaded the files listed in [Table 1.1-2](#). Again, the file transfer times were much quicker and there were no errors. The important differences between these downloading tasks was the use of different combinations of TCP/IP stacks.

### 1.2.3 Packetized Radio

Wireless data transfer can also be performed utilizing a packet radio service. There are two main services that users can subscribe to, Advanced Radio Data Information Service (ARDIS) and RAM Mobile Data (RAM). These wireless services allow users to transmit and receive information from their portable computers via switching centers to destinations of their choice within the available networks provided by these service companies. These services allow a user to maintain a continuous connection through transparent hand-offs between coverage areas while roaming throughout many areas in the U.S. Their networks were initially located in major metropolitan areas but these service providers are continuing to build-out their networks.

ARDIS network is currently operating at 4,800 bps though they are planning to upgrade to 19.2K bps in selected cities. RAM is also currently operating at 4,800 bps throughout their network and is also planning to upgrade to 19.2 K bps.

We researched the RAM services and found several limitations of cost and proprietary equipment that made using this system not desirable. We identified two possible approaches to use the RAM system with the PENS software.

The simple approach is to install RFMLib on both the client and server computers, which is the RAM mobile data system interface, and add RAM mobile wireless modems. Both systems will access the RAM Mobile Data Wireless Service Network System to transfer the desired information. However, this configuration will not operate within an Windows NT environment, the planned AFS server operating system. RFMLib will only support a DOS/Windows environment. To make this system work with the PENS application would require a complete rewrite of the whole PENS software at both the client and server side to make it work.

The second approach will overcome this problem but is a very expensive option. First, it requires more RAM proprietary software to be purchased for each server. The server side requires the application X.25 RFGate to connect the local area network and each server location (e.g., FSDO, Regional office, etc.) will need to have a X.25 wide area network installed. The X.25 lease line is required to link to RAM mobile data system. This configuration will make the mobile client system to connect the Windows NT server. Additionally the client side software would also require a major software rewrite to make this configuration operate. The high cost of the additional software and leased lines makes this a prohibitively expensive solution.

In summary, the ARDIS and RAM both have a couple of years headstart on the other wireless service providers. They have established networks and markets for their services. Several commercially available [LAN](#)-based E-mail software packages are currently ARDIS and RAM enabled. At this time though, many non-metropolitan areas are still not covered by these services. Since many of the ASIs destinations are in such areas, the use of these services would be limited. However, if expansion plans for these companies are completed over the next few years, it would be appropriate to further evaluate their services at that time.

### 1.2.4 One-way and two-way paging

One-way paging has been available for several years and is a cheap and easy method to notify a subscriber that someone is trying to reach him/her. Initially this was in the form of a signaling device worn by the subscriber that alerted the subscriber that he/she was required to call an operator by telephone to receive the message and phone number. Now several services are providing minimal messaging capability to send phone numbers and limited alpha-numeric messages as part of the paging signal. These systems provide a very large area of coverage encompassing large metropolitan areas and surrounding suburban communities. One-way service providers are also marketing up-to-the-minute information on specific topics such as sporting scores, stock prices, etc. Unless there is a vital need for an ASI to be contacted immediately, this technology has limited use

for AFS.

Two-way paging is relatively new. This technology builds upon one-way paging by adding receivers to the existing transmitter towers to pick up the return traffic from their subscribers. The return information will vary depending on the capabilities of the sending device. Some devices are quite simple and send limited alpha-numeric strings, many of which will be "canned", back to the sender. Others are much more capable, such as a notebook computer, and can receive limited sized files. These service providers have also recently purchased part of the Narrowband PCS frequencies and plan to use them in the near future (See PCS Section below). Further investigation by the research team is planned to better evaluate this new service.

