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Human Factors in Aviation Maintenance – Phase Five Progress Report

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Federal Aviation Administration
Washington, DC 20591

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Final Report

U.S. Department
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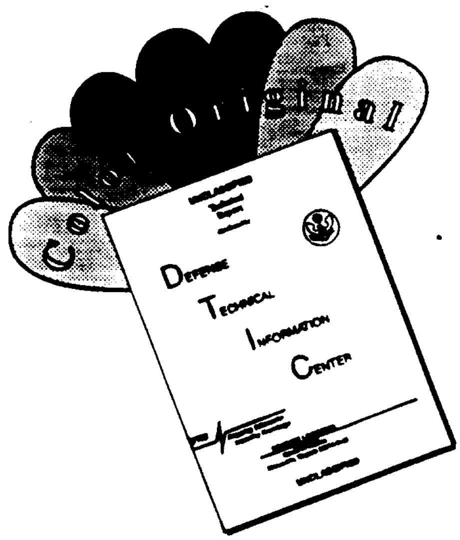

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16. Abstract

The fifth phase of research on human factors in aviation maintenance continued to look at the human's role in the aviation maintenance system via investigations, demonstrations, and evaluations of the research program outputs. This report describes the following areas: (Ch. 2) PENS mobile computing software for FAA inspectors; (Ch. 3) STAR computer-based training for aviation regulations; (Ch. 4) HIS digital documentation systems, a hypertext multimedia software system; (Ch. 5) software/hardware distribution on the Internet; (Ch. 6) human factors program reviewing human performance issues associated with inspection; (Ch. 7) human factors audit program providing a valid tool for evaluating human factors in maintenance tasks; (Ch. 8) a study of how the design of workcards affects their use and the subsequent potential for error; (Ch. 9) the process of visual inspection and evaluation measuring visual inspection performance; (Ch. 10) a battery of mechanical aptitude tests, a simulated NDI task, and the ability of the tests to predict performance; (Ch. 11) the results of a report on an evaluation of a teamwork training program in a FAR 147 school; and (Ch. 12) ARAC rule changes and impending rule changes.

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The authors also recognize the many government and industry personnel who continue to participate 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 list all the individuals who have provided guidance and cooperation.

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LIST OF ABBREVIATIONS

A & P	Airframe and Powerplant
AAM	Office of Aviation Medicine
AANC	Aging Aircraft NDI Development and Demonstration Center
ACS	Aviation Compliance Services
AFS	Aviation Flight Standards Service
AME	Aircraft Maintenance Engineers
AMOs	Approved Maintenance Organization
AMT-T	Aviation Maintenance Technician - Transport
AMTs	Aviation Maintenance Technicians
ANSI	American National Standards Institute
AOL	America On Line
ARAC	Aviation Rulemaking Advisory Committee
ARC	American Red Cross
ARS	Aviation Repair Specialists
ASA	American Sailing Association
ASIs	Aviation Safety Inspectors
ASNT	American Society for Non-destructive Testing
ASRS	Aviation Safety Reporting System
ATA	Air Transport Association
ATEC	Aviation Technician Education Council
ATP	Aircraft Technical Publishers
AWS	American Welding Society
BBS	Bulletin Board System
CACRC	Commercial Aircraft Composite Repair Committee
CAMC	Canadian Aviation Maintenance Council
CASE	Coordinating Agency for Supplier Evaluation
CBT	Computer-Based Training
CD-ROM	Compact Disc, Read Only Memory
CFR	Code of Federal Regulations
CMAQ	Cockpit Management Attitudes Questionnaire
CPS	Comprehensive Professional Services
CRM	Crew Resource Management
CSD	Constant Speed Drive
DOS	Disk Operating System
DOT	Department of Transportation
EAAM	Ergonomic Audit for Aircraft Maintenance
EMT	Emergency Medical Technicians
EPA	Environmental Protection Agency
EPI	Eysenck Personality Inventory
ERNAP	Ergonomics Audit Program
FAA	Federal Aviation Administration
FARs	Federal Aviation Regulations
FBO	Fixed Base Operators
FCC	Federal Communications Commission
FSAS	Flight Standards Automation System
FSDO	Flight Standards District Office

FTP	File Transfer Protocol
GML	Galaxy Markup Language
GSC	Galaxy Scientific Corporation
HCI	Human-Computer Interaction
HIS	Human Factors Information Systems ? or Hypermedia
HTML	Hypertext Markup Language
IAM	International Association of Machinists
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ISO	International Standards Organization
ISP	Internet Service Provider
ISSA	International Sailing School Association
JAA	Joint Aviation Authority
KB	Knowledge-Based
LAN	Local Area Network
MAINAUD	Audit Program for Maintenance
MB	MegaBytes
MESH	Managing Engineering Safety Health system
MFFT	Matching Familiar Figures
MRM	Maintenance Resource Management
MSG	Maintenance Steering Group
MUDs	Multiple User Domains
NAFTA	North American Free Trade Agreement
NASA	National Aeronautic and Space Administration
NDI	Non-Destructive Inspection
NDT	Non-Destructive Testing
NR W/C	Non-Routine Work Card
NRR	Non-Routine Repair
NSI	National Standards Institute
NTSB	National Transportation Safety Board
OCR	Optical Character Recognition
OJIs	On-The-Job Injuries
PADI	Professional Association of Diving Instruction
PAMA	Professional Aviation Maintenance Association
PC	Personal Computer
PENS	Performance Enhancement System
POD	Probability of Detection
PRF	(Jackson) Personality Research Form
PTRS	Program Tracking and Reporting Subsystem
RAM	Random Access Memory
RB	Rule-Based
SAE	Society of Automotive Engineering
SB	Skill-Based
SFARS	Supplemental Federal Aviation Regulations
SGML	Standard General Markup Language
SHEL	Software, Hardware, Environment, Liveware
SLIP	Serial Line Internet Protocol
SRC	Structure Repairs Committee
STAR	System for Training Aviation Regulations

SUNY	State University of New York
TC	Transport Canada
TCP/IP	Transmission Control Protocol / Internet Protocol
TEAM	Team Evolution And Maturation
URL	Universal Reference Locator
VIRP	Visual Inspection Research Program
WAD	World Aviation Directory
WAIS	Wechsler Adult Intelligence Scale
WWW	World-Wide Web

PHASE V OVERVIEW

William Johnson, Vice President
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1.0 INTRODUCTION

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 assemtote; 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).

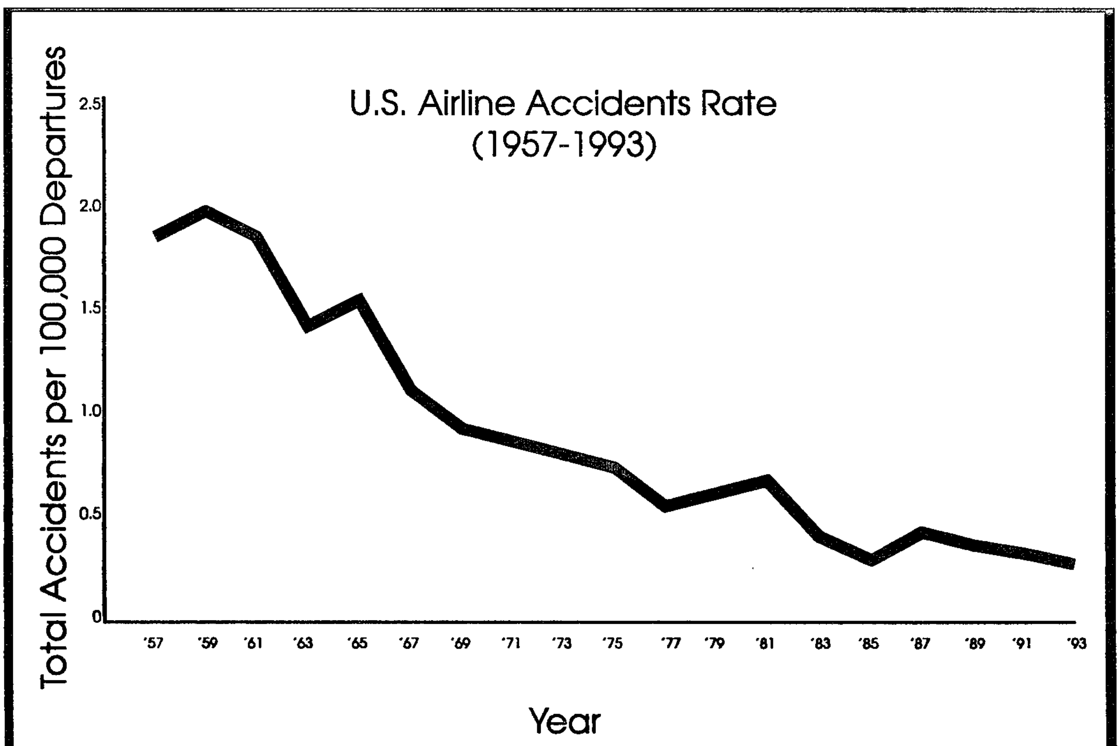

Figure 1.1 U.S. Airline Accident Rate per 100,000 Departures (1957-1993)
NTSB, *U.S. Air Carriers Operating Under 14 CFR 121, All Scheduled Service (Airlines)*, 1994

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.

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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 (next page). The features listed in Table 2.2 (next page) 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

Table 2.1 Characteristics of the Four Computers Used in Field Study			
GRiD Convertible	NEC VersaPad	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

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

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.

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.

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 (next page), 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.

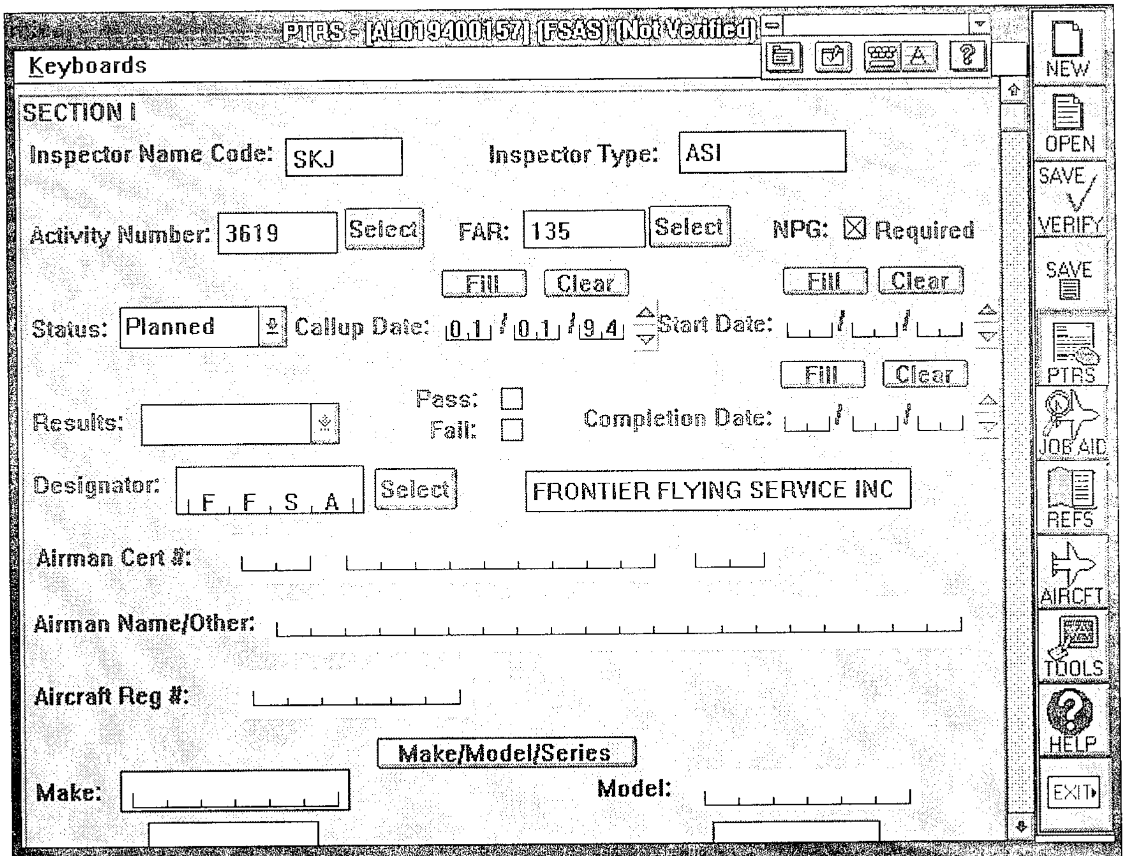

Figure 2.1 Performance Enhancement System *Version 1*

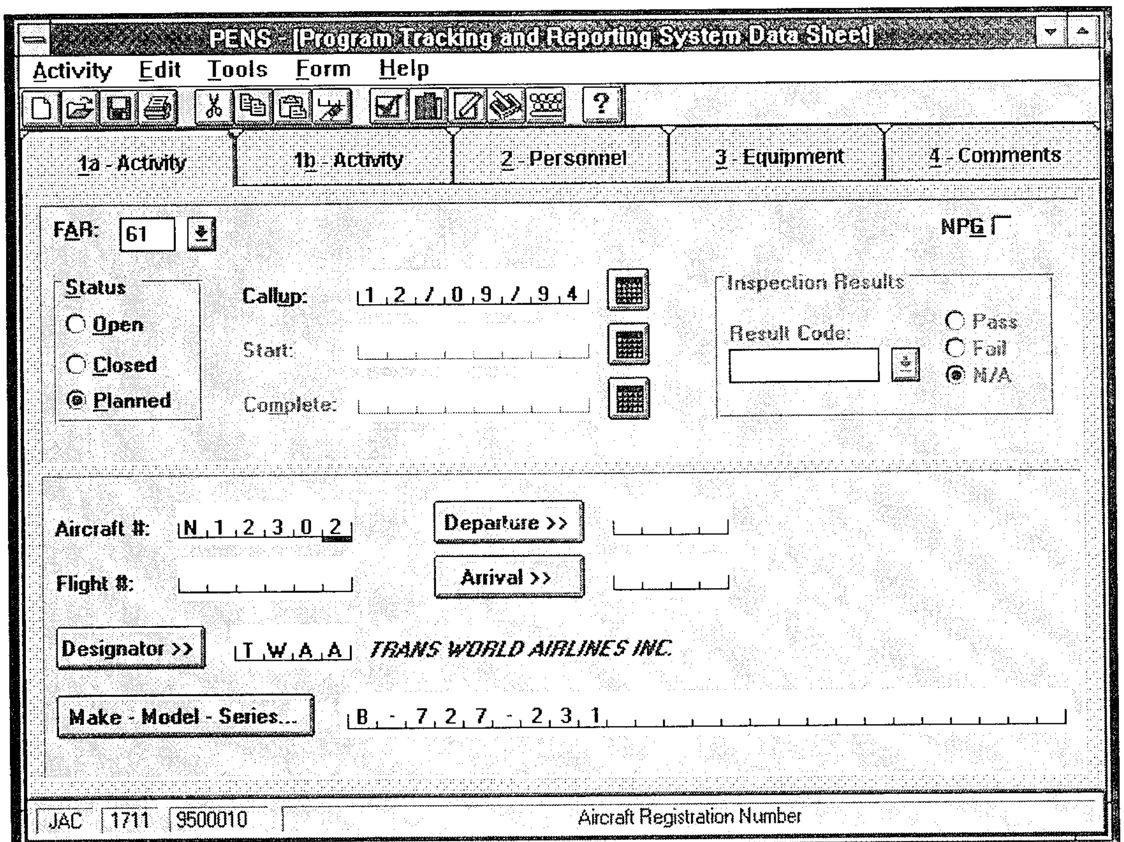

Figure 2.2 Performance Enhancement System *Version 2*

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 (next page).

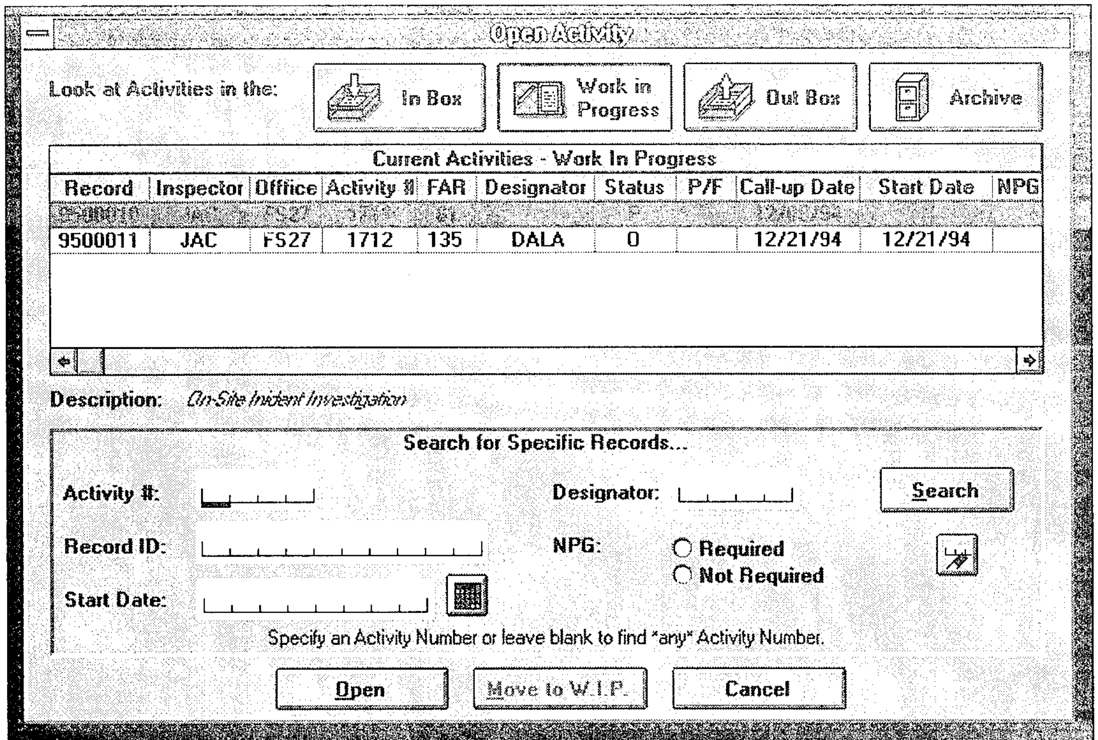

Figure 2.3 Work Program Management

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 (next page). 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 (next page).

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.

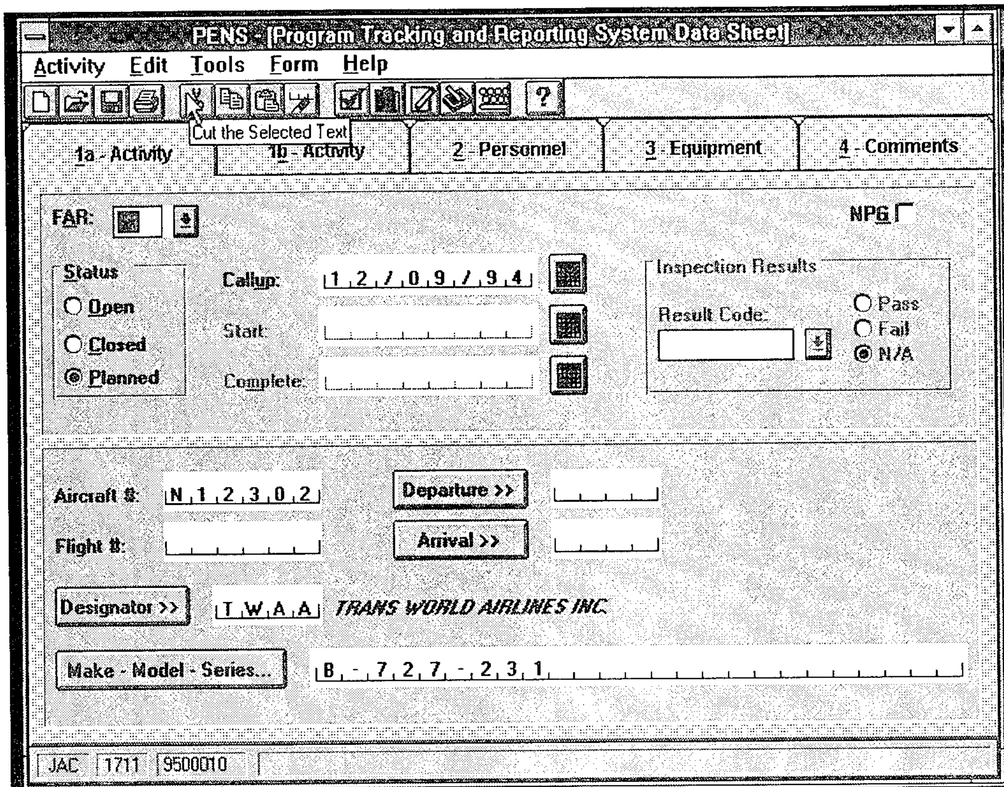

Figure 2.4 Bubble Help Example

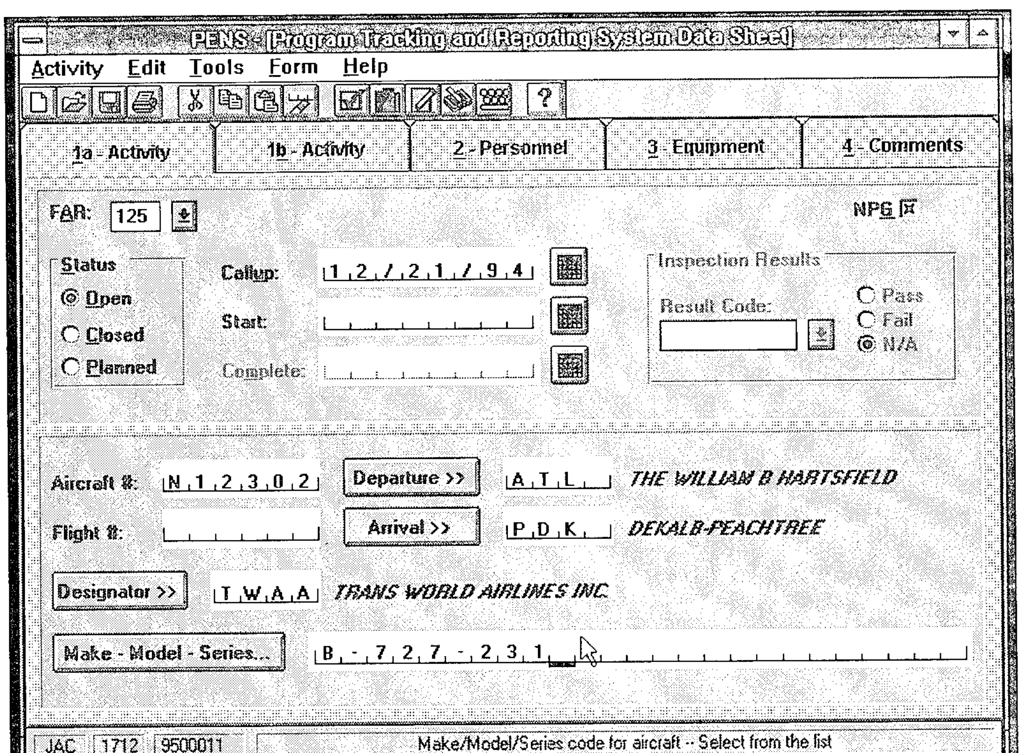

Figure 2.5 Micro Help Example

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 (next page). 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 (next page).