### **1.2.5 Personal Communication System**

The Personal Communications System (PCS) is represented by three major categories of communication services. The Federal Communications Commission (FCC) has re-allocated a portion of the electromagnetic spectrum to support new wireless services for voice, data, facsimile, and even some forms of multi-media communications. Potential PCS providers are creating strategic plans and corporate alliances to be able to finance the tremendous cost of creating a new segment of the communication industry. The potential for this communication technology is great but so are the risks. The following is a brief description of this technology and some of the capabilities promised.

The first type of PCS service is referred to as Narrowband PCS. Providers of this technology will offer new services that extend the capabilities of current pager technology. Such concepts as wireless voice messaging and two-way or acknowledgment paging are being discussed by providers. Some PCS providers plan to offer basic paging services in 1995.

The next type of service is referred to as Broadband PCS and represents the majority of the allocated PCS spectrum. Service providers will use this band to offer cellular-like service that will use an all-digital integrated voice/data infrastructure. Also possible for this service will be advanced network functionality, such as the "one person, one number" concepts proposed by advocates of this technology.

The third category of PCS services are outside of the Narrowband and Broadband options. This service is designed to allow unlicensed operation within short distances (e.g., indoor and campus-settings) for wireless voice and data devices, including wireless LANs and wireless private exchanges.

Currently, the PCS industry is in its infancy. There are no technology standards nor is there any defined infrastructure to date. While this technology promises to be an exciting new form of communication with potential uses by the AFS, it is at least five years from full operation using the most optimistic predictions. We will keep a close watch on this situation since it does have much to offer once several major hurdles are cleared.

### **1.2.6 Satellite**

The idea of seamless national or world-wide coverage is the goal for many communications providers. One method to achieve this goal is to launch a fleet of low earth orbiting (LEO) satellites. These satellites would be low enough to the Earth's surface to minimize transmission delays and would allow for the use of low-power personal communicators the size of a small cellular phone. There are six companies that are planning to offer this service over the next 10 years. Their plans range from launching a constellation of short-lived, low-cost, basketball-sized satellites that operate with a low-cost, small earth station to the other extreme of large, costly, complex satellites that have the capability of intersatellite links and rerouting calls around the globe. Some of these companies are predicting data transmission rates as high as 144K bps. Again, this technology is in its infancy and will be several years before commercial operation is achieved.



## 1.3 Short Distance Data Communication

These communication systems are for short distance networks such as within building, campus, and center-city sites. So far, no application of these services have been identified that have the potential to aid the ASI in the field though the research team will continue to investigate possible uses. These services have been briefly covered in the following sections.

### 1.3.1 Spread Spectrum

Metricom Inc. has offered a high speed wireless data service (77K bps), referred to as Ricochet, which operates in the unlicensed 902 - 928 MHz spectrum band. This system utilizes a meshed network of low-powered, microcellular radios located on street lights, utility poles, and buildings. The system users are required to use Metricom's low-powered, spread-spectrum modem technology to access the system. This system is intended to be used only in metropolitan areas so it is not intended to have complete nation-wide coverage. This system would not be a viable candidate for AFS usage since the majority of airports are not located in the center of large metropolitan communities.

### 1.3.2 Infrared

Infrared (IR) data transmission is becoming more prevalent now that the Infrared Data Association (IRDA) have established standards enabling a broader use of this technology. With IR line-of-site connections, users will be able to transfer data over a serial connection at speeds up to 115.2K bps between PDAs, notebook computers, and desktop computers. For example, this will allow information collected by an ASI on a notebook computer in the field to be synchronized with the desktop system when the ASI returns to the office. In addition, desktop peripherals can be connected, such as printers, without the use of cables. Hardware and software companies are now supporting the IR standard that will enable dissimilar devices from different manufactures to operate together. A infrared wireless system was purchased from National Semiconductor called Laplink Wireless to evaluate this technology.

#### 1.3.2.1 LapLink Wireless Evaluation

LapLink Wireless can connect two computers to allow a user to access the disk drives and printers of the other. It uses the AirShare radio modules and the LapLink Remote Access Software. The following briefly describes the process of setting up the system and of the functions of the program and findings during the process.

##### *System Setup*

##### **AirShare Modules**

AirShare hardware is composed of two modules: an "Air" module and a "Share" module. The Air module is used with the laptop computer and the Share module is used with the desktop computer. The AirShare hardware can use one of three power supplies: an AC adapter, a battery pack, or the mouse port cable for PS/2 mouse port. There is one channel switch and two LED lights on each module. The channel switch is used to change the radio frequency of communication between the three channels available. The red LED light indicates the status of the port (enabled or disabled). The green LED light indicates whether the system is ready to connect or not.

The software can be configured to use either a DOS or Windows operating environment. The installation is straight forward and not complex. After loading the software, you can start Windows. There will be a program group called LapLink Wireless. All the programs you needed for connections are in this program group. There are three main programs. LapLink Wireless Control Center provides the status of the communications connection. LapLink Remote Access controls the linkage between the host and remote computer. Synchro Plus updates directories between the two computers when ever a connection is made.

### **Findings and Troubleshooting**

One important issue when installing any program is the potential conflict over computer resources already allocated by previous applications and/or peripherals. This was an issue that was quickly resolved once the conflict was identified. In this case, network drivers and a sound card had to be worked around before the Laplink system operated properly.

Once the two machines were connected, the application operated properly. We were able to access the hard drives of other machine just as if they were network drives. We also tried to open and save files and did not encounter any problems.

To print remotely required additional modifications to the application. The user must first select how the local port is mapped to the remote computer's port. For instance, if the printer you want to print to is connected to LPT2 on the remote machine, you must specifically map this port to a local port (e.g., LPT1). The second option that must be changed is the Printer Setup on your Windows environment.

The performance of the host machine slowed down when there was extensive file access, such as copying files. The performance was similar to the access time for files from a floppydisk drive. Printing did not seem to appreciably slow the performance of the host computer though.

## 1.4 Wireless Communications Summary

Several general statements can be made regarding the issue of data transmission over any of the wireless technologies either evaluated or researched. First, transmitting large files, such as multimedia and video applications, over the wireless services available today or in the near future is not a viable option. None of the services offered will support the multi-megabyte data rates required by these applications. For the foreseeable future, these types of applications will require CD-ROM or wired connections through high-speed landline networks.

Second, all of the wireless networks described in the previous sections will have 40% - 50% less performance than the published data rates. This is due to the protocol overhead and long packet latencies.

Third, there is currently no interoperability between the various service providers at this time. Until this occurs, a different suite of modems and air-link protocols will be required for each service provider if a user moves between locations serviced by different wireless communication providers.

Fourth, re-engineering client/server applications may be required to minimize the amount of data sent over the air, since most wireless networks charge on a per-packet or per -kilobyte basis.

Fifth, most of the hardware required to use wireless services are currently too large, require too much power, and are too heavy to be convenient for most users. This will change in the next year as PCMCIA versions of the different types of modems will be offered to the market.

Finally, we are confident that wireless connectivity will prove to be a benefit for AFS ASIs but it is not time to commit to any one technology yet. Transmission costs are currently higher than landline connections and complete nationwide coverage is not available, but these situations will change in the next year or two. The growth of the wireless market is very rapid and there is no way to know how the industry will shake out in the next few years. We will keep up with this technology and make specific recommendations when appropriate.

## **2.0 Activity 2. Identify Limitations of Current FAA Databases and Data Communication Systems.**

This activity was terminated due to the fact that the Flight Standards Service is planning on completely overhauling the national and regional database subsystems and communications links that are used by the Aviation Safety Inspectors (ASI) on a daily basis. The product resulting from Activity 1.2 will be of no use when the database change occurs as currently planned in 1996. It is proposed by the contractor and accepted by the customer that the funding for this activity be combined with the work underway for Activity 1.0

## 3.0 Activity 3. Identify, Procure, and Test Advanced Technology Data Collection and Verification Systems for FAA Safety Data

The contractor shall continue to investigate emerging technologies not covered in other research efforts for field data collection and verification that hold promise of increasing inspector efficiency and effectiveness.