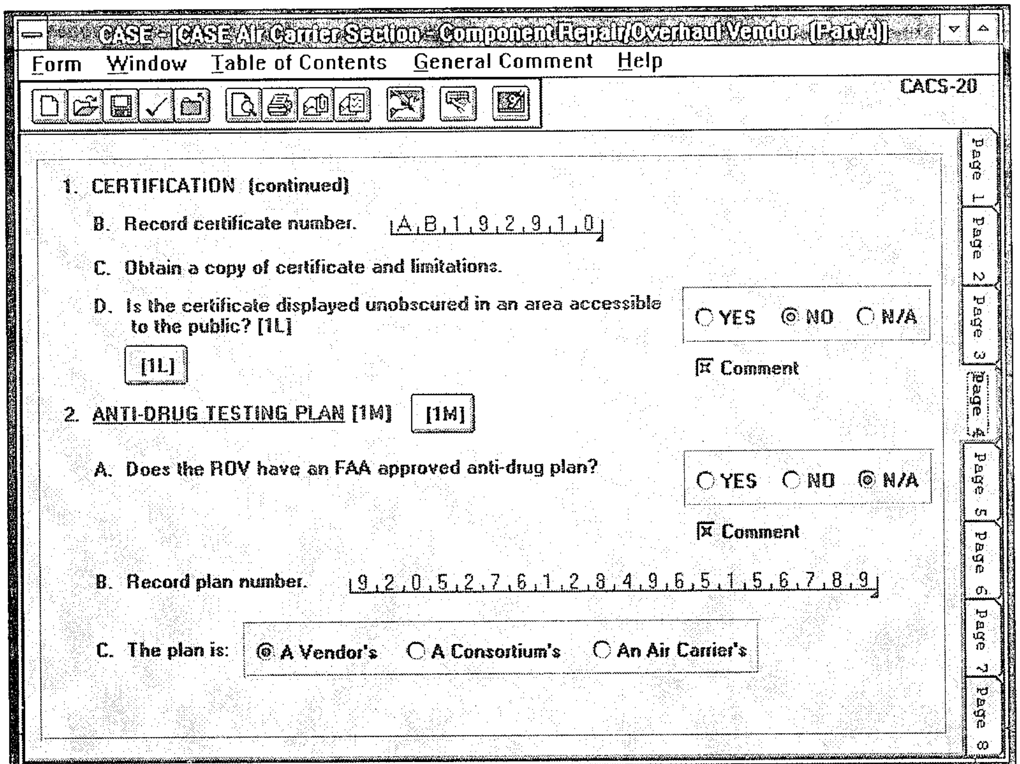

Figure 2a.1 Example CASE Form

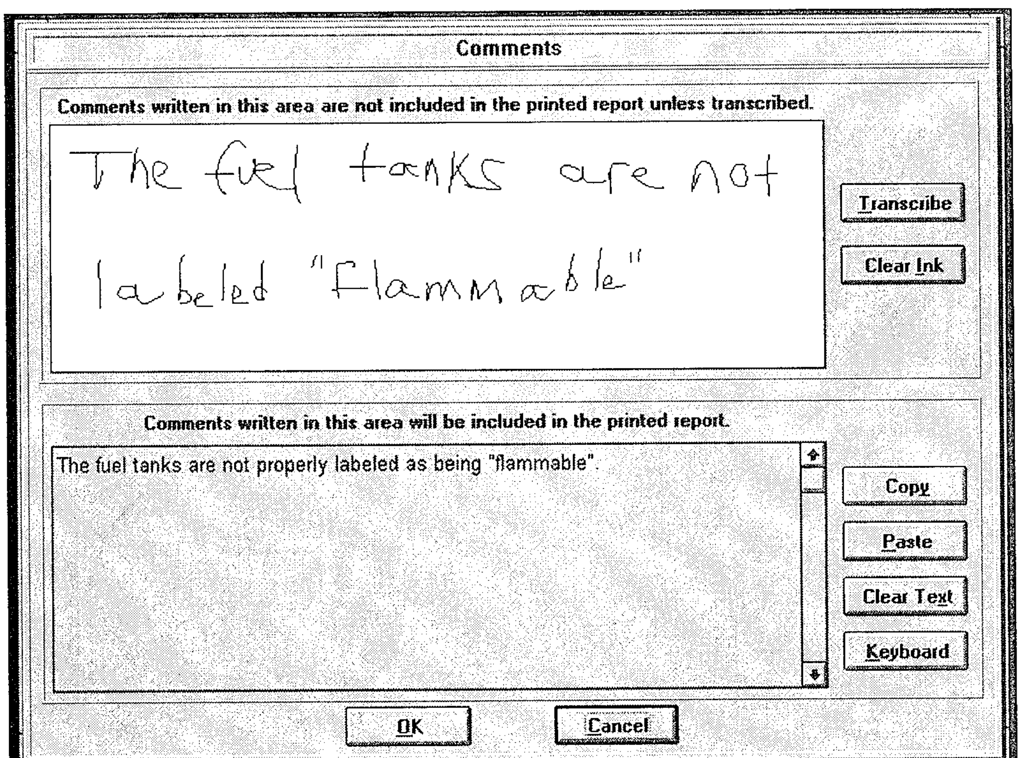

Figure 2a.2 Example Comment

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

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.

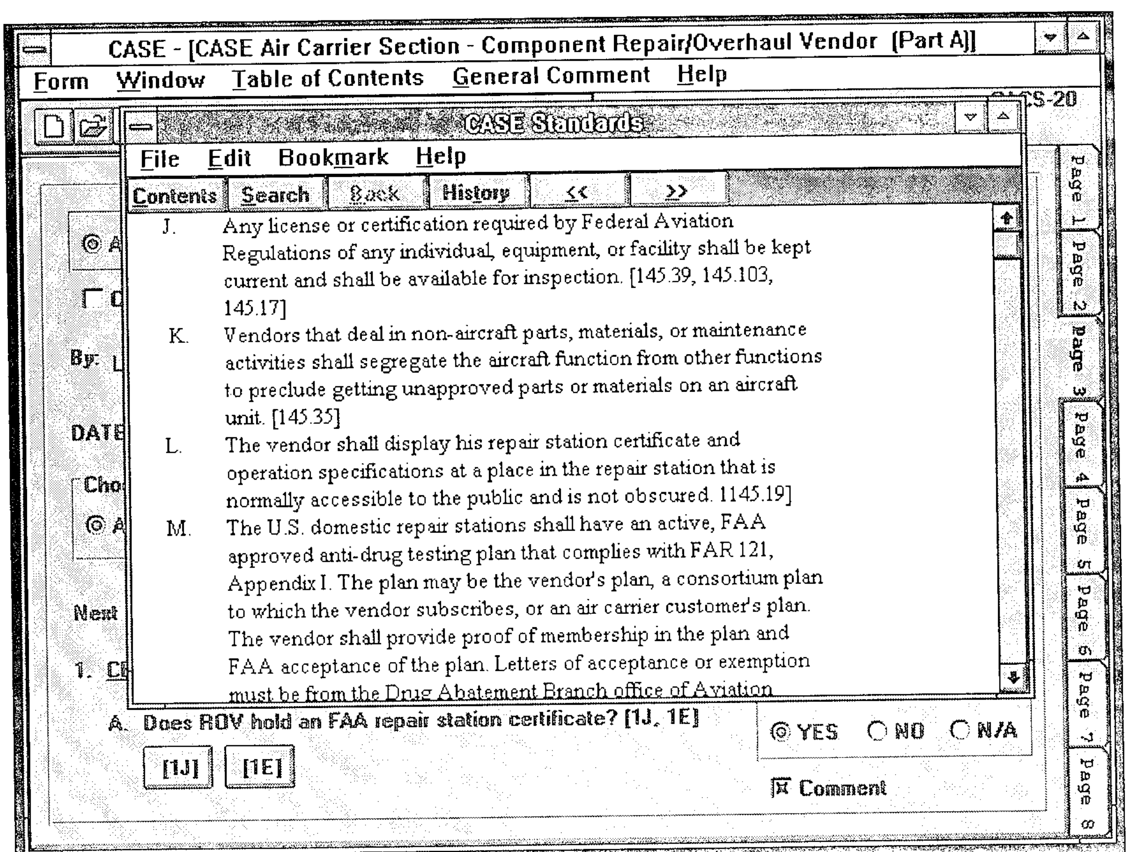

Figure 2a.3 Example of On-Line Standard

SYSTEM FOR TRAINING OF AVIATION REGULATIONS

Terry Chandler, Ph.D.
Galaxy Scientific Corporation

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.

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.

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

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 inquires 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.

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

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 en-

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

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?

vironment 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, next page) 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.

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.

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

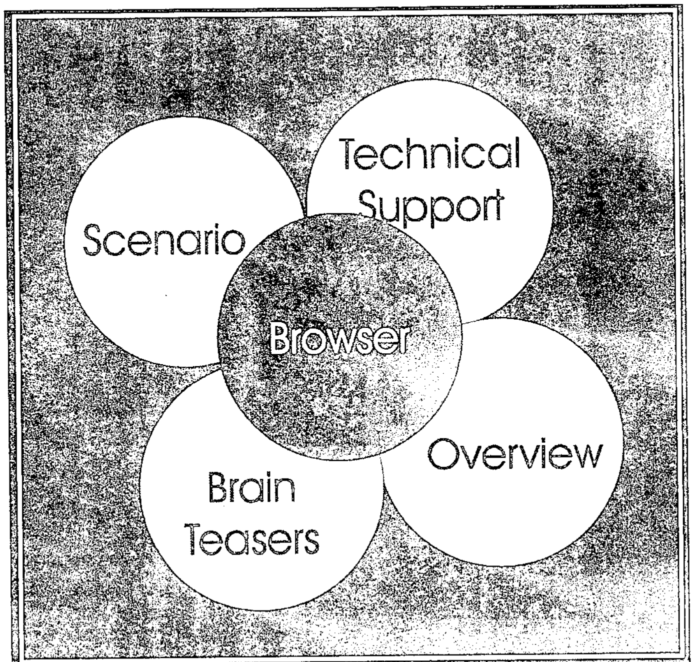

Figure 3.1 Learning Environments Identified for STAR

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 (next page), 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.

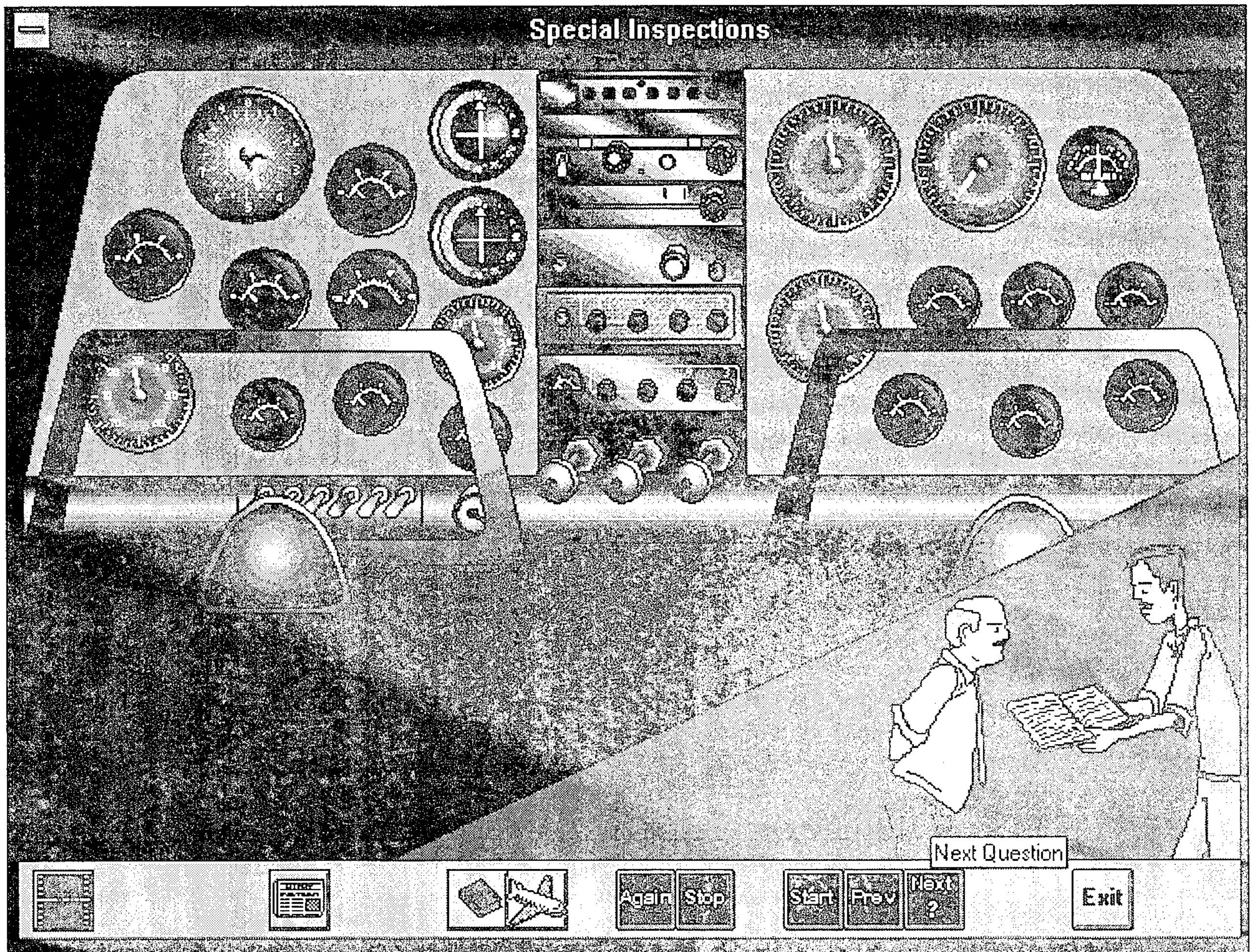

Figure 3.2 Colored Items Can Be Selected For Detailed Explanations

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 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 objec-

Table 3.5 Tasks for Phases VI and VII.

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.

tives we have set for our students. This indeed is an opportunity.

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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

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.

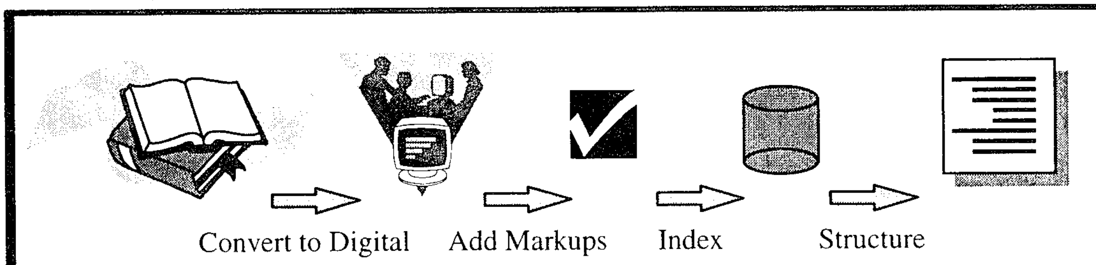

Figure 4.1 HIS Digital Documentation Process: Four Basic Steps

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 (next page) 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.

Common Formatting Markups

Bold:	<B> ...*text*... </B>
Italics:	<I> ...*text*... </I>
Underline:	<U> ...*text*... </U>
Font:	<F"(font),(fontsize)"> ...*text*..
Indent:	<indent"(level),(pre-indent string)"> ...*text*... </indent>
Center:	<center> ...*text*... </center>
Flush Right	<right> ...*text*... </right>
Margins	<margin"(left margin),(right margin)> ...*text*...

Common Hypermedia Markups

Tag:	<TG"(tag reference),(caption)">
Hot Table:	<HT"(file),(caption)"> ...*text*... </HT>
Hot Graphics:	<HG"(file),(caption)"> ...*text*... </HG>
Hot Media:	<HM"(file),(caption),(start),(end)"> ...*text*... </HM>
Hot Executable:	<HE"(command line)"> ...*text*... </HE>
Hot Link:	<HL"(tag reference)"> ...*text*... </HG>

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 (next page), 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

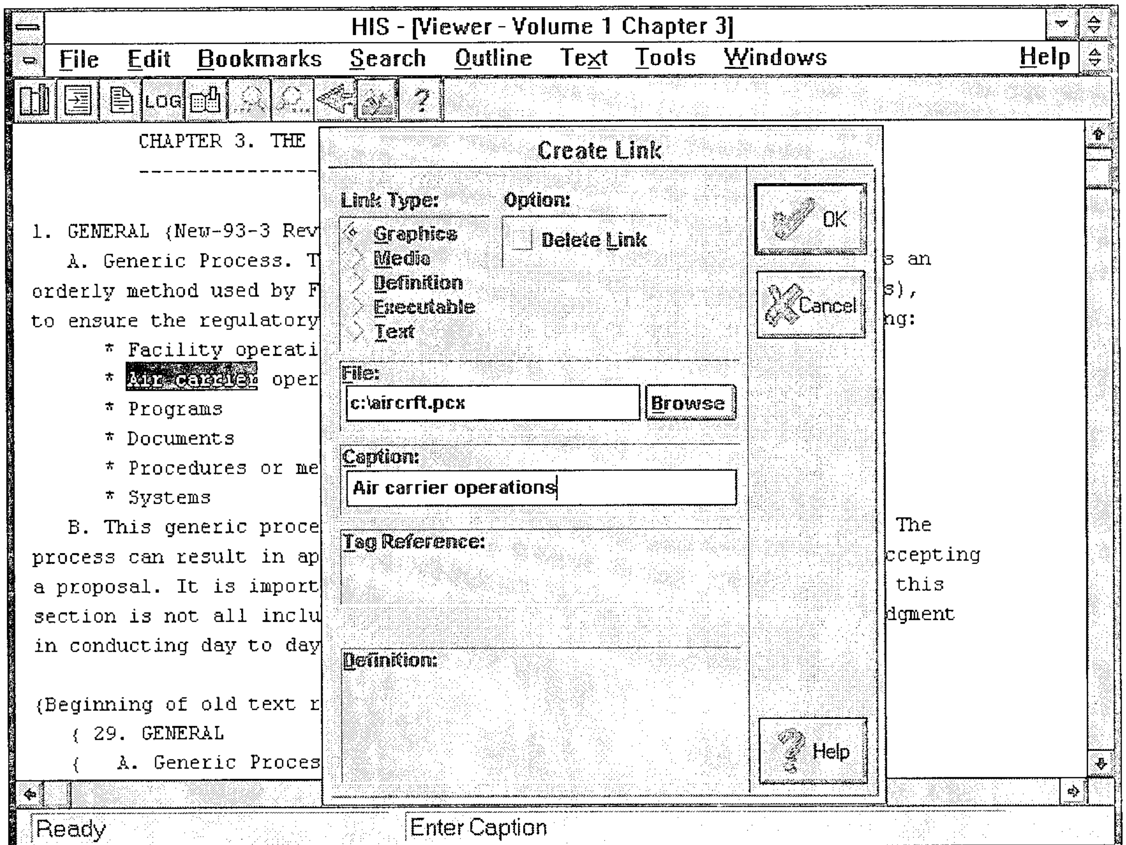

Figure 4-3 Adding a Hotword in HIS Authoring Mode

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.

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" 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.

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

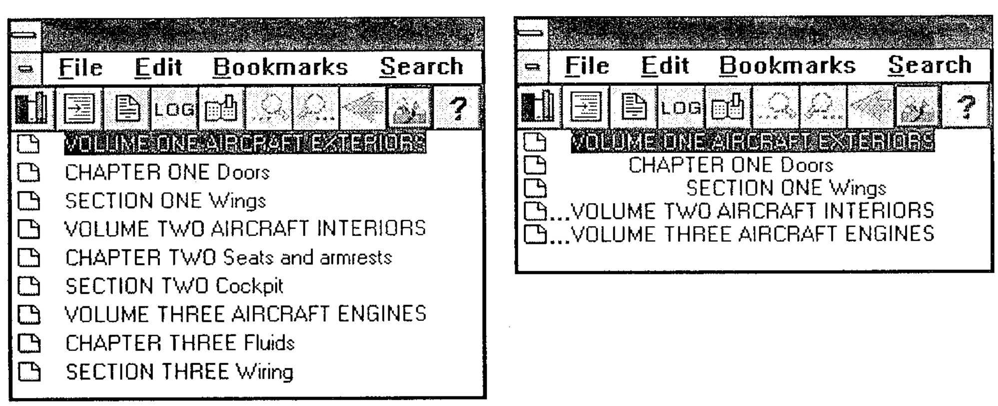

Figure 4.4 HIS Table of Contents: Unstructured vs. Structured Topics

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.
- 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-

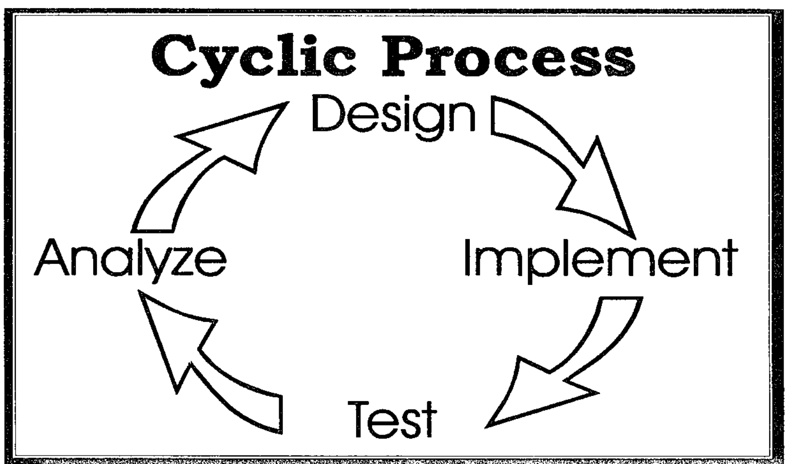

Figure 4.5 The Cyclic Design Model

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.

4.2.2.3 The Information Viewer

The Information Viewer displays the *Guide*'s content (Figure 4.7, next page). 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

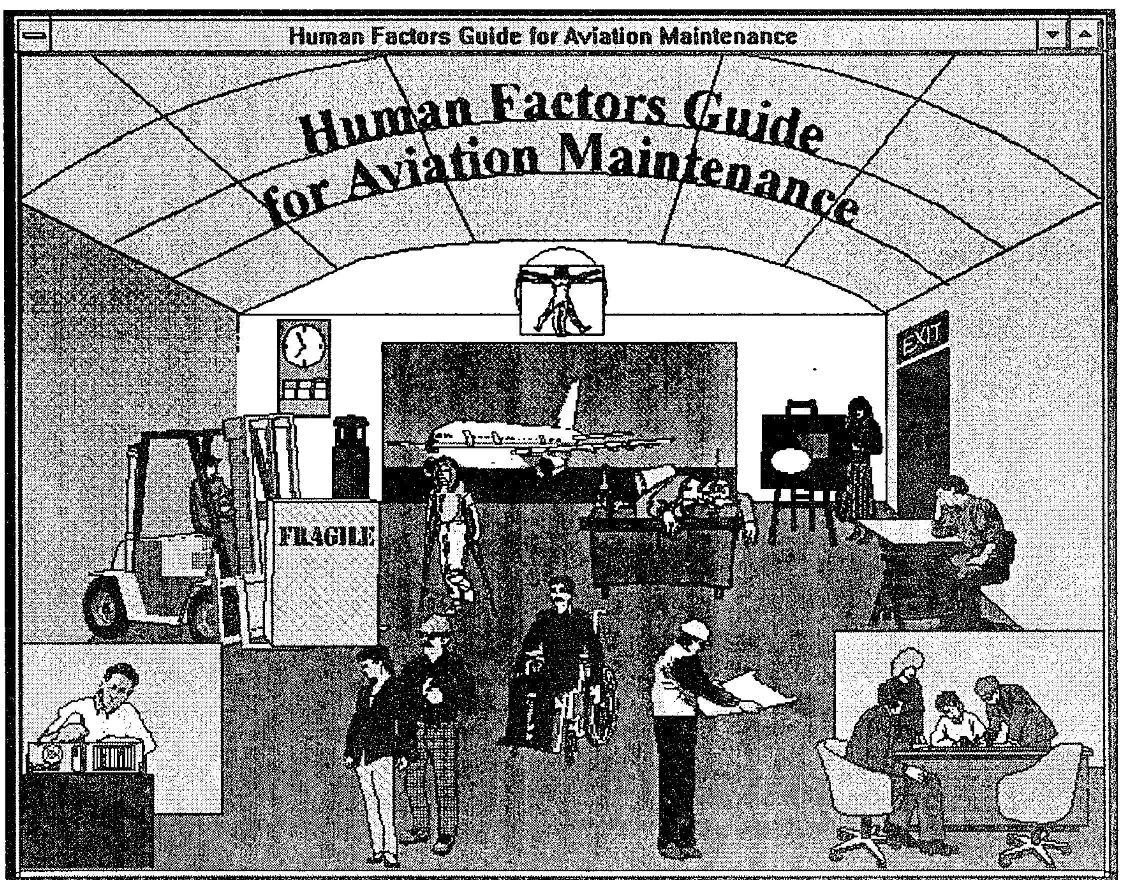

Figure 4.6 The Electronic Guide Table of Contents

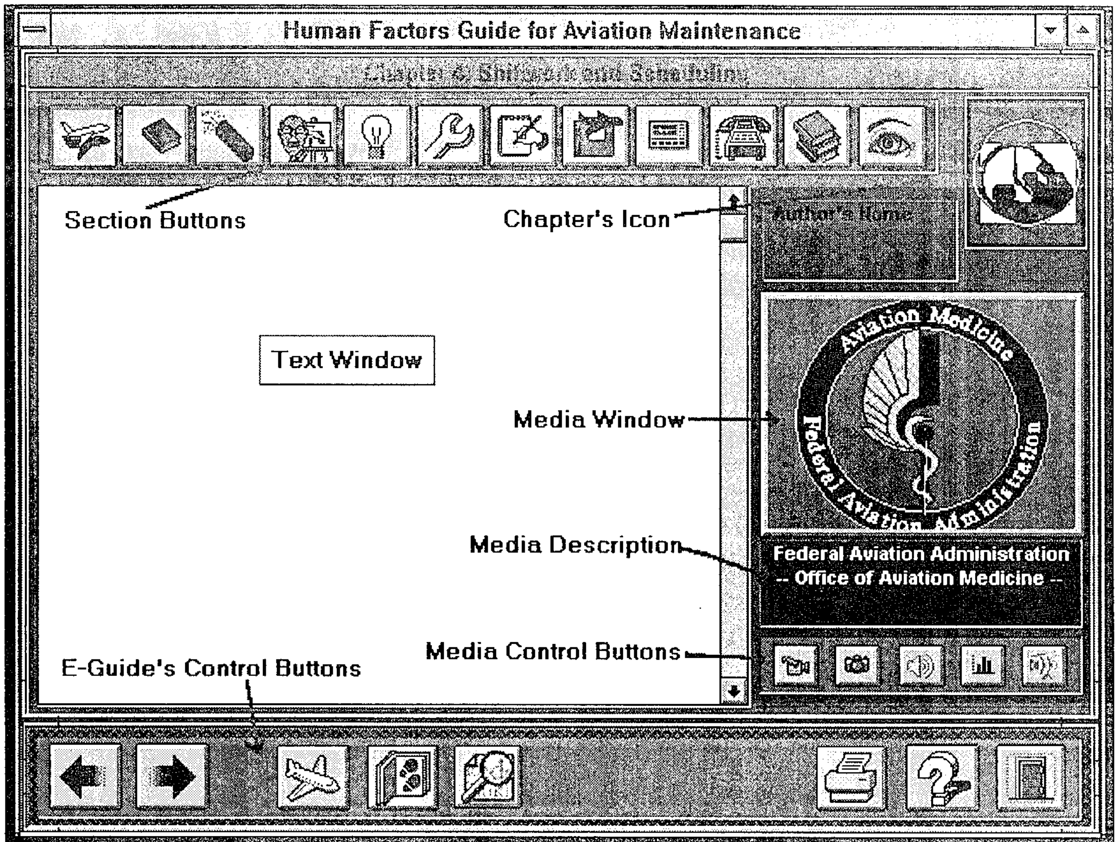

Figure 4.7 The Electronic Guide Information Viewer

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.

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.

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, next page) 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 phase 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 (next page), 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

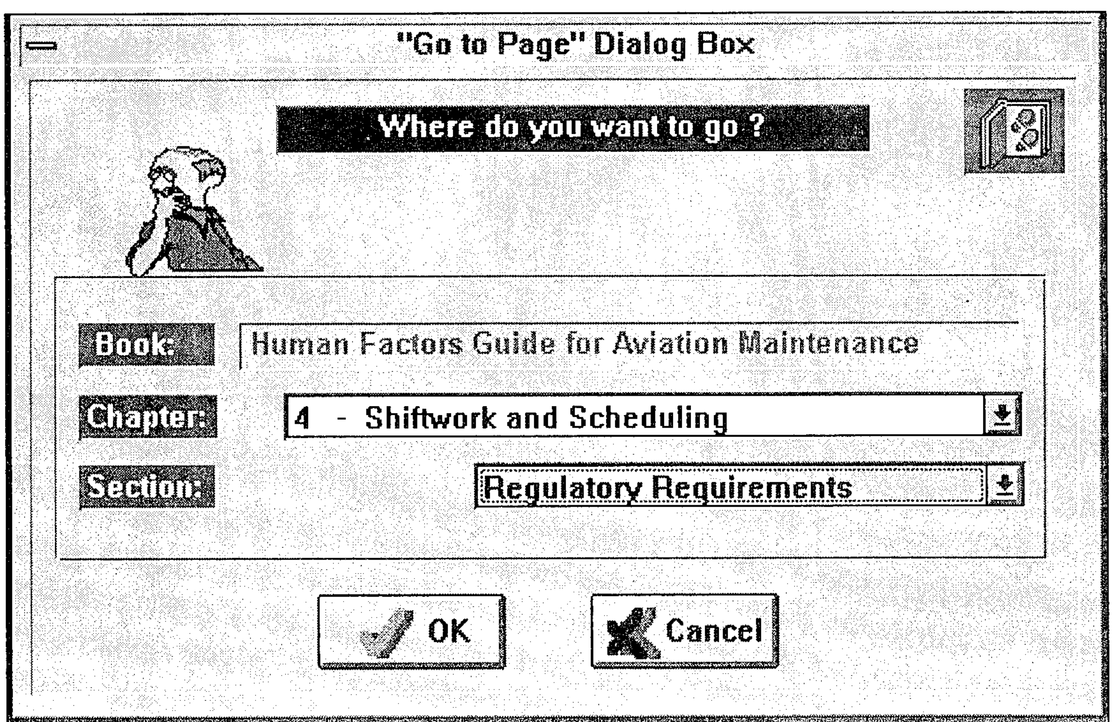

Figure 4.8 Electronic Guide "Go To" Dialog Box

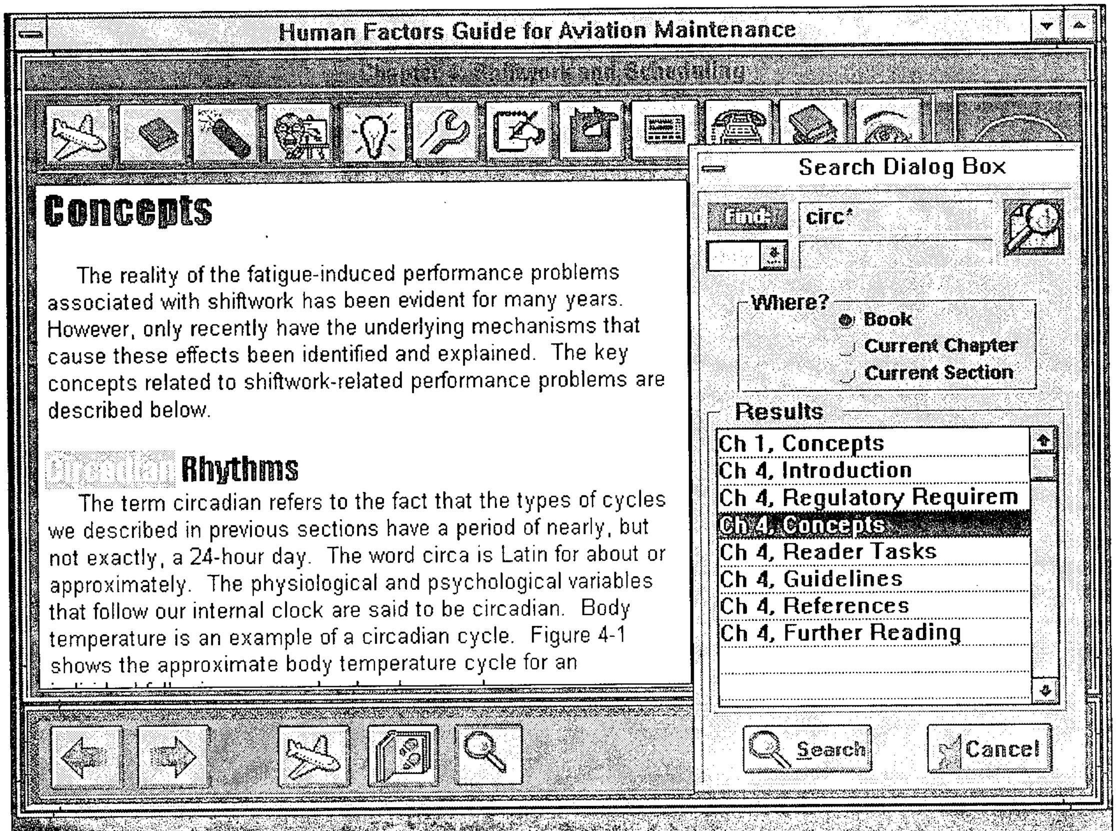

Figure 4.9 The Search Dialog Box

the user is only interested in reading text. We will implement this option.

- **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

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).

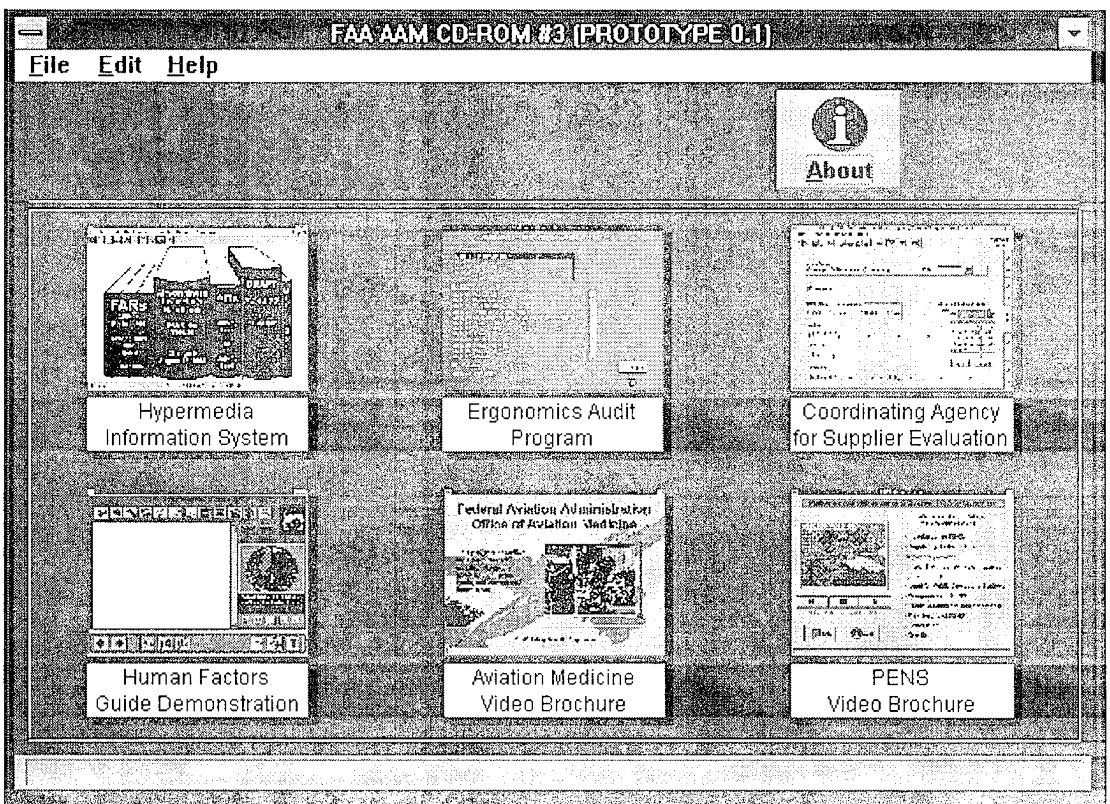

Figure 4.10 FAA AAM CD-ROM #3 Main Menu

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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Hartzell, Karin. (1994). "CD-ROM Interface Evaluation" unpublished report.

Maddox, Michael. (1994). "Introducing a practical *human factors guide* into the aviation maintenance environment."

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

THE FAA INFORMATION SKYWAY

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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*.

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 Infor-

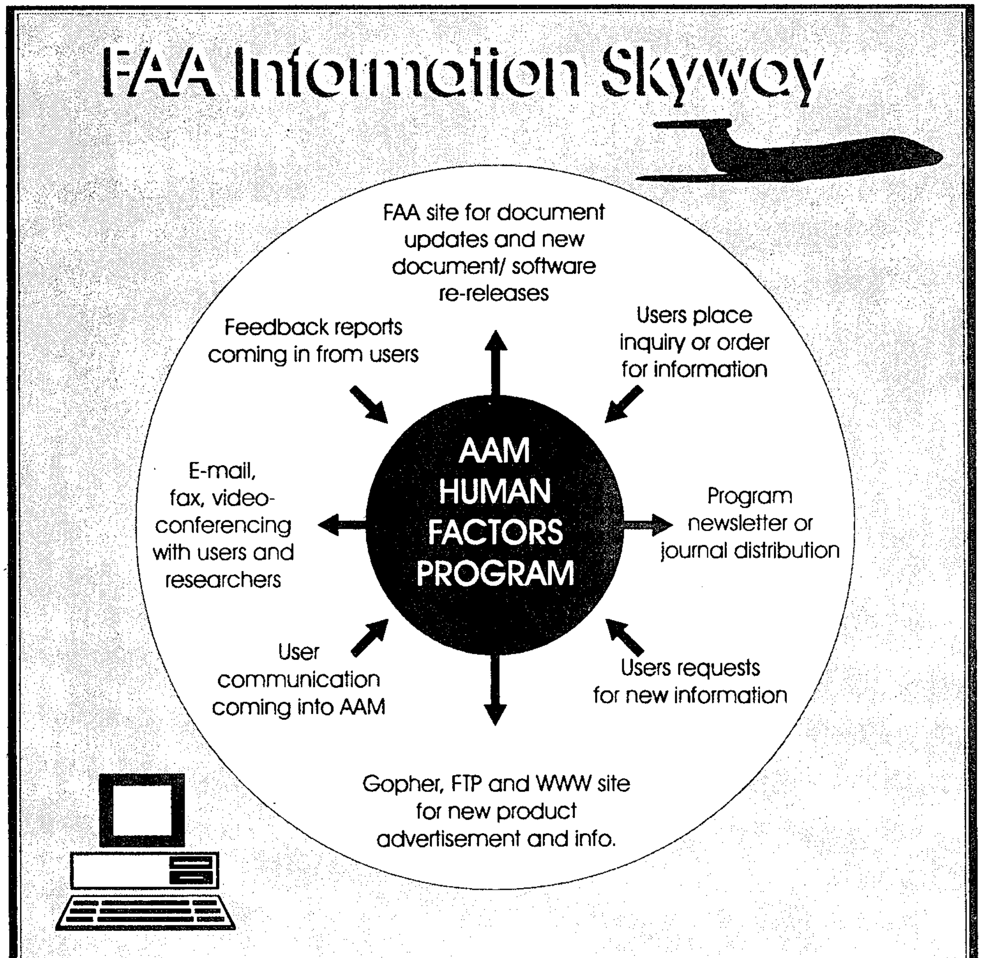

Figure 5.1 AAM Use of the Internet (Adapted from Nejmeh, 1994)

mation 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, next page).

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.

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

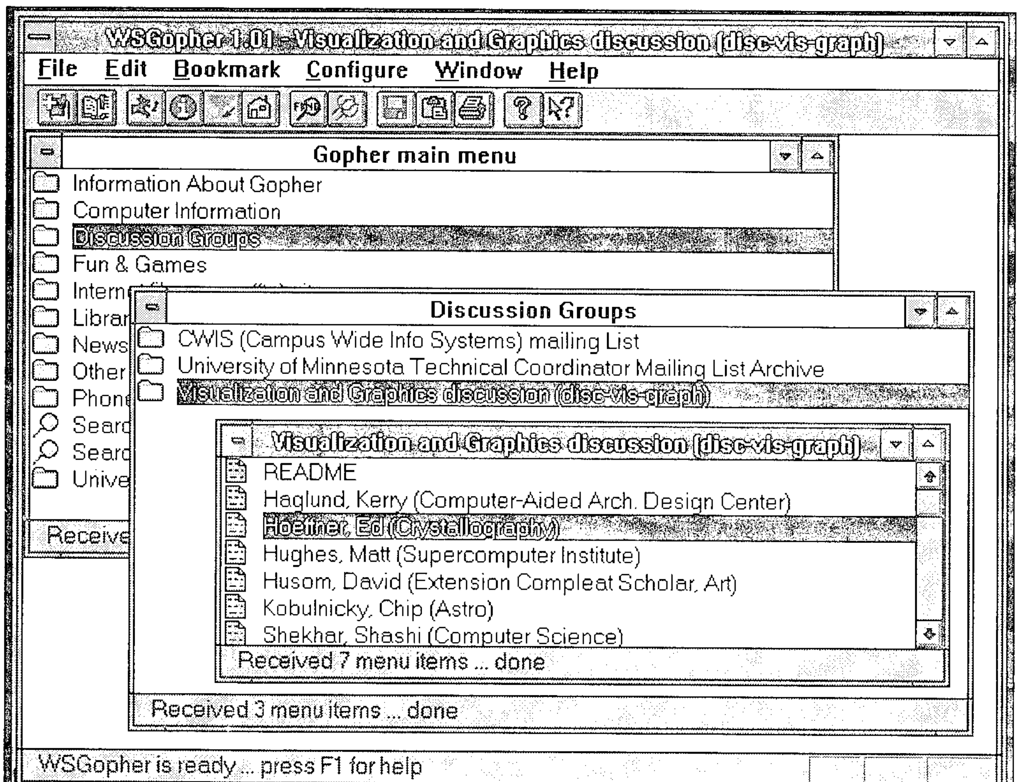

Figure 5.2 Example of an Internet Gopher

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.

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

Table 5.1 Cost Estimates for Establishing On-Site Skyway.

Item	Cost	UA	Description
SparcServer5	$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

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.

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 scaleable 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.