### 3.1 Remote Access Software

For an Aviation Safety Inspector (ASI) who is at a remote location away from the office, the ability to connect to the office computer to upload and/or download files via a modem has the potential to be a valuable asset. We performed a literature review on remote control software and selected a product highly recommended for purchase and conducted an evaluation. These products also will connect to a Local Area Network (LAN).

Unauthorized access to a Host system is restricted by the use of a user ID and password. The user ID also contains the default settings of that user's local machine. These default settings include modem and Network configurations, printer output destination, keyboard handling, cache file size, file transfer protocol, etc.

#### *Application Capabilities*

This application allows the user to either operate as a host computer or contact a host from a remote location. When at a remote location calling a Host computer, the user can maintain a list of hosts that may be called. Each host has its own setting like computer name, phone number, recording, logging etc. If connecting over the network, it will then show a list of available hosts to choose from. When assuming the role of a Host, the user can specify the privileges for the caller. Each caller can have their own privilege or every caller can be provided with the same default privileges. Privileges include permission to reboot host, blank host screen and keyboard handling method, etc.

When operating as the remote computer, the user can bring up the on-line menu from the control menu of the current session. The on-line menu contains a number of functions: (1) End session; (2) File Transfer function that will bring up a file manager in which the user can transfer from or to the host machine, (3) Reboot host, (4) Save screen function that will save the current screen to be viewed later or stop the recording of the current session, (5) On-line setting function will display a dialog box to change the remote operation setting and also provide a Chat function to let the user interactively query someone at the host machine, (6) Scripts function allows the user to define and edit new script and the script to be run on the current session, and (7) Turning the recording off.

The script language provided by the software is quite complete from the point of view of terminal emulation program or using DOS application. However, the script language was designed for text-based application. It would have been nice if the script would have provided more control over the Windows environment like choosing a menu or accessing a window.

This application allows the user to record the session and save it into a file. This allows the user to play the session back at any future time. It can also capture a particular screen and display it later. Moreover, it provides a logging function that can keep track of activities and statistics within a session. It keeps track of when the session starts and ends, information concerning files transferred, and names of computers connected that were connected.

One drawback of this application is that after it is installed, if the user wants to change the resolution of the computer display or install a new video driver, the application must be either reinstalled or the user must modify the SYSTEM.INI file to reflect the change.

### *Performance Evaluation*

The application response speed operating within the Windows environment has to be discussed in two aspects: displaying speed and processing speed. The sharing of menus and dialog boxes from the Host computer to the remote computer was a slow process. The cache file size was increased but there was no noticeable improvement. When the DOS window was open the response time was decreased. This indicates that the delay is due to the transfer of the graphical images. On the other hand the actual file copy time is dependent on network traffic. During times of light network traffic we were able to transfer a one Megabyte file in two minutes. During moderate network traffic, two minutes is required to send a 250 KB file. We found that we were able to improve the file transfer situation by first copying a file from either the Host or remote computer to a network drive first then have the other computer copy it to its own hard drive

## **3.2 Handwriting Recognition Software**

The contractor has evaluated several handwriting recognition software engines that recognize printed characters. We became aware of a product was released recently that advertised to be able to recognize both cursive and printed handwriting. We purchased this product and performed the following evaluation.

This application is a word-based recognizer which recognizes handwriting word-by-word instead of character-by-character. It finds the closest match between the users handwritten word and the words in the dictionaries that are currently in use. This application will not recognize words that have any of the following; (1) all uppercase letters, (2) a capital letter in the middle of the word, or (3) punctuation in the middle of a word.