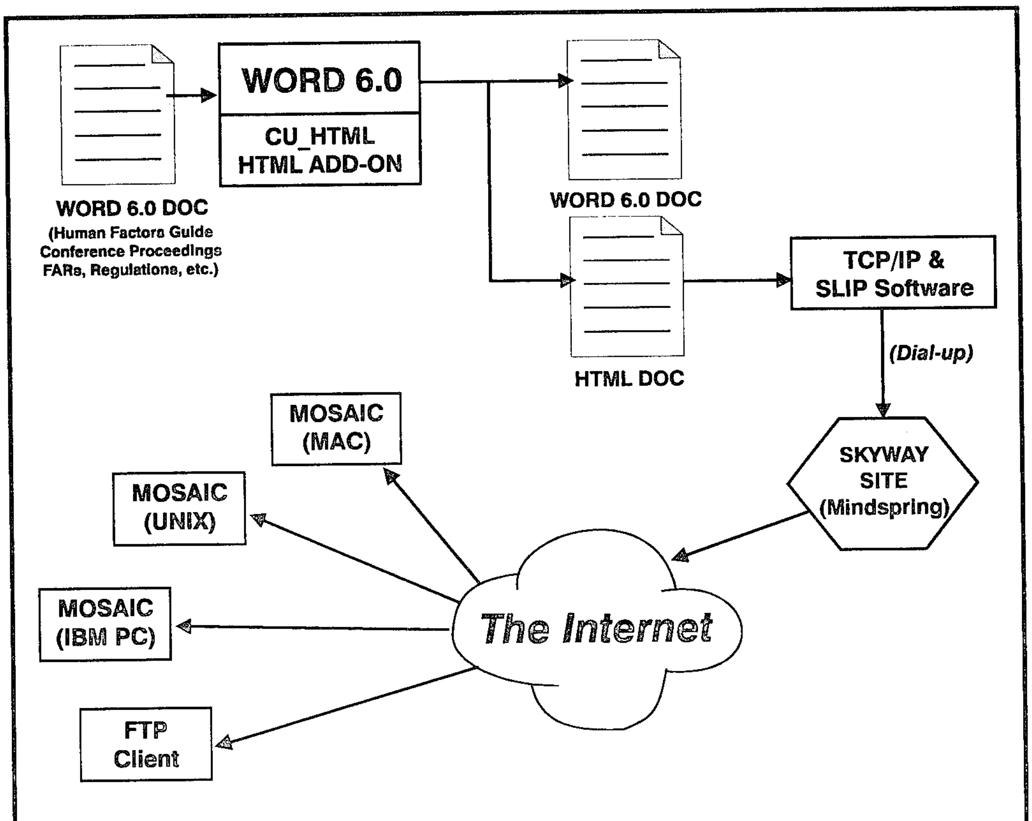

Figure 5.3 Current Skyway Implementation

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 (next page) shows the MOSAIC page introducing the *Human Factors Guide*.

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 (next page) shows the MOSAIC page containing one particular graphic.

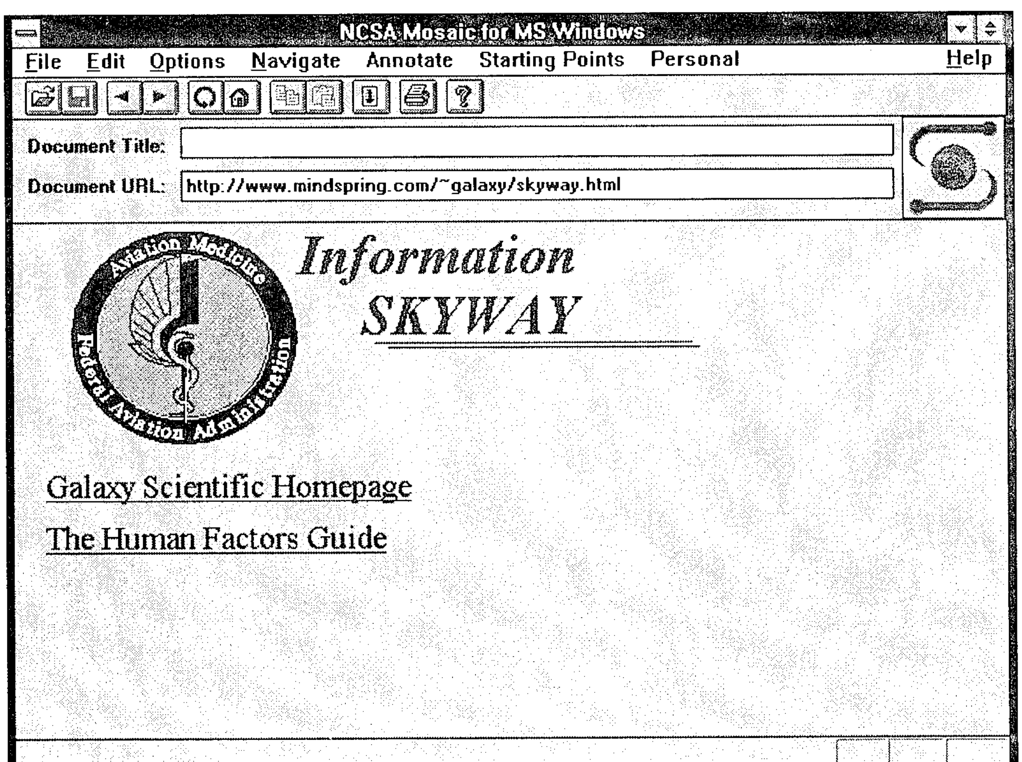

Figure 5.4 Skyway WWW Page as Viewed from MOSAIC Viewer

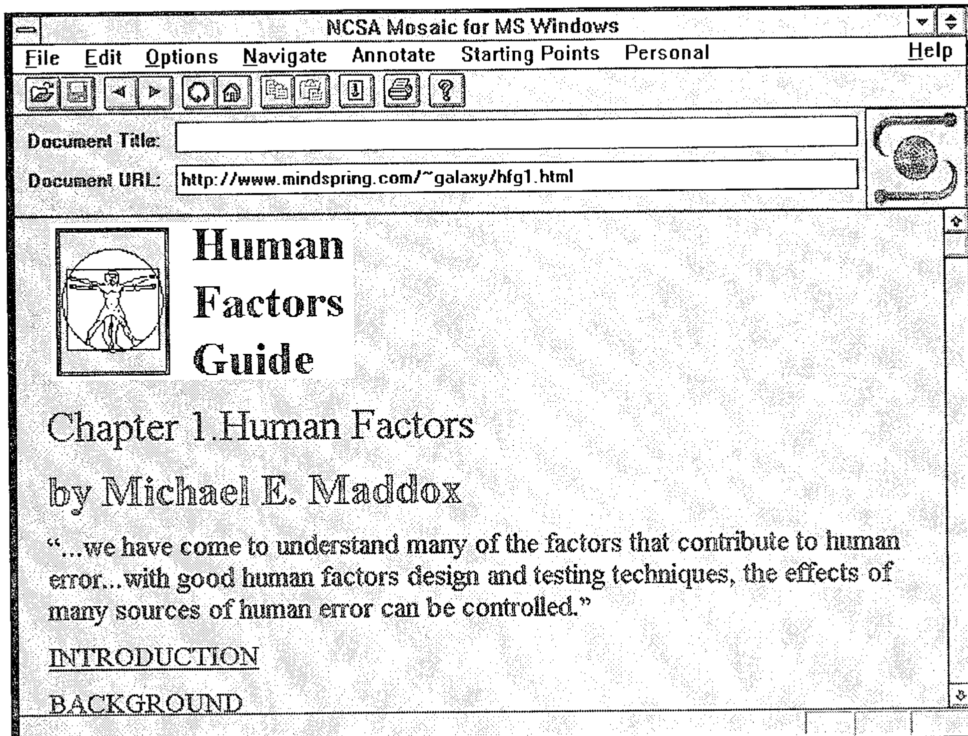

Figure 5.5 Human Factors Guide WWW Page

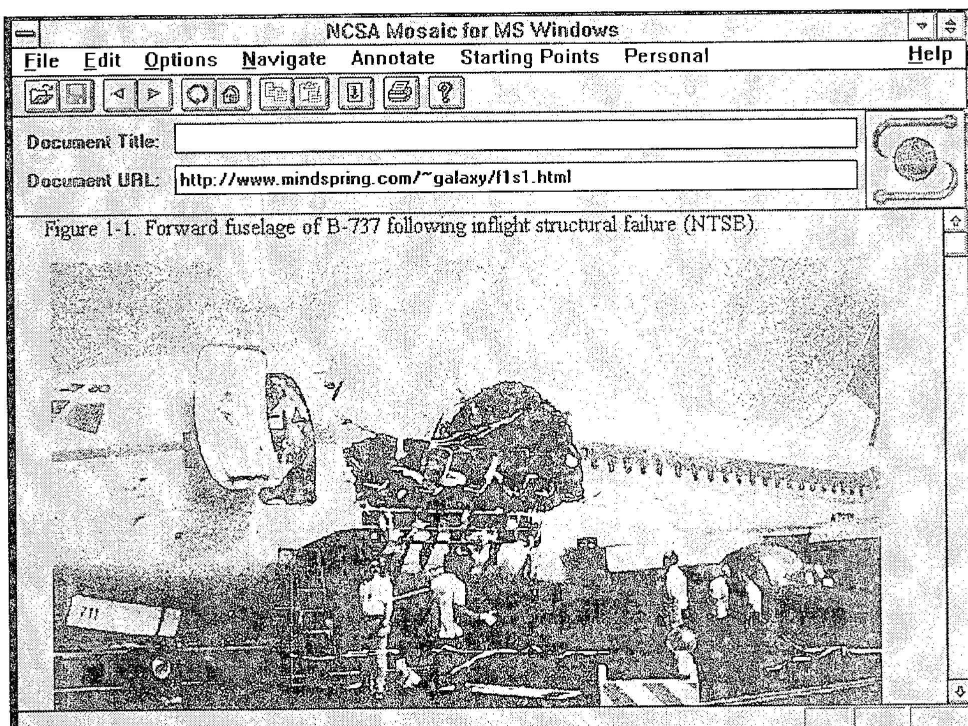

Figure 5.6 Graphic from Chapter 1 of the Human Factors Guide

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

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 (next page). Finally, we surveyed Aviation/Human Factors CD-ROM databases, as shown in Table 5.4 (next page).

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 FSDO BBS	(407)648-6963 (407)648-6309 (800)645-3736 (800)645-FSDO
Portland MMEL 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

Table 5.3 Aviation/Human Factors Internet-Based Services

Type of Service	Reference	Information Provided
WWW	http://www.faa.gov	FAA Home Page
WWW	http://www.dtic.dla.mil/iac/cseriac/iac.html	CSERIAC Home Page
WWW	<unable to locate at this time>	Embry-Riddle Avion WWW Site
WWW	http://www.virtual-airline.co.uk/virtual/ OR http://www.demon.co.uk/virtual/	"The Virtual Airline" "Knowledge and Resources for the Airline Industry."
WWW	http://www.sonic.net/aso/	Aircraft Shopper On-line
WWW	http://www.CdnAir.CA/	Airline: Canadian Air
WWW	http://www.iconz.co.nz/airnz/ airnz.html	Airline: Air New Zealand
WWW	http://www.winternet.com/~tela/ nwa-info.html	Airline: Northwest
WWW	http://www.winternet.com/~tela/ nwa.html	Northwest (travel survey)
WWW	http://www/seanet.com/Bazar/ Aeroflot/Aeroflot.html	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 Message to send: subscribe airline	Discussion Group for Airline Industry

Table 5.4 Aviation/Human Factors CD-ROM Databases

CD-ROM	Summit Aviation	Database of FARs, ACs, ADs
CD-ROM	ATP	Database of FARS,JARs, SBs
CD-ROM	ACS	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
Paperwork Reduction Project
MS 2120-0587
Washington, DC 20503

US Department of Transportation
Federal Aviation Administration
Office of Aviation Medicine AAM-240
Washington, DC 20503

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

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:

- 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

Table 6.1 Communication Failures

	Communicates To:						
Originator	Mechanic 1	Mechanic 2	Inspector	Logbook	Flight Crew	Supervisor	Next Shift
Mechanic 1	M M M M M	F V V V		F F F F F 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

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 (next page).

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

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	lead inspector, mechanics, other inspectors, managers (inspection, maintenance), anyone who asks
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 warnings important work in progress what tasks managers want done on a shift
Should STL 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%)

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.

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 COMMUNICATION 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 (next page) 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 (next page) 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 (next page) 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

	log	notes	recorders	computer tools	blackboard/ whiteboard	meetings	verbal	N-R 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, next page) 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, page 72). 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) Figure 6.2 Inspection Log: Blue Bay

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.

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

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

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 (following pages) show the second draft of the shift change log.

Figure 6.3 Lead Inspector Shift Turnover (Second Draft)

Figure 6.3 Lead Inspector Shift

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

Name	Destination	Departure Time	Return 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 (previous page) and 6.4. Table 6.5 (next page) 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 =

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? 0 - Of No Use 4 - Useful 8 - Extremely Useful	5.08	1.56
How useful is a separate log for each hangar bay? 0 - Of No Use 4 - Useful 8 - Extremely Useful	4.09	2.10
How useful is the practice of maintaining a separate log for each aircraft? 0 - Of No Use 4 - Useful 8 - Extremely Useful	3.50	2.27
Rate the ease of understanding of the proposed shift turnover log: 0 - Not At All Easy 4 - Easy 8 - Very Easy	4.70	1.69
Rate the usefulness of the information in the proposed turnover log: 0 - Of No Use 4 - Useful 8 - Extremely Useful	5.05	1.34
How often would you read all sections of the proposed turnover log? 0 - Never 4 - 3 times/week 8 - Every Shift	5.35	2.57
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	6.98	1.64
How often would you make an entry into the turnover log? 0 - Never 4 - 3 times/week 8 - Every Shift	5.96	2.19
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.	4.16	1.01
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.	4.14	1.02
Rate the type of information in the general section of the proposed turnover log: 0 - Of No Use 4 - Useful 8 - Extremely Useful	4.77	1.25
Rate the type of information in the aircraft section of the proposed turnover log: 0 - Of No Use 4 - Useful 8 - Extremely Useful	4.83	1.29
How does the proposed turnover log compare to the current turnover log? 0 - Less Useful 4 - As Useful 8 - More Useful	5.48	1.42
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	5.20	1.51
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	4.86	1.49
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	4.93	1.52
How useful is the current shift turnover log? 0 - Of No Use 4 - Useful 8 - Extremely Useful	4.12	1.69
How useful is the proposed shift turnover log? 0 - Of No Use 4 - Useful 8 - Extremely Useful	5.26	1.43

.015, .016). Finally, they indicated that the proposed log is more than useful (median = 5.200, p = .002). It is possible to use data in Tables 6.4 (previous page) 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 (next page) 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.

Table 6.6 Comparison of First Draft and Second Draft

User Needs Analysis Question	1st Draft Mean	2nd Draft Mean	P Value
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	5.08	0.61
How useful is a separate log for each hangar bay? 0 - Of No Use 4 - Useful 8 - Extremely Useful	4.09	4.09	1.0
How useful is the practice of maintaining a separate log for each aircraft? 0 - Of No Use 4 - Useful 8 - Extremely Useful	3.88	3.50	0.64
Rate the ease of understanding of the proposed shift turnover log: 0 - Not At All Easy 4 - Easy 8 - Very Easy	4.53	4.70	0.79
Rate the usefulness of the information in the proposed turnover log: 0 - Of No Use 4 - Useful 8 - Extremely Useful	4.24	5.05	0.19
How often would you read all sections of the proposed turnover log? 0 - Never 4 - 3 times/week 8 - Every Shift	4.63	5.35	0.43
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	6.98	0.40
How often would you make an entry into the turnover log? 0 - Never 4 - 3 times/week 8 - Every Shift	4.21	5.96	0.11
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	4.16	0.90
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	4.14	0.79
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	4.77	0.081
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	4.83	0.081
How does the proposed turnover log compare to the current turnover log? 0 - Less Useful 4 - As Useful 8 - More Useful	5.38	5.48	0.85
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	5.20	0.51
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	4.86	0.038
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	4.93	0.011
How useful is the current shift turnover log? 0 - Of No Use 4 - Useful 8 - Extremely Useful	4.35	4.12	0.68
How useful is the proposed shift turnover log? 0 - Of No Use 4 - Useful 8 - Extremely Useful	4.64	5.26	0.19

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.

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.

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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 deg. 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 deg. 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 recleaned–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.

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, next page). 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.

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 7.1 Generic Task Description of Inspection

Function	Visual Example
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.

Table 7.2 Generic Functions in Aircraft Repair

Function	Tasks
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/repaired. 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 (previous page) 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 (previous page), 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

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, next page) 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, page 98). 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, page 98), in turn, from the Pre-Maintenance phase through the Post-Maintenance Phase. Each module (e.g.,

Table 7.3 Classifications of Modules in EAAM

Human Factors Grouping	PHASE		
	Pre-Maintenance	Maintenance	Post-Maintenance
Information Requirements	1. Documentation 2. Communication	6. Documentation 7. Communication	23. Buy-Back
Environment	3. Visual Characteristics	8. Task Lighting 9. Thermal Characteristics 10. Thermal Perception 11. Auditory Characteristics	
Equipment/ Job Aids	4. Equipment Design 5. Access Equipment	12. Equipment Availability 13. Access Availability	
Physical Activity Workspace		14. Hand Tools 15. Force Exertion 16. Manual Materials Handling 17. Vibration 18. Repetitive Motion 19. Physical Access 20. Posture 21. Safety 22. Hazardous Materials	

Figure 7.4, page 99) 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, page 99). 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, page 100) to allow the analyst to record comments or notes.

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, page 100).