To use this application, the user can write directly to the application that is being used if it is designed to recognize pen inputs. The other option is to use the sub-editor that comes with this application. To use this sub-editor, the user first activates the window that contains the sub-editor. The user then writes the desired text onto the sub-editor which then translates it to text. At this point the user has the option to rewrite the words or modify the translated text using a single character editor. This application will also provide a list of alternatives optional words which the recognition engine identified as similar to what was written so that the user can choose from the list instead of rewriting the whole word again. When the word or text is correct, it is then sent to the application.

## **Evaluation**

Since the recognition is restricted by the dictionaries used, the testing material was structured so as not to contain too many special names or acronyms. We decided that the form for reporting aircraft accidents satisfied this requirement. A Visual Basic form was created to allow user to input these data. Two people were invited to participate in the tests. Here is the outline of the testing procedures.

### *Introduction to Pens computing (10-15 min)*

- Let the participant go through the "Learning Pens Basic" program (10 - 15 min). This program will teach the participant how to use the pen.

### *Introduction to the application (5-10 min)*

- Explain rules with examples
- 2 ways of input
  - a) Write directly onto the application
  - b) Use the Editor

- Explain different options available
- Show the functions available

*Practice (10 min max.)*

- Let the participant to write using the pen until he feels comfortable with the environment

*Fill out the form (15 min max.)*

## Results

In general, more negative comments are collected than positive comments. The comments are summarized as follow.

This application does recognize cursive writing well if the user's hand writing is good and does not contain any numbers or special names. Also, the speed of recognition is very good. For example, a ten word string will take approximately one second to translate.

One the other hand, this application does not recognize punctuation and all capital letter acronyms. Numbers are also easily mis-recognized. The reason is that the recognition engine tries to find a closest match from the dictionary for every entry. It tries to recognize the numbers and surrounding letters together as a word. The numbers are then recognized as letters instead. Moreover, it seems that the chance is higher to recognize a character as a letter than as a digit. The numbers 0, 1 and 5 are often recognized as the letters O, l(lower case L) and S respectively. In general, many of the typical data entry text that is used by ASIs, such as acronyms, all capital abbreviations, and numbers are not accommodated by this software.

The other issue is that this application does not recognize editing gesture well. This problem is important because there are always mistakes. A large amount of time is spent in correcting the mis-recognized words. In addition, when a written word is recognized as different word, the whole word has to be corrected. Compared to other character-based recognizers, it takes more time to correct a whole word than correcting characters within a word.

This recognition engine does not require training due to the fact that it claims that the manufacturer claims it product is handwriting independent. This means that it can recognizes all styles of handwriting. Unfortunately, a character in one person's style may be very similar to another character in a different person's style. The more styles it can recognize, the higher possibility this situation happens and the easier it mis-recognizes words. Other recognizers which provide training a function can usually recognize less number of styles but more accurately.

In summary, while this application is able to do a good job at recognizing typical written words, it does not recognize the typical type of handwritten entry that ASIs use on a daily basis. The following is a summary of the brief evaluation that was conducted.

## **4.0 Activity 4. Identify, Procure, and Test Advanced Technology Communications for FAA Safety Data Transmittal**

## 4.1 Summary

A detailed study of data security for the different hardware, software, and communication for PENS application system was completed. The primary data security concerns for the AFS computer systems were identified as privacy, access fraud, personnel tracking, and computer viruses. It is recommended that the AFS data should be secured at the system access, transmission process, and storage locations.

The ASIs will use their PENS notebook computers at the office and in remote locations. These computers will be used in a stand-alone situation or connected over a communications network (phone line or, in the near future, wireless) back to their home office or a national database. Therefore, two parts of data security, data storage security and data transmission security, will be addressed. Data storage security will be the security system at the server and the database system. Data transmission security will be the security features from a wired and wireless network. In addition, the security of accessing a network system will also be addressed.

The available data security technologies and standards are discussed at the first section. Those technologies and standards that are recommended to protect the data of PENS application system as identified at the end of this chapter.

## 4.2 Data Security Technologies And Standards

### 4.2.1 Encryption

Encryption is the transformation of data into a form unreadable by anyone without a confidential decryption key. Its purpose is to ensure privacy by keeping the information unusable from anyone for whom it is not intended, even those who can see the encrypted data. For example, one may wish to encrypt files on a hard disk to prevent an intruder from reading them.

### 4.2.2 Data Encryption Standard (DES)

Data Encryption Standard (DES) is an encryption block cipher defined and endorsed by the U.S. government in 1977 as an official standard. It is also the most well-known and widely used cryptosystem in the world.

DES is a secret-key, symmetric encryption system. When used for communication, both sender and receiver must know the same secret key, which is used both to encrypt and decrypt the message. DES can also be used for single-user encryption, such as to store files on a hard disk in an encrypted form. In a multi-user environment, the secure key distribution may be difficult. It was designed to be implemented in hardware, and therefore its operation is relatively fast. It also works well for bulk encryption such as for encrypting a large set of data.

### 4.2.3 C2 Security

The requirements for a C2 secure system were articulated by the U.S. Department of Defense's National Computer Security Center (NCSC) in the publication *Trusted Computer System Evaluation Criteria*. Some of the most important requirements of C2-level secure system are:

1. The owner of a resource (such as a file) must be able to control access to the resource.
2. The operating system must protect data stored in memory for one process so that it is not randomly reused by other processes.
3. Each user must uniquely identify himself or herself. The system must be able to use the unique identification to track the activities of the user.
4. System Administrators must be able to audit security-related events and the actions of individual users. Access to this audit data must be limited to authorized administrators.
5. The system must protect itself from external interference or tampering, such as modification of the running system or of system files stored on disk.

## 4.3 Data Security for the PENS Computer

The available methodologies to protect the access for notebook computers are data encryption, signature verification, and voice verification.

Data encryption is the most common data security technology for controlling access to a computer. The most common data encryption technology for the PC is DES. The software, such as Assure from Cordant, Inc, provides authentication of users at the workstation level, selective audit of user activity, and protects information through a seamless combination of access permissions, as well as automatic encryption.

Signature verification is the way for specifically controlling access to a pen-based computer system. The Signature Verification for Windows from Sign-On Systems, Inc is an example of this type of software that can be integrated into the PENS software. First, it will create the signature template, which is an encoded version of all the signature data. The template can be stored in a file or database for later retrieval. The verification process consists of testing all the templates and returns the results. The pen-type device, which should install at all pen-based system, is recommended for signature verification.

Voice verification is another method for controlling access to a workstation. This concept is very similar to signature verification, except it uses a voice template instead of handwriting template for verification. The Voice Tools from Dragon Systems offers the software and hardware for this technology.

At this time it is our opinion based upon the research we have conducted that neither the voice nor handwriting recognition technologies are mature enough for implementation for the PENS program.

## 4.4 Data Security At Data Storage Level

The AFS is planning to upgrade their network and database systems in the near future. We therefore concentrated our efforts to evaluate the data security on these new types of systems. The final destination of data is planned to reside on the Microsoft SQL Server which is installed on a Windows NT server computer. Therefore, data security at Windows NT Server and SQL Server will be discussed.

It is worth mentioning that the AFS currently is using a Novell

3.1X network that only uses login user ID and Password for controlling access to the network. The new Novell 4.1 adds C2 data security measures in addition to the login user ID and Password though we are not aware of any plans to make this upgrade.

The Windows NT Server offers the storage space for the SQL databases. The databases saved at NT servers are protected by four separate security software components; login process, local security authority, security account manager, and security reference monitor. The login process is required by each user and uses security features such as password encryption, password aging, and minimum length restrictions on passwords. The local security authority is to ensure that the end-user has permission to access the system. The security account manager will maintain the user accounts database to keep all of the security information. The security reference monitor will determine if the user has permission to access an object, such as file directory, and perform whatever action the user is attempting. The NT server administrator can setup the user access permissions and restrict some data storage areas for the specific users. NT servers also supports the C2 security feature.