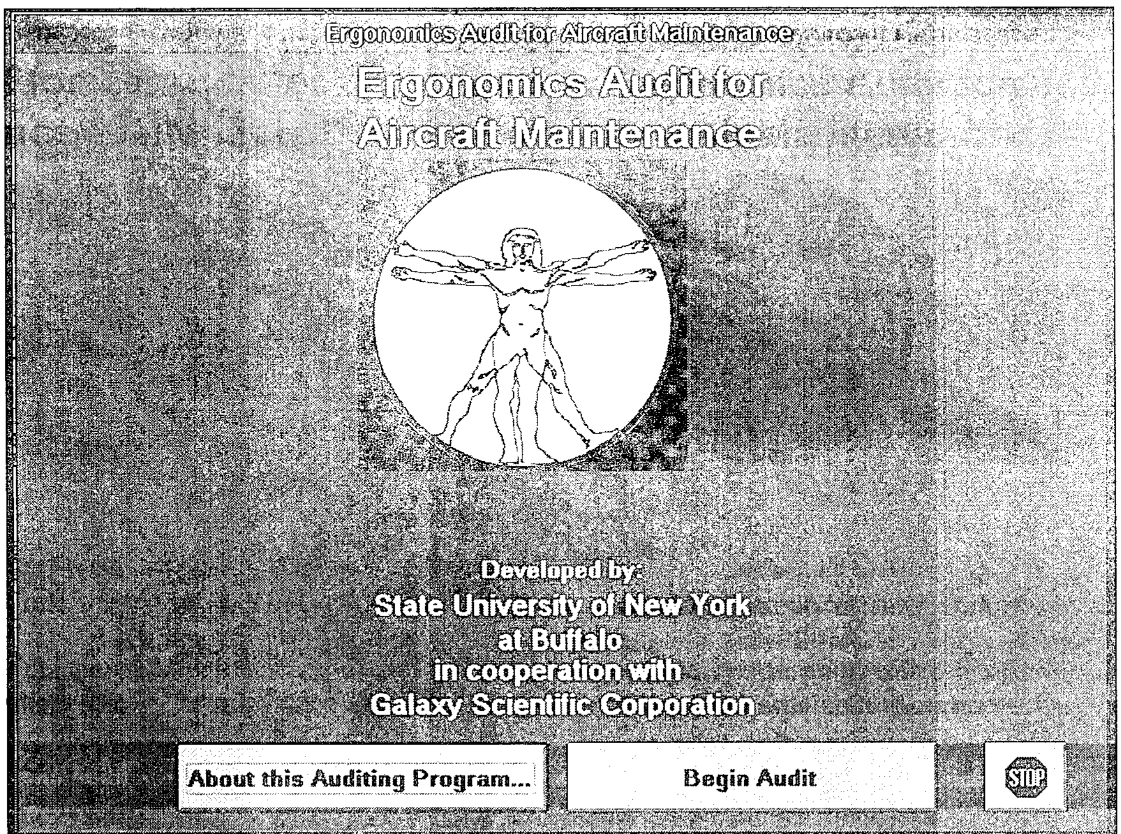

Figure 7.1 Title Screen

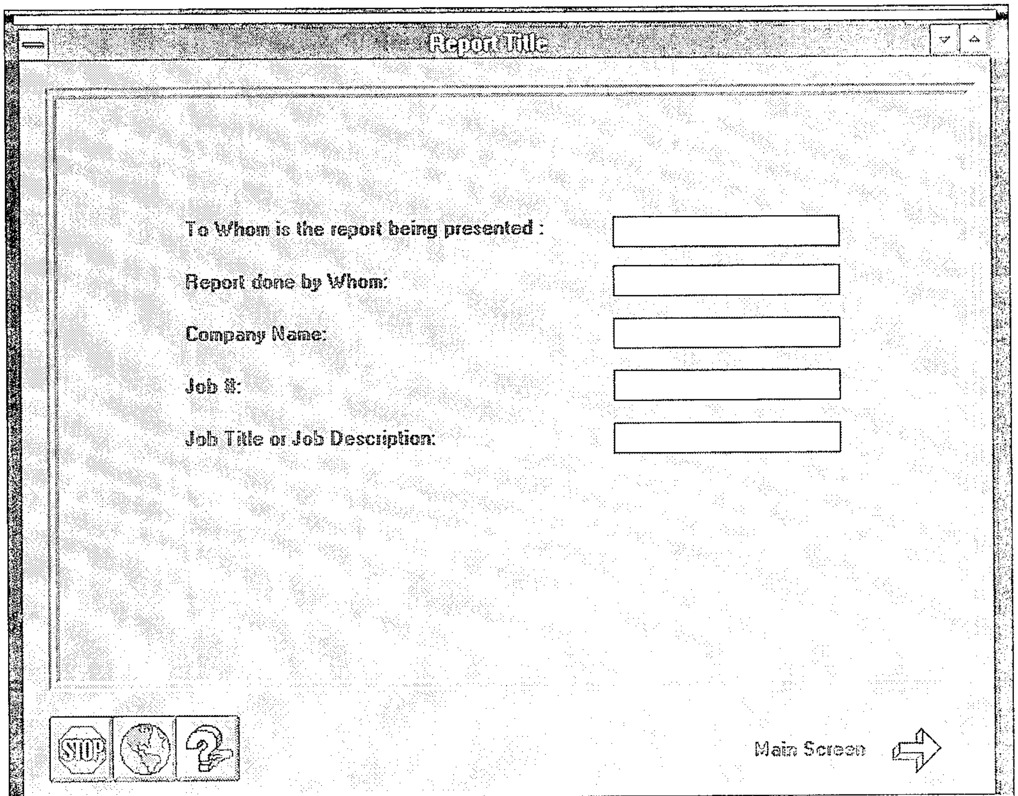

Figure 7.2 Heading Information Screen

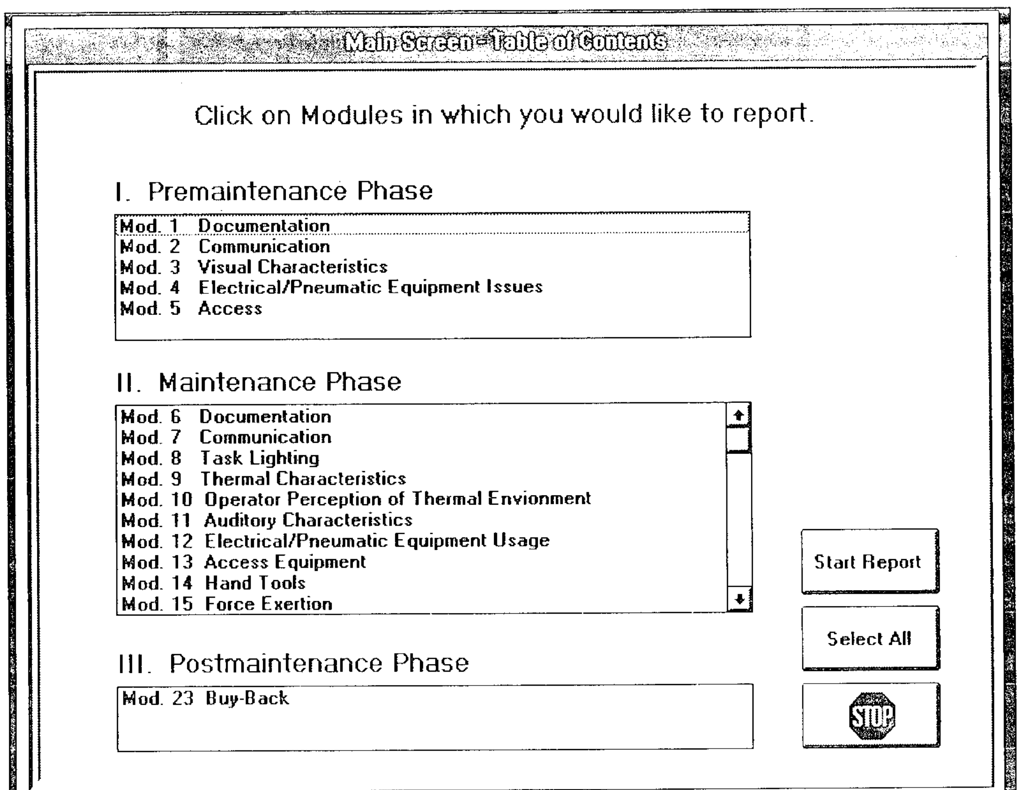

Figure 7.3 Main Program Screen

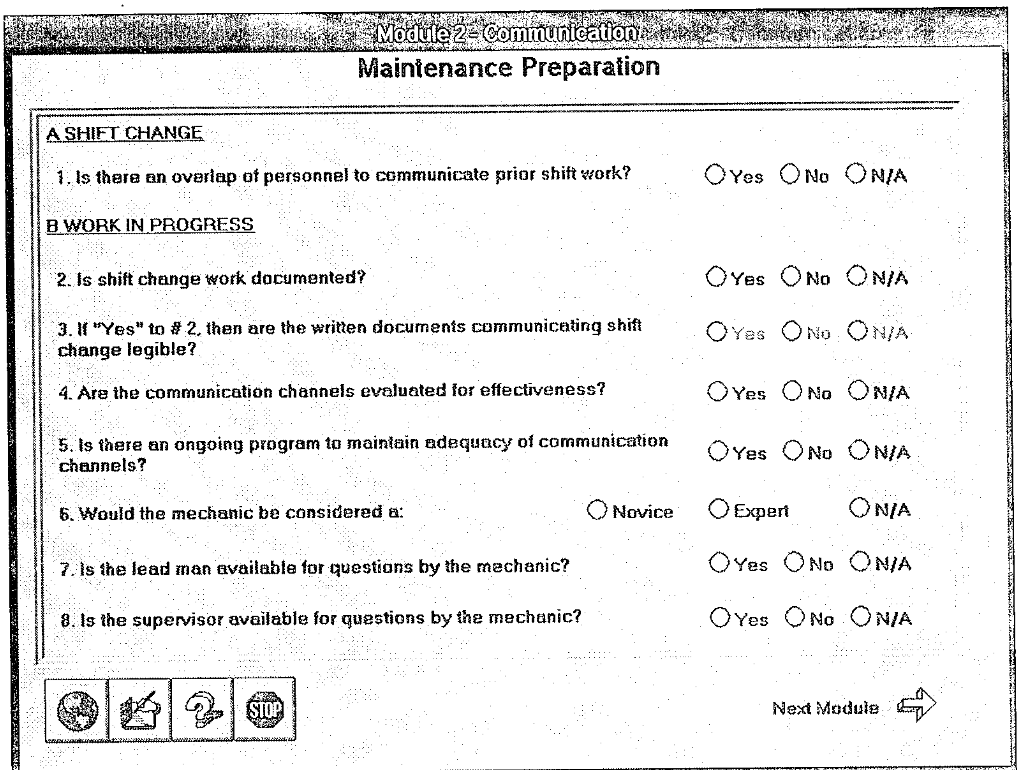

Figure 7.4 Maintenance Preparation Screen

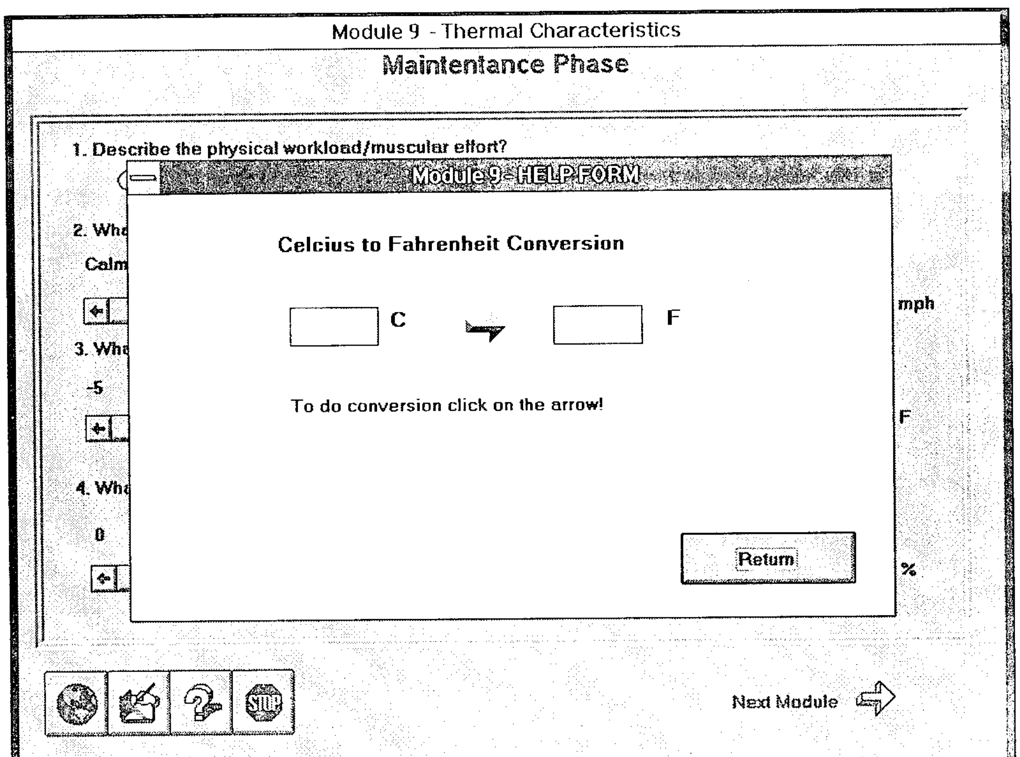

Figure 7.5 Help Screen

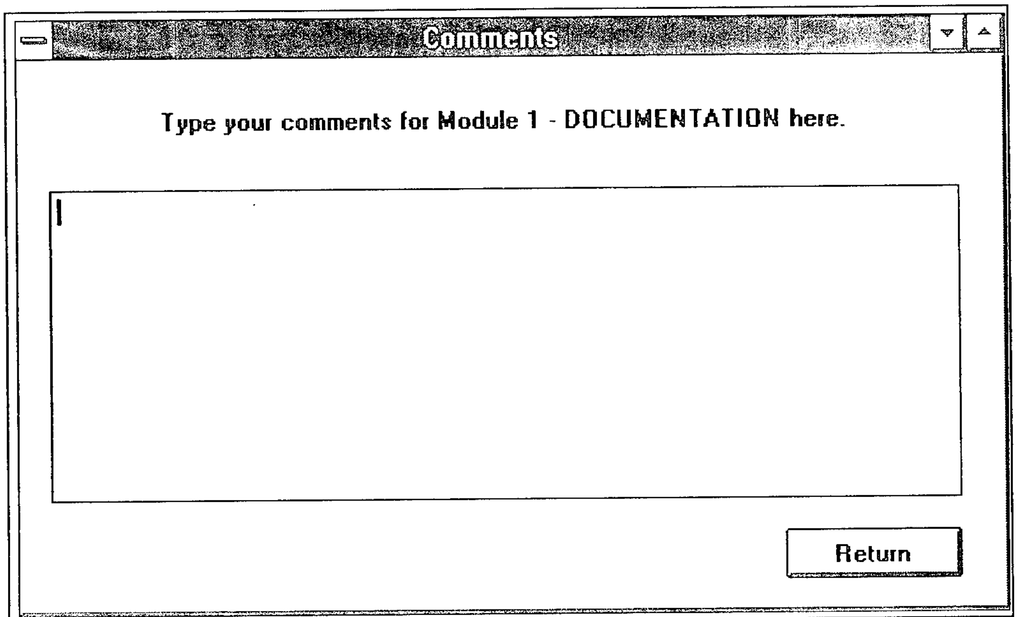

Figure 7.6 Comment Screen

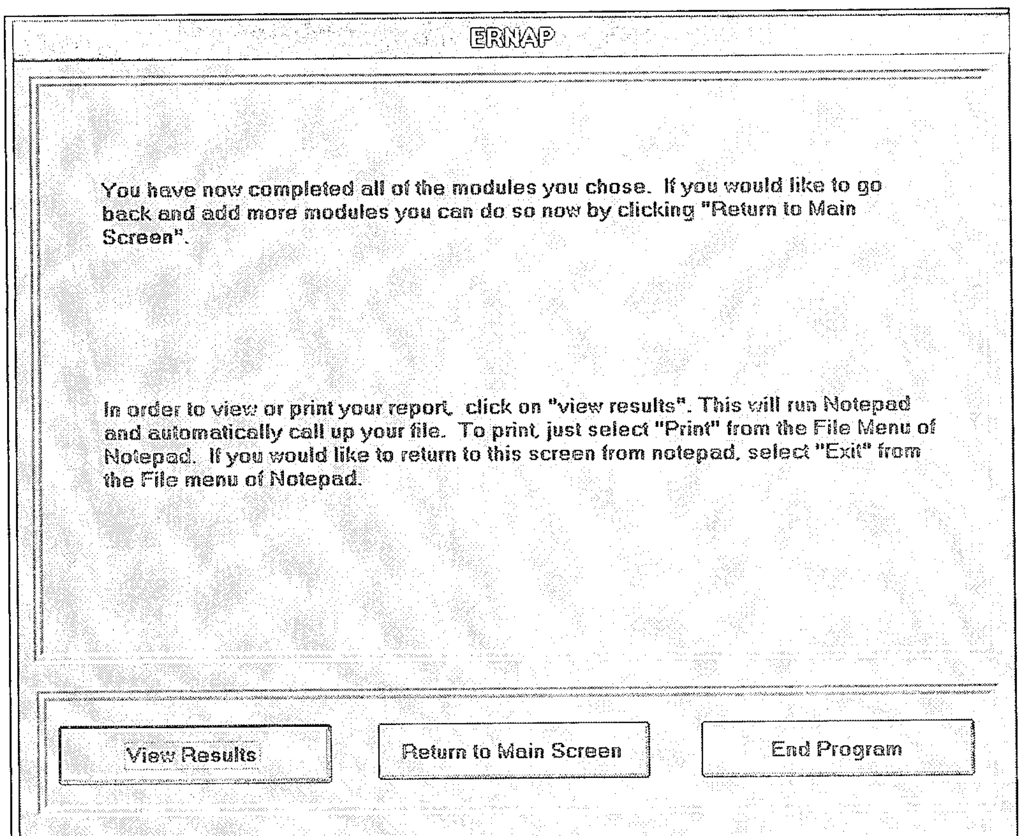

Figure 7.7 EAAM Screen

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.

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

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

Table 7.4 Reliability Data on Maintenance Audit for Four Tasks

Task	# Questions	# Diff.	Reliab.	X^2	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

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)

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 (previous page) 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%.

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.,

Table 7.6 Classification of Differences by Error Type

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

where one analyst states that the hand tool requires a power grip, while the other analyst records nothing.

Table 7.6 (previous page) 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.

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.

Table 7.7 Reliability Data on Maintenance Audit Version 2.0

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

Table 7.8 Results of Q Test on Maintenance Audit Version 2.0

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

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).

Table 7.9 Issues Identified by Checklist

Category	Ergonomic Issues
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
Total	55

Results: The results of the four subjects and that of the checklist are listed in Table 7.10 (next page). 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.

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

Category	Ergonomics Issues				
	Subject 1	Subject 2	Subject 3	Subject 4	Checklist
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
Total	**37**	**34**	**34**	**25**	**55**

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)____

6. If yes, its resolution matrix is:
   a. 5 X 5
   b. 5 X 7
   c. 7 X 9 or higher

(a/b/c)____

7. Are the graphics/attachments *legible* with reference to print quality? (Y/N) ____

8. Are there time & quality *standards for changing printer ribbons & toner cartridges*? (Y/N) ____

9 If yes, are the standards *obeyed*? (Y/N) ____

10. Have *acronyms/abbreviations* been used in the workcard? (Y/N) ____

11. If yes, *how many for the entire task*?
   a. less than five?
   b. greater than five? (a/b) ____

b. Graphics

12. Is *spatial information of body station positions* presented in pictorial form? (Y/N) ____

13. How are *figures represented*?
   a. Perspective(3-Dimensional)
   b. mode in which the user sees it (a/b) ____

14. Do figures have *back references* to workcard? (Y/N) ____

15. Are figures/graphics for *mirror-image tasks* separately drawn? (Y/N) ____

16. In figures/graphics, are *close-up views* distinguished from *distant views*? (Y/N) ____

MAINTENANCE PREPARATION

c. Information Organization

17. Is there a definite *ordering/sequencing* of tasks? (Y/N) ____

18. Does task information *carry-over* to the next page? (Y/N) ____

19. What is the *maximum number of tasks per action statement*?
a. 2
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

13. If control function is *ON*, is movement *RIGHT, CLOCKWISE, FORWARD* or *PUSH*?(Y/N) ____

14. If control function is *INCREASED*, is movement *RIGHT, CLOCKWISE* or *FORWARD*?(Y/N) ____

15. If control function is *RIGHT*, is the movement *RIGHT* or *CLOCKWISE*? (Y/N) ____

16. If the control is *RETRACT*, is the movement *UP, REARWARD* or *PULL*? (Y/N) ____

MODULE 5. ACCESS EQUIPMENT - LADDERS, SCAFFOLDS

1. Do ladders/scaffolds have *non-skid surfaces* on landings? (Y/N) ____

2. Do ladders/scaffolds have *safety screens* behind open stairs and at landings? (Y/N) ____

3. Do ladders have *hand rails*? (Y/N) ____

4. What is the cross section of the hand rails?
   a. circular
   b. rectangular
   c. other (a/b/c) ____

5. What is the *angle of inclination* of the ladder with the horizontal? A= ____ ^{o}

6. What is the *riser* height? R = ____ inches

7. What is the *tread* length? X = ____ inches

8. If non-tread ladders are used: what is the *distance between vertical rails*? Y = ____ inches

9. If non-tread ladders are used: What is the *cross section* of the *rungs*?
   a. circular
   b. rectangular
   c. other (a/b/c) ____

10. If non-tread ladders are used: What's the *cross section* of the *vertical rails*?
    a. circular
    b. rectangular
    c. other (a/b/c) ____

MAINTENANCE PREPARATION

ACCESS EQUIPMENT - PORTABLE LADDERS (Step Ladders & Tall Step Ladders)

<u>Step ladders</u>

11. What is the *height* of the step ladder? H = ____ inches

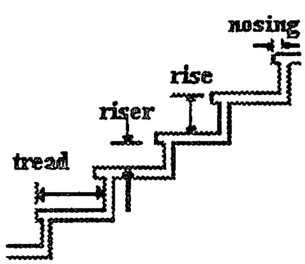
12. Does the step ladder have *non-slip treads*? (Y/N) ____

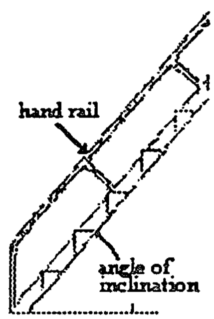
13. Does the step ladder have *rubber feet*? (Y/N) ____

<u>Tall Step Ladders</u>

14. Does the tall step ladder have *braces* on the lower steps? (Y/N) ____

15. Do the folding braces of the ladder have *locking detents*? (Y/N) ____





MAINTENANCE STAGE

A. Information Requirements

MODULE 6. DOCUMENTATION (Physical Handling & Environmental Factors)

1. When did the mechanic *last perform* this task? a. a day ago b. a week ago c. a month or more (a/b/c) ____

2. Does the Mechanic read the workcard? (Y/N) ____

3. Do you feel the *information content* of the workcard *complete with respect to the scope of the task*? (Y/N) ____

4. Do you feel a *novice mechanic can understand* this current workcard? (Y/N) ____

5. Do you feel there is any handling difficulty with respect to the *size of the workcard/graphic attachments* while conducting maintenance? (Y/N) ____

6. Do you feel there is *adequate readability* in the current light conditions? (Y/N) ____

7. Is maintenance being conducted in conditions of: a. wind (Y/N) ____ b. rain (Y/N) ____ c. snow (Y/N) ____

8. Does the mechanic *sign-off* the workcard after each subtask? (Y/N) ____

9. Do *writing tools* facilitate writing in all positions? (Y/N) ____

MODULE 7. COMMUNICATION

(Maintenance person to be asked the following questions)

1. How *easy* is communication (work-related) with co-worker? a. very easy b. adequate c. very difficult (a/b/c) ____

2. Did you get explicit *verbal instructions* from the supervisor? (Y/N) ____

3. How *easy* is communication with supervisor? a. very easy b. adequate c. very difficult (a/b/c) ____

4. Are you given feedback when you are *not performing up to the standard*? (Y/N) ____

5. Are you encouraged to help *identify error likely situations* in: a. existing design (Y/N) ____ b. maint. proc. (Y/N) ____

6. Are the suggestions reviewed? (Y/N) ____

MAINTENANCE PHASE

MODULE 8. TASK LIGHTING

1. What *type of work* is being audited?
   a. ordinary maintenance
   b. detailed maintenance
   c. fine maintenance (a/b/c)____

2. Does mechanic look from bright to dark places routinely? (Y/N) ____

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
   b. moderate
   c. high (a/b/c) ____

2. What is the wind speed? ____ Mph

3. The air temperature is approximately? ____ °F

4. What is the Humidity of the hangar? ____ %

MODULE 10. OPERATOR PERCEPTION OF THERMAL ENVIRONMENT

This module evaluates the perceptions of the operators to climate changes. All the questions in this module are to be addressed to the inspector performing the task.

1. How do you *feel now*? Scale reading ____

1	2	3	4	5	6	7
hot	warm	slightly warm	neutral	slightly cool	cool	cold

2. Indicate how you would *like to be now?*
   a. warmer
   b. cooler
   c. no change (a/b/c) ____

SUMMER

3. How do you *feel during summer*? Scale reading ____

1	2	3	4	5	6	7
hot	warm	slightly warm	neutral	slightly cool	cool	cold

4. Indicate how you would *like to be during summer?*
   a. warmer
   b. cooler
   c. no change (a/b/c) ____

WINTER

6. How do you *feel during winter*? Scale reading ____

1	2	3	4	5	6	7
hot	warm	slightly warm	neutral	slightly cool	cool	cold

7. Indicate how would you *like to be during winter?*
   a. warmer
   b. cooler
   c. no change (a/b/c) ____

MAINTENANCE PHASE

MODULE 11. AUDITORY CHARACTERISTICS

Measurement Tools: Sound-level meter that measures sound in decibels.

1. The *noise levels* recorded over the entire inspection task duration are:
   Reading# 1_____dBA
   Reading# 2_____dBA
   Reading# 3_____dBA
   Reading# 4_____dBA
   Reading# 5_____dBA

2. At each reading, the main source of noise from:
   a) pneumatic tools
   b) music
   c) conversation
   d) engines
   e) passing aircraft
   f) other

   answer (a,b,c,d,e,f)
   Reading # 1 ____
   Reading # 2 ____
   Reading # 3 ____
   Reading # 4 ____
   Reading # 5 ____

3. What is the approximate *exposure time* to the existing noise levels? ______ hours/day

4. Does the maintenance person wear *earplugs*? (Y/N) ____

5. Does the maintenance person wear *earmuffs*? (Y/N) ____

6. The *maximum distance* which the maintenance person needs to communicate verbally is? ____ feet

7. Is there a high pitch noise component? (e.g.,. over 2000 Hz) (Y/N) ____

8. Is the main source of noise from other workstations? (Y/N) ____

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) ____

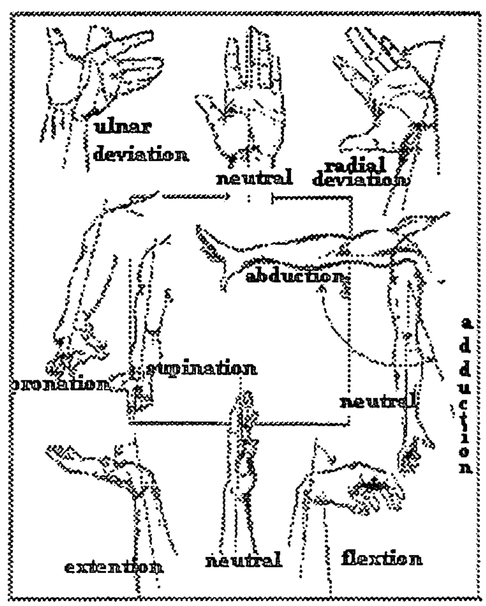
16. The type of activating trigger is :
    a. single finger? (Y/N) ____
    b. multiple finger strip? (Y/N) ____
    c. thumb? (Y/N) ____

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) ____

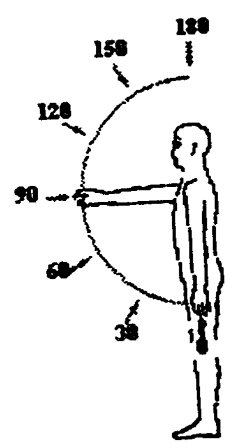
20. If the tool is heavy is it supported or counter balanced? (Y/N) ____



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.)



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) ____

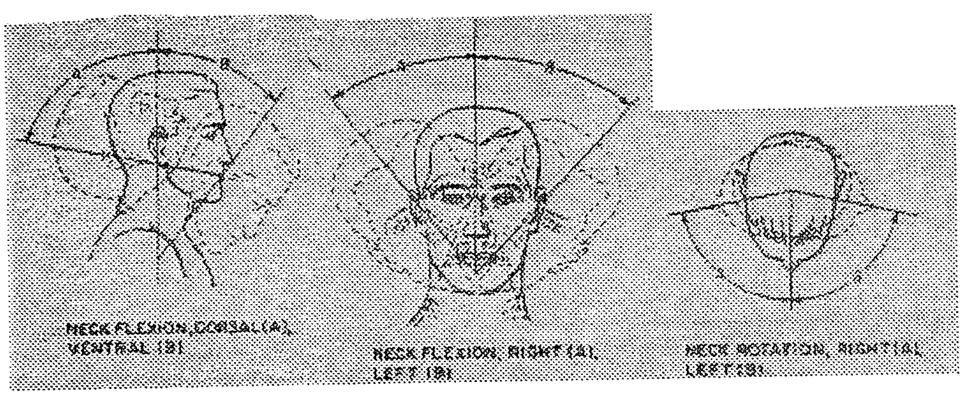
9. What is the duration of maximum continuous vibration exposure? (Min) ____

10. What is the total duration of vibration exposure on this shift? (Min) ____

11. What is the vibration acceleration? (m/s^2)____

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) ____



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%*	*10% - 25%*	*above 25%*
1	*arm(s) in air*	*back bent*	*leg(s) bent*				
2	*arm(s) in air*	*back bent*	*kneeling/crawling/laying*				
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 twisted*	*leg(s) bent*				
6	*arm(s) in air*	*back bent and twisted*	*kneeling/crawling/laying*				
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) ____

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 traveled. 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 coworker 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 (next page) 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

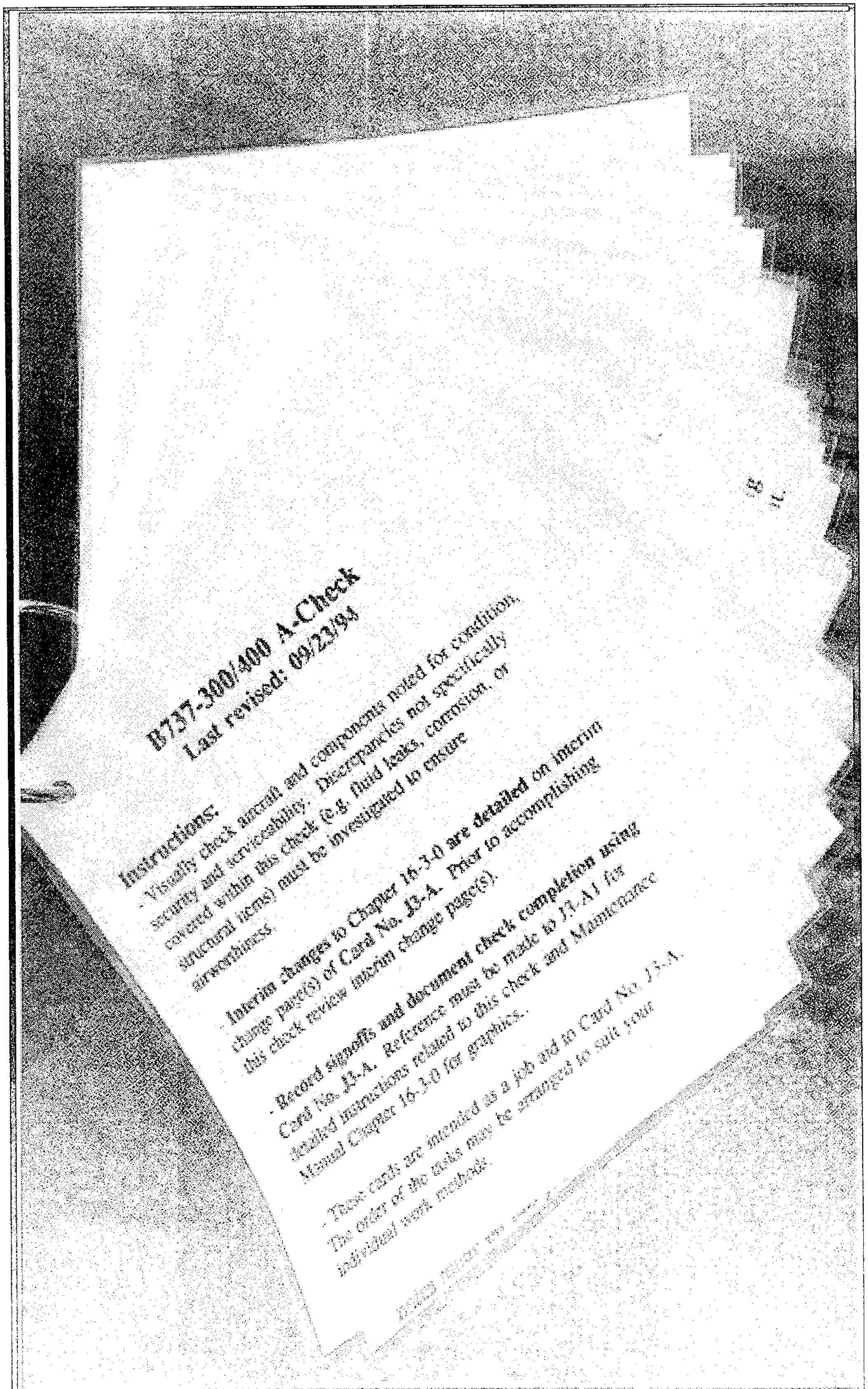

Figure 8.1 Top Card of the Job Aid for a B737-300/400 A-Check

> 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, next page). 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, page 139) 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, page 140).

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.

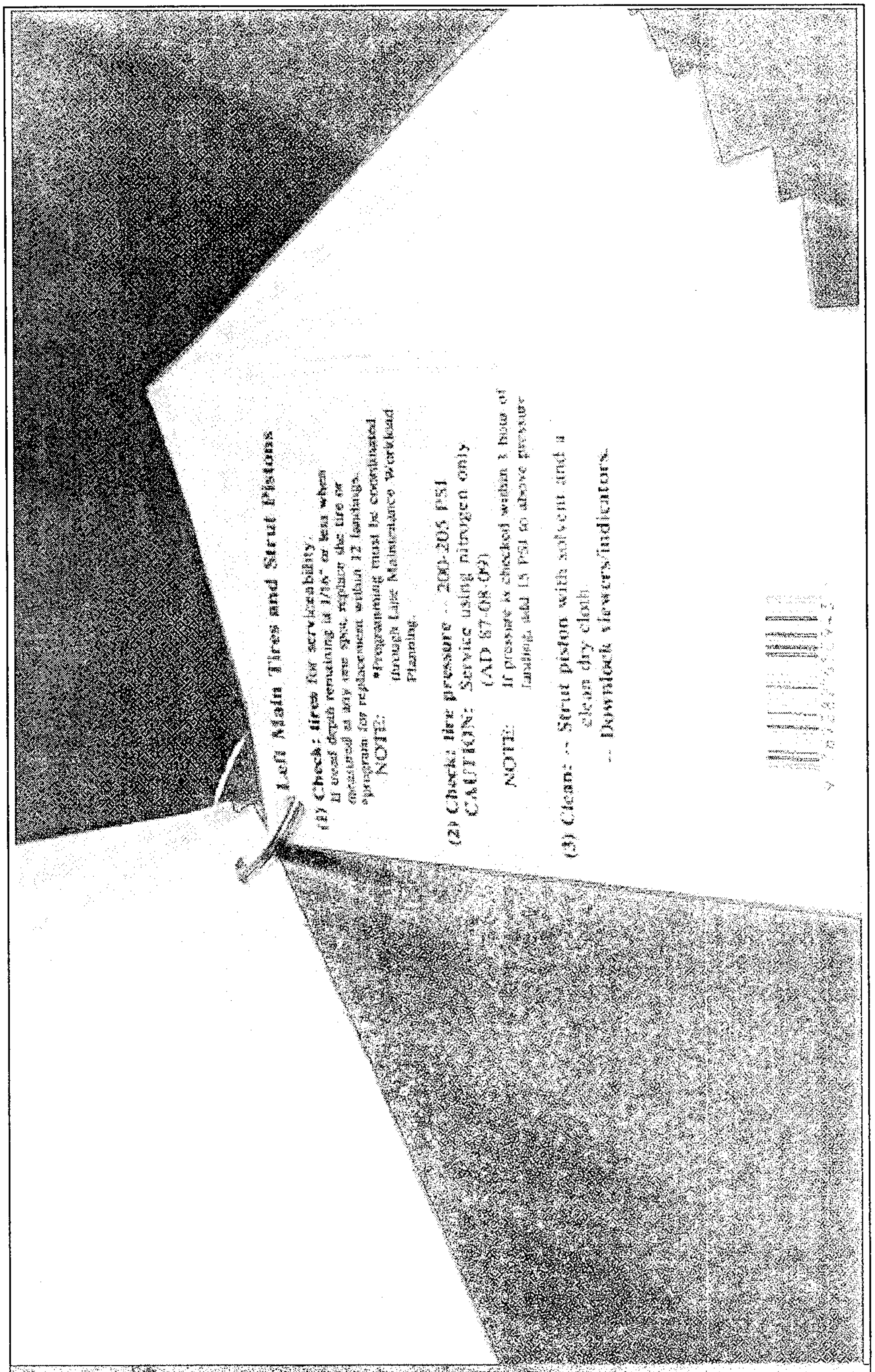

Figure 8.2 Example of Job Aid Layout, with Barcode

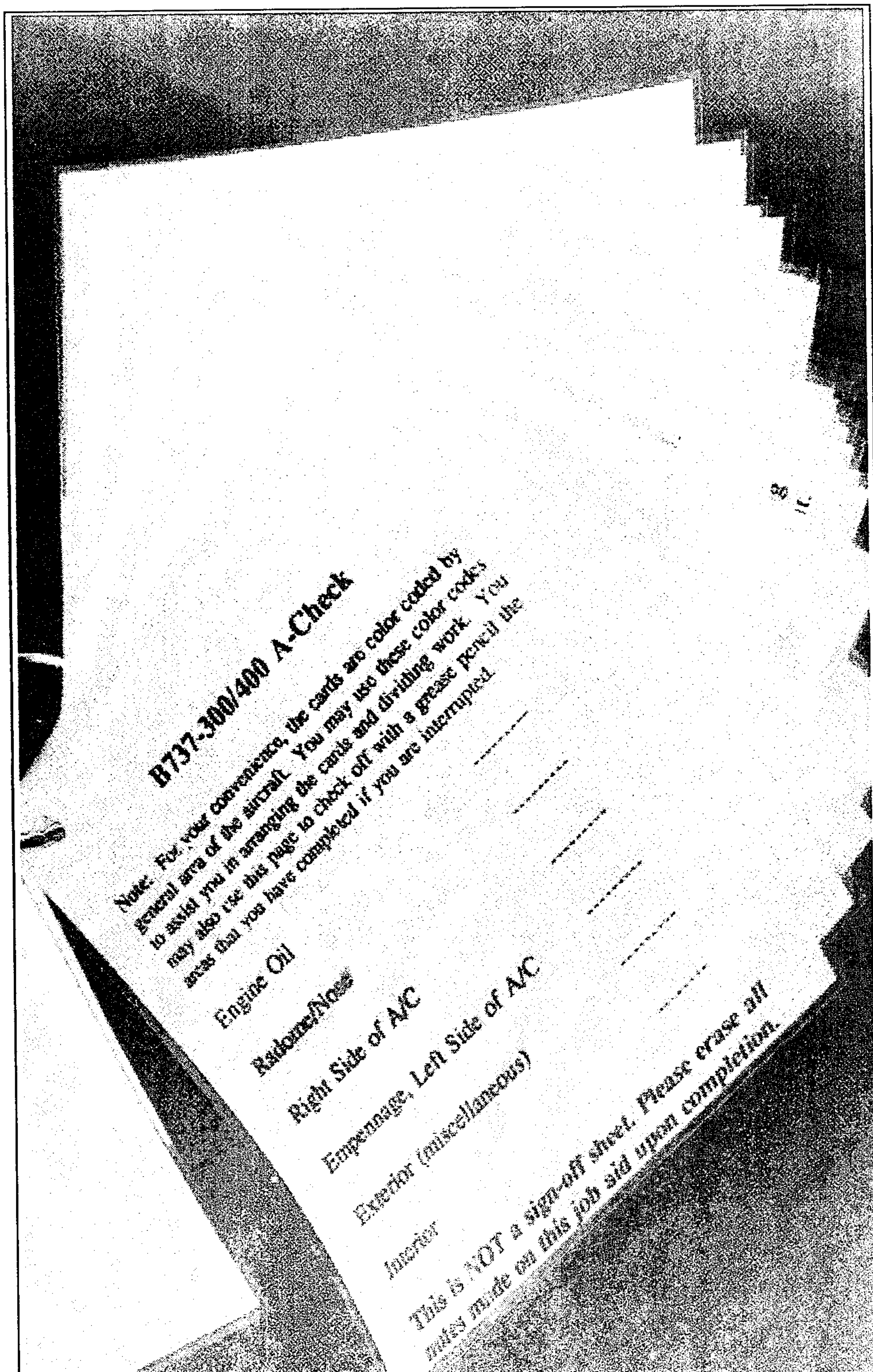

Figure 8.3 Spatial Layout Grouping for Work Card Items in Job Aid

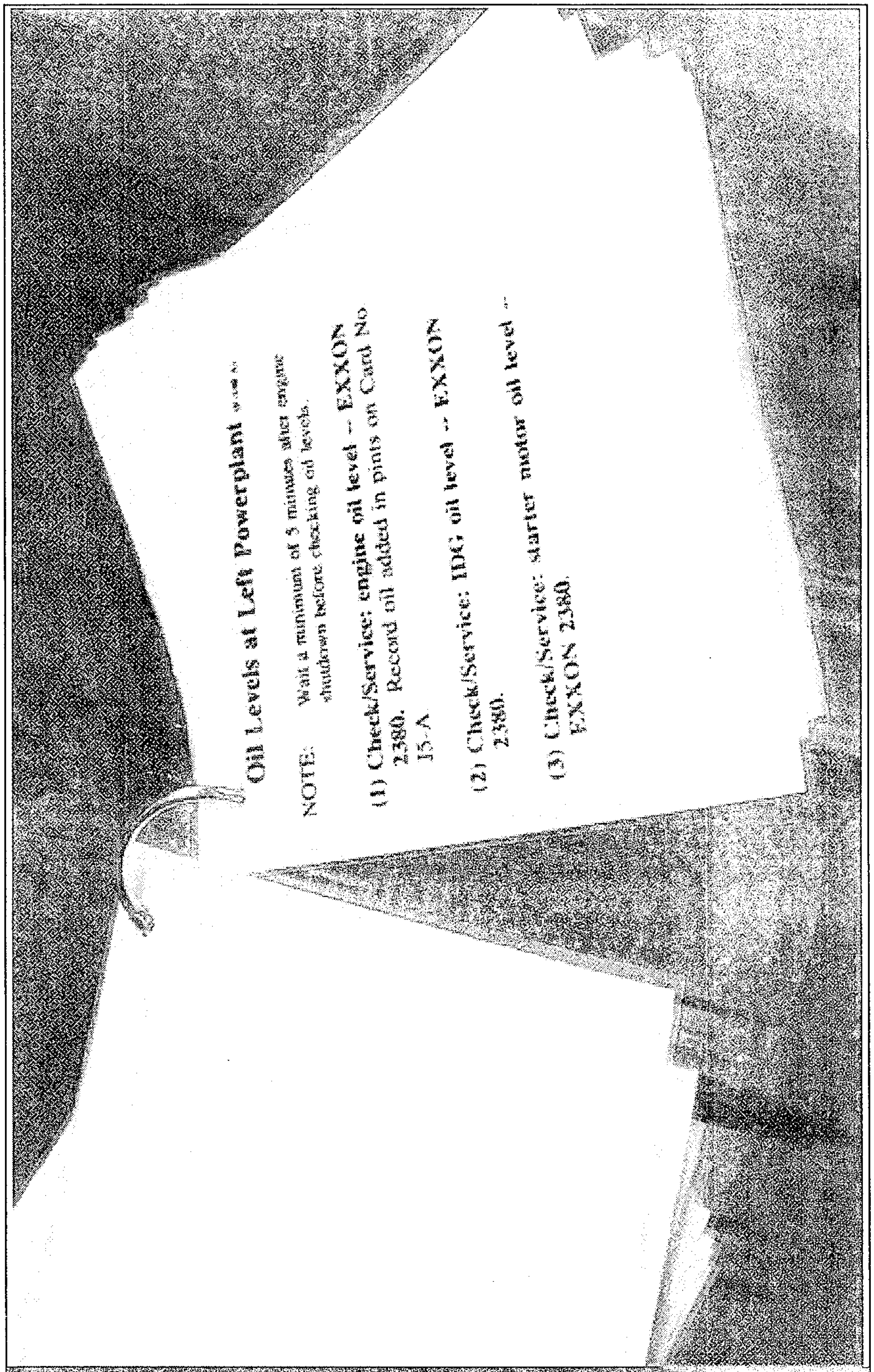

Figure 8.4 Typical Page Layout and Lamination of Job Aid

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 placemarker 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 placemarker page separated completed cards from those yet to be performed. Our observations and interviews revealed that mechanics were reluctant to move the placemarker page after they completed tasks on a card. We removed the placemarker 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 of 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

Task	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 indicator.	0.6 (0.7)	1.1 (2.4)

Task	Prob. of Discrepancy: mean (sd)	Difficulty of Task: mean (sd)
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)

Task	Prob. of Discrepancy: mean (sd)	Difficulty of Task: mean (sd)
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. Clean MLG & NLG downlock viewers/indicators.
7	Check fuselage, empennage, and wings for obvious damage or irregularities as viewed from the ground.
8	Check tail skid.
9	Check engine fire bottle pressure.
10	Check APU fire bottle discharge disc (yellow) and thermal relief disc (red).
11	Check exterior lights for proper operation.
12	Fuel tank sumps.
13	Hydraulic fluid (System A, B, and Standby).
14	Auxiliary Power Unit Oil.
15	Engine oil.
16	Constant speed drive #1, #2.
17	Oxygen–Crew, portable.
18	Attendants' seats for proper operation and condition.
19	Ensure outboard seat in the emergency exit row has a non-standard thinner seat bottom cushion installed.
20	Check passenger life vest, for aircraft that are equipped for over water operation.
21	Protective breathing equipment (PBE) for serviceability.
22	Lavatory flush pumps/timers.
23	Emergency lighting system.
24	Entrance area for appearance and condition.
25	Galley area for general appearance and condition.
26	Cabin area for general appearance and condition.
27	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[1]	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	4
9	3	1	3	4	7	15	4
10	5	16	5	6	7	15	5
11	2	7	6	9	7	16	1
12	1	1	9	13	8	16	1
13	9	7	10	7	9	1	6
14	7	3	13	2	10	1	6
15	7	2	13	3	11	2	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

Order	m-q	m1-v	m2-q	m2-v[1]	m3-q	m4-q	m5-q
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*			

Order	m-q	m1-v	m2-q	m2-v[1]	m3-q	m4-q	m5-q
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.