The SQL Server provides several levels of security for stored data. At the outermost layer, SQL Server login security is integrated directly with Windows NT security. The SQL security Manager utility will integrate the login security process between Windows NT Server and SQL. SQL Server administrators can also monitor the login successes and failures of users by checking the monitor screen. All messages will be sent to Windows NT event log updating the user login information.

Moreover, SQL Server has a number of facilities for managing data security. Access privileges (select, insert, update, and delete) can be granted and revoked on objects such as tables, rows, columns, and views to users or groups of users.

## 4.5 Data Security At Data Transmission Level

One possibility for future applications of the PENS program is to incorporate wireless data transfer. During our research of wireless data transmission we used two different communications network systems, Cellular Digital Packet Data (CDPD) and Frame Relay, to transfer the information. The data transfer suign CDPD is between the mobile, wireless-networked computers with the MD-IS (Mobile Data Intermediate System), which is the central data exchange for the CDPD network. Frame Relay is the public wide area network system used to transfer the data connecting between the MD-IS and the Windows NT Server at the local or regional office. The security features for CDPD and Frame Relay will be addressed.

CDPD is packet-switched wireless data transfer network used to transfer the data from the wireless remote stations to the MD-IS. The data from mobile computers will be broken down into packets of data and will send these packets to their destination server through different cellular channels. This feature will keep the information more secure in the data transmission procedure.

Wide Area Network Communication (Frame Relay):

Frame Relay is also packet-switched network. It is point-to-point public wide area network system. The servers and MD-IS are connected through Frame Relay network system. The concept of data transmission for Frame Relay is really similar to CDPD. The data is broken down packets of data and send to the destination system through different network paths. This feature will keep data more secure in the public network.

## Appendix

### 1. Sample Data

Date : February 10,1988

Name of Reporting Facility : Control Tower, Airville, Arkansas

Location of accident : 1500 feet from approach end of runway 4

Nature of Accident : Crashed on final approach

Type of Flight : Cross country - IFR Flight Plan

Name : R. L. Smith

Position : Pilot

Address : Airville, Arkansas

Aircraft Damage : Demolished

Property Damage : Utility power pole

Conditions at accident : 1226 CST, ceiling 1000 feet, overcast, visibility 1 mile, light snow showers, wind 030 degrees at 9, altimeter 30.07.

First report subsequent : Airville Special No. 2 - 1237 CST ceiling measured 900 ft BKN.

Summary of Flight 1 : N1234 departed Flyway airport and the pilot established radio contact with Forth Worth ARTCC.

Summary of Flight 2 : N1234A was handed off to the Airville Approach Control and was vectored for an ILS approach. A clearance to descend to 3,000 was issued.

### 2. Visual Basic form used in the test

0	1	2
Date	<input type="text"/>	
Name of Facility	<input type="text"/>	
Location of Accident	<input type="text"/>	
Nature of Accident	<input type="text"/>	
Type of Flight	<input type="text"/>	
Name	<input type="text"/>	
Position	<input type="text"/>	
Address	<input type="text"/>	

0	1	2
<b>Aircraft Damage</b>	<input type="text"/>	
<b>Property Damage</b>	<input type="text"/>	
<b>Conditions at accident</b>	<input type="text"/>	↑ ↓
<b>First report subsequent of accident</b>	<input type="text"/>	↑ ↓

0	1	2
<b>Summary of Flight 1</b>	<input type="text"/>	↑ ↓
<b>Summary of Flight 2</b>	<input type="text"/>	↑ ↓

2. Purchase equipment and/or software needed for evaluation.
3. Test and evaluate equipment with respect to FSS needs.

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