Question	M1	M2	M3	Mean
How useful would you find the placemarker 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? 0=of no use 4=useful 8=extremely useful	4	1	5	3.3
How useful do you think the proposed job aid would be? 0=of no use 4=useful 8=extremely useful	6	6	5	5.7
Do you perform the tasks in the order given by the present w/c? 0=never 4=sometimes 8=always		0		0
Would you perform the tasks in the order you arranged using the job aid? 0=never 4=sometimes 8=always	6	8	5	6.3

Question	M1	M2	M3	Mean
How often do you refer to the present workcard as you perform a lower-level 2 check? 0=never 4=sometimes 8=always	4	0	5	3
How often would you refer to the job aid as you perform a lower-level 2 check? 0=never 4=sometimes 8=always	6	6	3	5
How often do you refer to the present workcard as you perform an A-check? 0=never 4=sometimes 8=always	5	5	7	5.7
How often would you refer to the job aid as you perform an A-check? 0=never 4=sometimes 8=always	6	6	7	6.3

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. Placemarker/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 placemarker/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)

Question	Present Workcard Mean (sd)	Job Aid Mean (sd)
How would you rate the ease of readability of the text? 0=terrible 2=poor 4=fair 6=good 8=excellent	5.47(1.42)	6.12(1.27)
In general, how easy is the information to understand? 0=very difficult 4=moderately easy 8=very easy	6.06(2.19)	6.12(1.65)
How would you rate the effort required in locating a particular task? 0=very difficult 4=moderately easy 8=very easy	5.35(2.42)	5.59(1.77)
What would be the chance of you missing a sign-off or a task? 0=always 2=usually 4=sometimes 6=seldom 8=never	5.94(1.84)	6.35(1.27)
How would you rate the ease of physically using the workcard/job aid? 0=very difficult 4=moderately easy 8=very easy	5.47(2.10)	6.06(1.92)
Would you perform the tasks in the order given by the workcard/job aid? 0=never 2=seldom 4=sometimes 6=usually 8=always	2.47(2.40)	5.18(2.40)
How often do/would you refer to the workcard/job aid as you perform a lower-level 2 check? 0=never 2=seldom 4=sometimes 6=usually 8=always	5.12(2.42)	5.41(2.09)
How often do/would you refer to the workcard/job aid as you perform an A-check? 0=never 2=seldom 4=sometimes 6=usually 8=always	6.18(1.85)	6.47(1.59)
How useful do you find the workcard/job aid? 0=of no use 4=useful 8=extremely useful	4.06(2.19)	5.12(2.12)
How useful would you find the color-coding of the tasks into areas? 0=of no use 4=useful 8=extremely useful		3.65(1.90)

How useful do you think the division of tasks into small cards would be? 0=of no use 4=useful 8=extremely useful		3.82(1.98)
Would you rearrange the cards to suit your individual work habits? 0=never 2=seldom 4=sometimes 6=usually 8=always		5.76(2.44)
Would you read the interim page at the end of the workcard before starting the check? 0=never 2=seldom 4=sometimes 6=usually 8=always		6.00(2.21)
Would you use the grease pencil to make notes while completing the check? 0=never 2=seldom 4=sometimes 6=usually 8=always		3.88(2.34)

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.*

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, next page . 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.

Table 9.1 Classification of Indication & Defect Type

CODE		DESCRIPTOR	
20		Wear and Tear	
	21		Loose
	22		Pulled
	23		Bent
	24		Dent
	25		Scratch
	26		Frayed
	27		Leaking
	28		Lighting Hole
30		Corrosion	
	31		Pillowing
	32		Exfoliation
	33		Intergranular
	34		Material Missing
40		Broken	
	41		Crack
	42		Disbond
	43		Delamination
	44		Part Missing

Table 9.2 Classification of Structure for Fuselage Inspection (Only includes items with indications in Baseline Data)

CODE		DESCRIPTOR	
10		Skin	
	11		Doubler
	12		Extension Skin
	13		Interior Skin
	14		Bulkhead
	15		Panel
20		Fasteners	
	21		Rivet
	22		Screw
	23		Bolt
30			Support Structure
	31		Frame
	32		Stringer
	33		Track
	34		Bracket
	35		Web
	36		Mount
	37		Clip
40		Other Structure	
	41		Rod
	42		Strap
50		Other Material	
	51		Seal
	52		Paint

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.

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 (previous page) 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, next page). They will also inspect a sample of the crack test panels developed for the NDI eddy-current reliability experiment (Figure 9.2, page 173) 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.

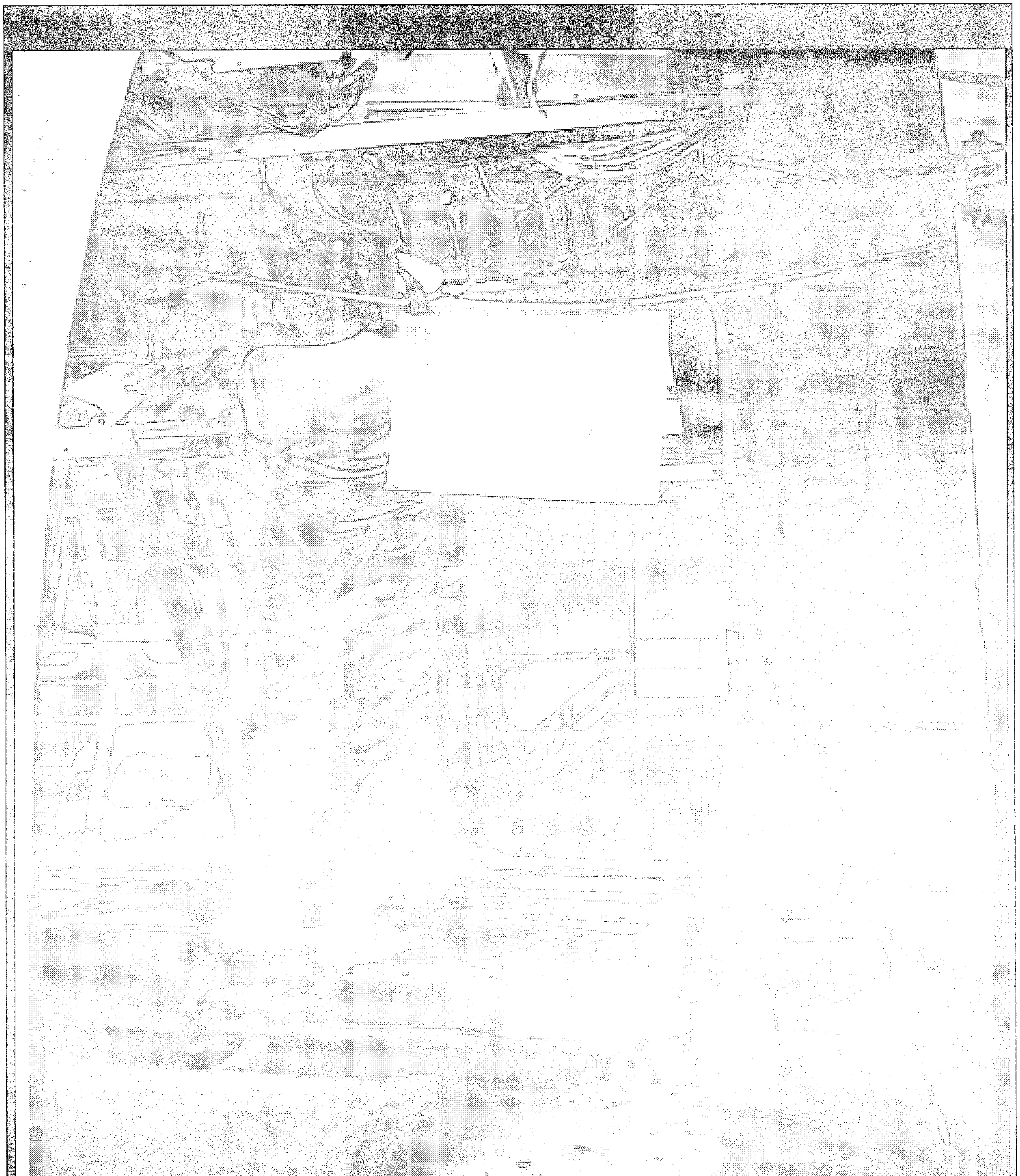

Figure 9.1 Subject Inspecting B-737 Structure

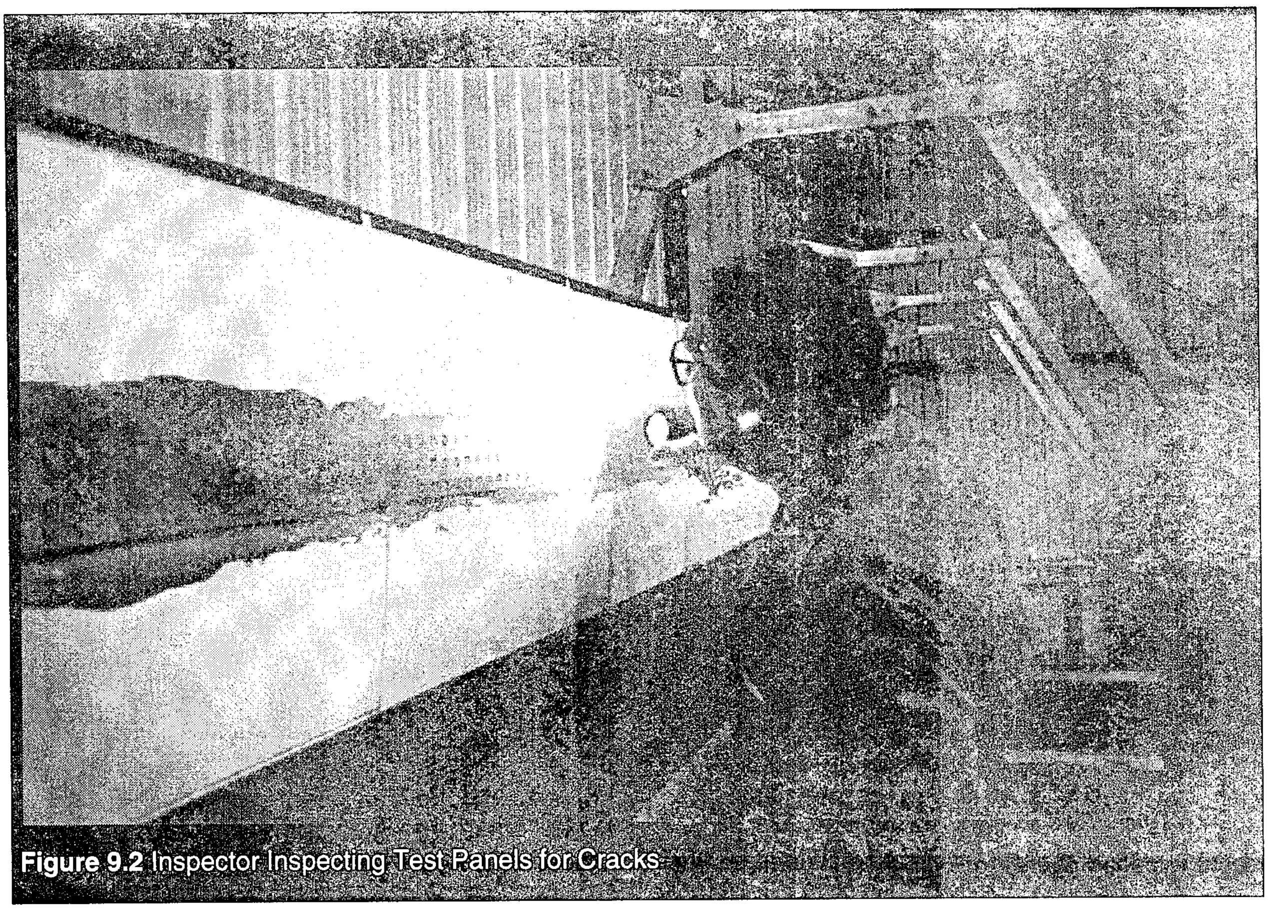

Figure 9.2 Inspector Inspecting Test Panels for Cracks

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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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).[1] 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.

[1] A more extensive background and rationale for the predictor measures employed, as well as the need for further information on possible fatigue-related performance changes, were provided in the earlier study and are not reviewed here.

The present study was conducted to follow-up on the findings of this previous study.[2] 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 (next page) 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

[2] Unless otherwise noted, the words "previous study" henceforth refer always to this earlier study.

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

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 characteris-

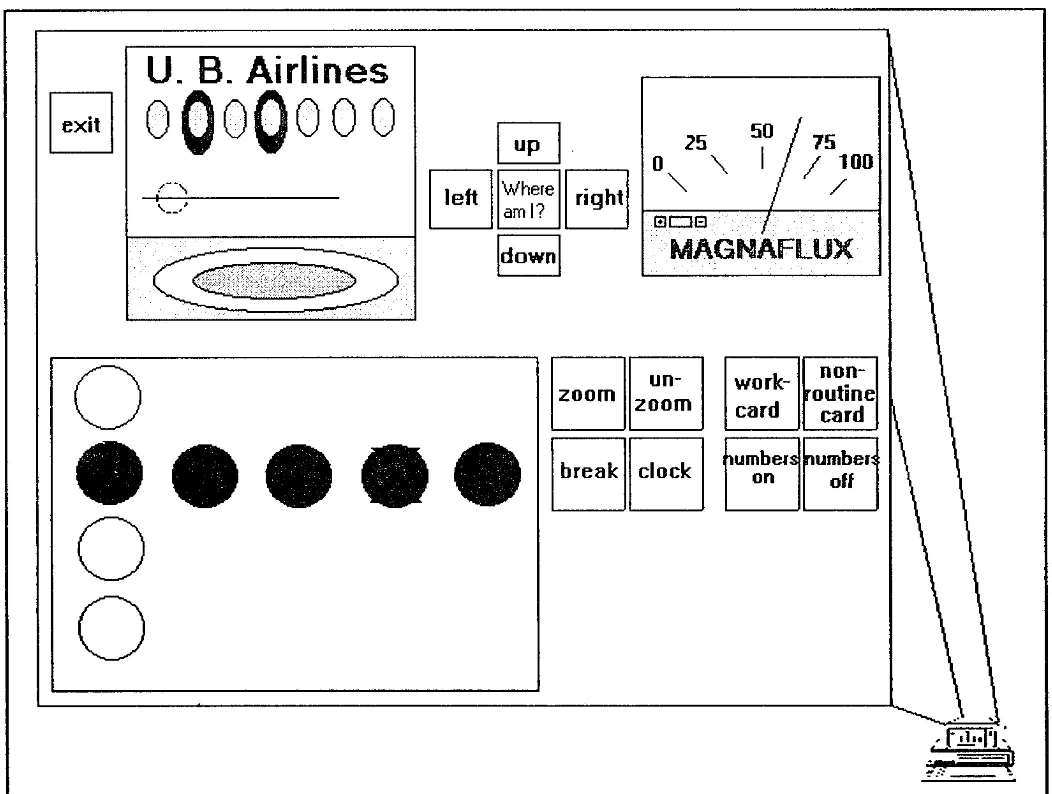

Figure 10.1 NDI Task Simulation (Drury et al., 1992)

tics 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 reexamination. 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 ($F<1.00$).

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

Table 10.1 Mean Values for the Performance Variables

	Session		
Performance Variables	1	2	Session Mns
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

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

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

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

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.

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 (previous page), 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.

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

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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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 skilis, their lassez-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 Wilheim, 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 Barett, 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 intervies 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 Questionairre) 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 the 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.

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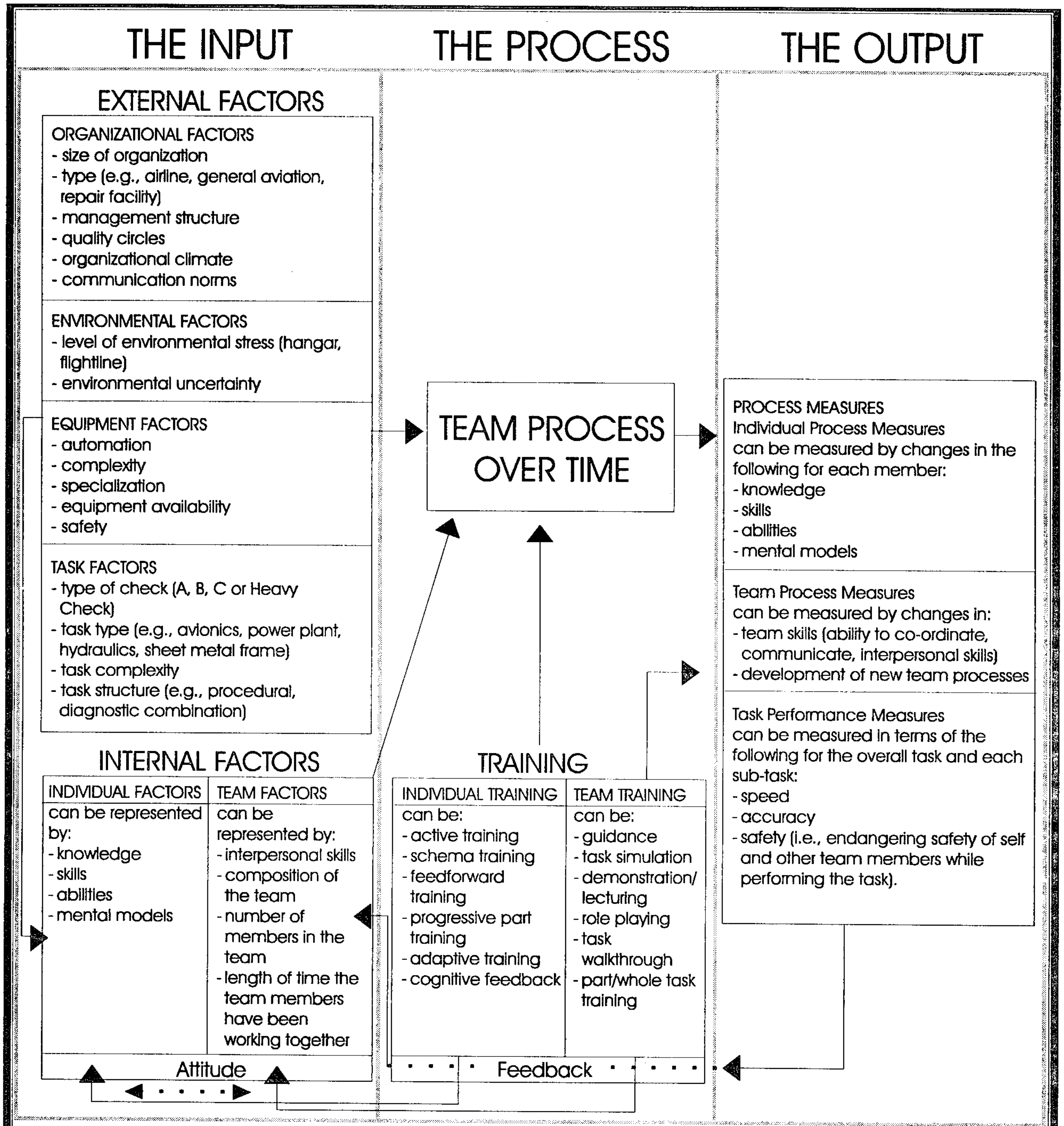

Figure 11.1 A Modified TEAM Effectiveness Model

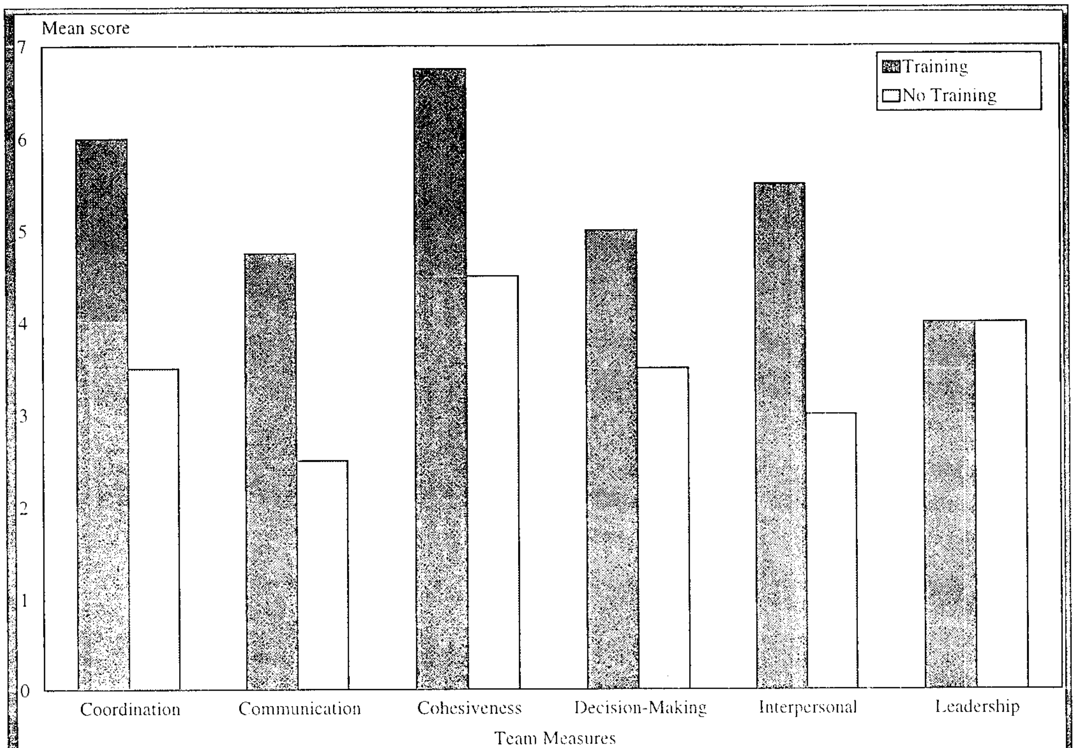

Figure 11.2 Evaluation of Team Performance Measures by Instructor - Engine Removal

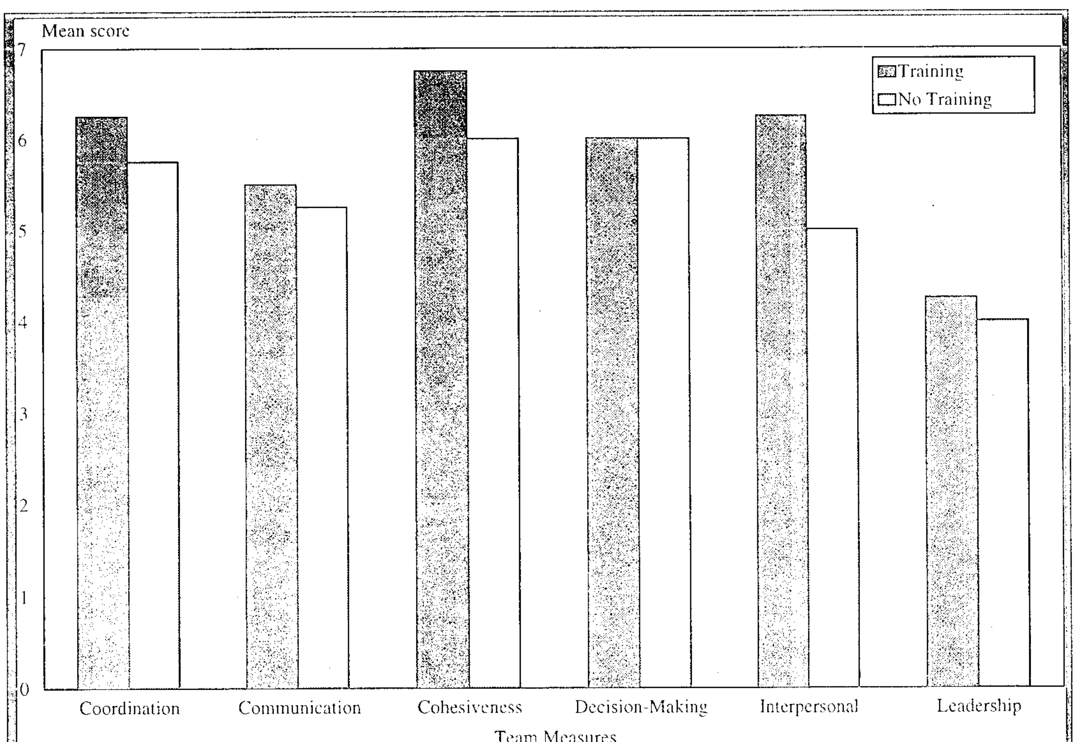

Figure 11.3 Evaluation of Team Performance Measures by Instructor - Engine Installation

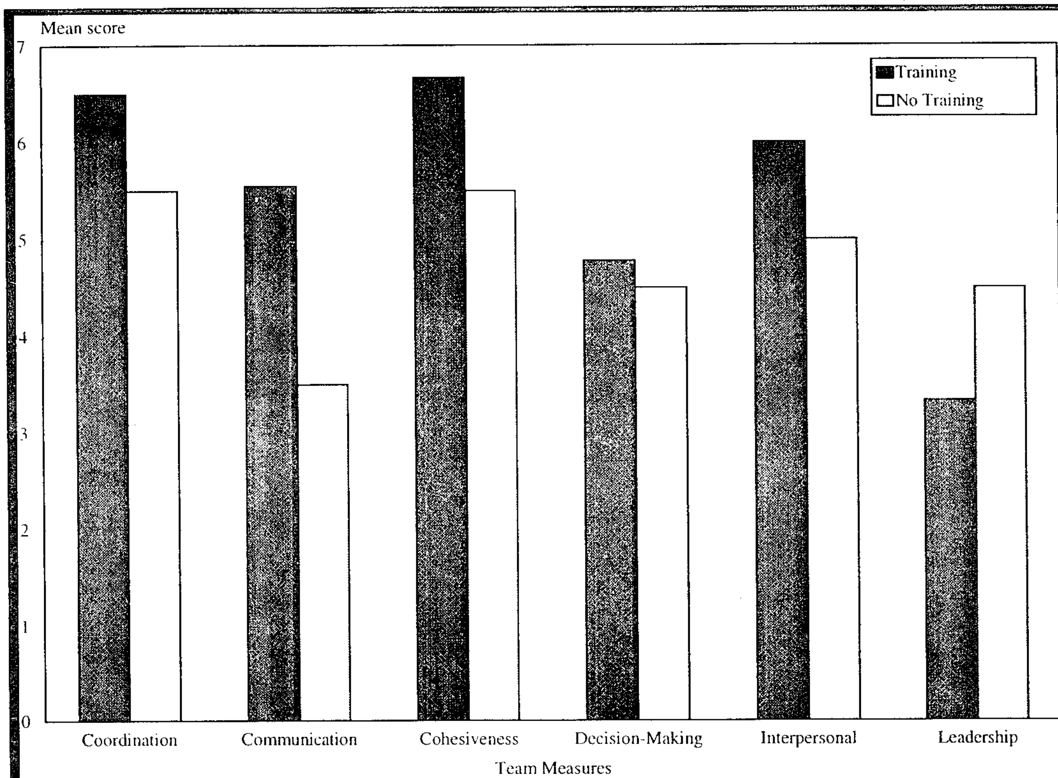

Figure 11.4 Self Evaluation - Engine Removal

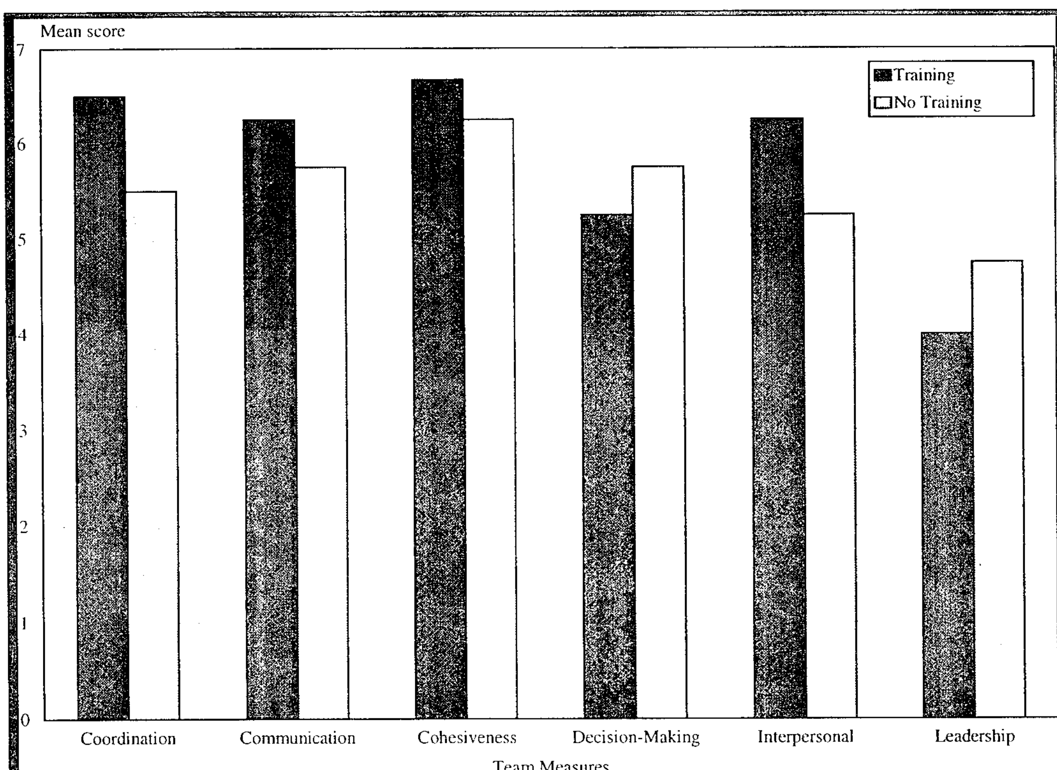

Figure 11.5 Self Evaluation - Engine Installation

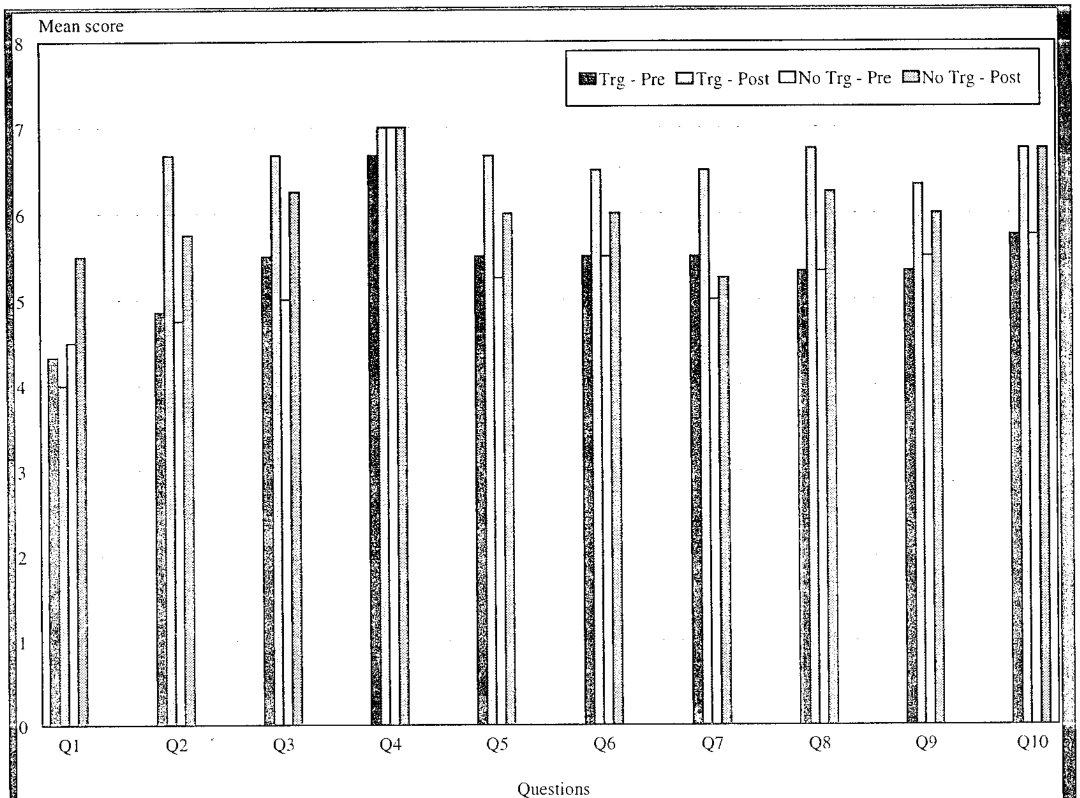

Figure 11.6 Pre and Post Training Data

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
1. **External Preparation** a) Set up tail stand b) Disconnect electric power c) Remove top cowling d) Disconnect actuator e) Remove bottom cowling	1. **Engine Installation** a) Install Engine b) Connect top V-brace c) Connect lower engine mounts d) Put bulhead bolts e) Unmount sling and hoist from engine
2. **Engine Preparation** a) Remove hoses and fittings b) Disconnect electrical leads c) Disconnect engine controls d) Drain oil e) Remove propeller	2. **Engine Preparation** a) Install propeller b) Fill oil c) Connect engine controls d) Connect electrical leads e) Put back hoses and fittings
3. **Engine Extraction** a) Mount sling and hoist on engine b) Remove bulkhead bolts c) Disconnect lower engine mounts d) Disconnect top V-brace e) Extract Engine	3. **External Preparation** a) Put back bottom cowling b) Connect actuator c) Put back top cowling d) Connect electric power e) Remove tail stand

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 No larger than 20 inches high X 20 inches long. (No Rollaways) 2. Chain and lock 3. Open-End Wrenches 1/4 x 5/16" 3/8 x 7/16" 1/2 x 9/16" 9/16 x 5/8" 5/8 x 3/4" 11/16 x 13/16" 3/4 x 7/8" 15/16 x 1" 4. Box-End Wrenches 1/4 x 5/16" 3/8 x 7/16" 1/2 x 9/16" 9/16 x 5/8" 11/16 x 13/16" 3/4 x 7/8" 15/16 x 1" 5. Socket Set 3/8" Drive 3/8" Regular 12 pt 7/16" 1/2" Deep 6 pt 9/16" 5/8" 11/16" 3/4" 13/16" 15/8" Plug Ratchet 3" Ext. Case 6" Ext. 7/8" Deep Spark Plug Socket Universal Joint	6. Socket Set 1/4" Drive 5/32" Regular 6 pt 3/16" 7/32" 1/4" 9/32" 5/16" 11/32" 3/8" 7/16" 1/2" 1/4" Deep 6 pt 5/16" 3/8" 7/16" 1/2" Ratchet Spinner Handle Ext. 1 1/2" Ext. 3" Universal Joint 7. Screw Drivers Set of ten - Range of Slotted and Phillips with a stubby of each. 8. Punch Pin Punch 1/16 - 1/8" Center Punch 3/8" Prick Punch 3/8" Line-Up Tools 3/16 x 9 & 5/32 x 7" 9. Allen Wrenches Long 5/64" 3/32" 7/64" 1/8" 9/64" 5/32" 3/16" 7/32" 1/4"

Table 11.4 (continued...)

10. Adjustable Wrenches - 10" 11. Measuring Tape 12 ft. 12. Hammer, Ball Peen 8 oz. 13. Hammer, Plastic Tip 14. Flash Light 2 Cell 15. Pliers, Common 8" 16. Pliers, Diagonal 7" 17. Pliers, Longnose 8" 18. Pliers, Duckbill 19. Pocket Knife 4" 20. Sheet Metal Snips Left Right 21. 10X Magnifying Glass 22. File Set - 8" or larger 1 - Bastard 1 - Round 1 - Half Round 1 - Triangular 23. File Handles 24. File Card 25. 1 - Extension Type Inspector Mirror 26. 1 - Mechanical Finger, 10 - 14 inch 27. 1 - Retrieving Magnet, 10 - 14 inch 28. 1 - Thickness Gage Set .002 - .035 or better	**OPTIONAL TOOLS** 1. Cold Chisels 1/4, 3/8, 1/2, 3/4" 2. Allen Wrenches Short .050" 1/16" 5/64" 3/32" 7/64" 9/64" 3. Adjustable Wrenches - 6" 4. Machinist Square 5. Hacksaw 6. Hacksaw blades 7. Pliers Arc Joint 9" 8. Socket Set 1/2" Drive Socket Regular 12 pt 7/16" 1/2" 9/16" 5/8" 3/4" 11/16" 13/16" 7/8" 15/16" 1" Deep 12 pt 1/2" Ext. 6" 9/16" Ext. 3" 5/8" 3/4" 11/16" 13/16" 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.

Item	Your Ranking 1 to 15	Your Error Score	NASA's Ranking 1 to 15	Team Ranking 1 to 15	Team Error Score
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
Total Error Points	______	______	______	______

Error points are absolute difference between your rank and NASA's (disregarding plus or minus signs)

0 - 25 execellent
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 Rank	Team 1 Rank	Error Points	Team 2 Rank	Error Points	Team 3 Rank	Error Points	Team 4 Rank	Error Points
Box of matches	No Oxygen on moon to sustain flame: worthless	15								
Food concentrate	Efficient means of supplying energy requirements	4								
Fifty feet of nylon rope	Useful in scaling cliffs, tying injured together	6								
Parachute silk	Protection from sun's rays	8								
Solar-powered portable heating units	Not needed unless on dark side	13								
Two .45 caliber pistols	Possible means of self propulsion	11								
One case of dehydrated Pet milk	Bulkier duplication of food concentrate	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	CO2 bottle in military raft may be used for propulsion	9								
Magnetic compass	Magnetic field on moon is not polarized: worthless	14								
Five gallons of water	Replacement for tremendous liquid loss on lighted side	2								
Signal flares	Distress signal when mother ship is sighted	10								
First-aid kit containing injection needles	Needles for vitamins, medicines, etc. Will fit aperture in NASA space suit	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 fedback				
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.

	Strongly Disagree			Neutral			Strongly Agree
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.

	Strongly Disagree			Neutral			Strongly Agree
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 11.1.1 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 General Regulations Aircraft Drawings Ground Handling and Servicing Materials and Corrosion Control Assembly and Rigging Algebra, Geometry, and Trigonometry I	**Fall Semester** Bonded Structures & Welding Utlity & Warning Systems Landing Gear Systems Airframe Inspection Propellers and Components Professional Communications
Spring Semester Basic Aircraft Electricty Wood, Dope, Fabric, and Finishes Sheet Metal Layout and Repair Reciprocating Engine Overhaul Conceptual Physics I	**Spring Semester** Lubricating Systems Ignition Systems Turbine Engine Overhaul Engine Inspection Engine Electrical, Instrument, and Fire Protection Elective
Summer Aircraft Environmental Systems Hydraulics and Pneumatic Systems Aircraft Electric Systems Aircraft Fuel Systems Personal/Interpersonal Psychology	**Summer** Powerplant Fuel Systems Induction Cooling and Exhuast Technology and Culture Elective

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.

TRAINING AND CERTIFICATION IN THE AIRCRAFT MAINTENANCE INDUSTRY
TECHNICIAN RESOURCES FOR THE TWENTY-FIRST CENTURY

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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 singe 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", 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.

<u>Emergency Medical Technicians (EMT) and Paramedics - *(California)*</u>

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 is 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 to 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

Federal Register Part VI, Department of Transportation, Federal Aviation Administration, 14 CFR Parts 65 and 66, Revision of Certification Requirements: Mechanics and Repairmen; Proposed Rule (Notice of Proposed Rule Making: Notice No. 94-27)

Education and Training Standard for Entry Level Avionics (Aviation Electronics) Technicians and Engineering Technologist Programs. Association for Avionics Education Working Document, Nolan Coleman, September 1994.

ARAC - 65 Working Committee Meeting Minutes and attendee notes from meetings conducted 1992, 1993, March 3-10, 1994, May 17-19, 1994, July 6-7, 1994, September 15-17, 1994, November 28-30, 1994.

US Department of Transportation Federal Aviation Administration - Pilot and Aviation Maintenance Technicians for the Twenty-First Century: An Assessment of Availability and Quality. Pilot and Aviation Maintenance Technician Blue Ribbon Panel (Blue Ribbon Panel Report) Initiated by: Deputy Associate Administrator for Regulation and Certification. August 1993

American Sailing Association - Official International Log Book. Copyright 1993 by the American Sailing Association.

American Welding Society Publications as follow:
OC1-G 1992 - Guide to AWS Welding Inspector Qualification and Certification
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 Pant 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

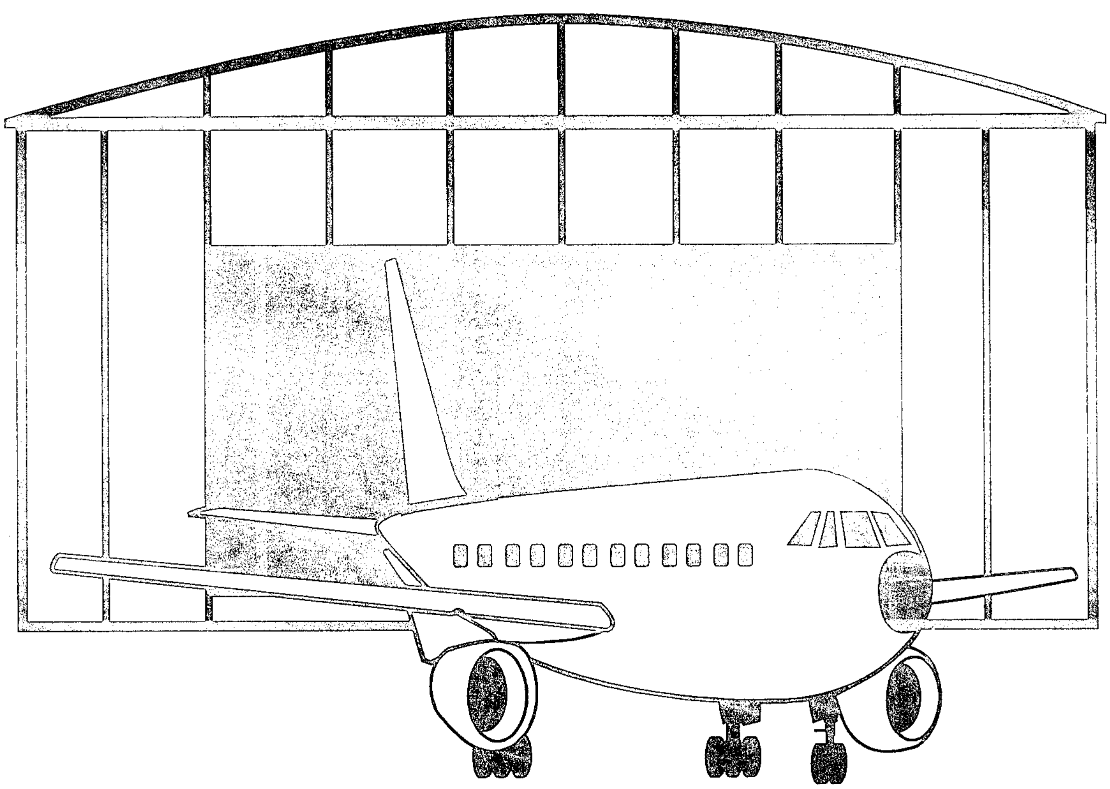
Phase V Report
Appendix

Modified Proceedings
from Meeting 9

Ninth Federal Aviation Administration Meeting on
Human Factors in Aircraft Maintenance and Inspection
Sheraton Inn - Old Town
Albuquerque, New Mexico

Agenda

"HUMAN FACTORS GUIDE FOR AVIATION MAINTENANCE AND INSPECTION"



Monday, November 7, 1994

3:30 p.m. - 4:30 p.m. Registration - No other activities planned

Tuesday, November 8, 1994

7:30 a.m. Continental Breakfast and Registration

9:00 a.m. Welcome and Meeting Objectives
William T. Shepherd, Ph.D.
Office of Aviation Medicine, FAA

9:10 a.m. **Keynote Address** FAA Perspective on Human Factors Research
Ms. Darlene Freeman
Associate Administrator for Aviation Standards, FAA

9:30 a.m. The Human Factors Guide for Aviation Maintenance - Introduction
Michael Maddox, Ph.D.
Sisyphus Associates

10:00 a.m. Break

10:20 a.m. Integrating Human Factors into a Maintenance Program
Colin Drury, Ph.D.
Dept. of Industrial Engineering, University of Buffalo

11:00 a.m. Workplace Safety
James Burnette, Ph.D.
Professional Ergonomist

11:45 a.m. Lunch (in Hotel/Hosted)

1:15 p.m. The "Guide" - Demonstration Exercise
Michael Maddox, Ph.D.

Tuesday, November 8, 1994 cont.

2:00 p.m. The Electronic Guide - A Demonstration
Kiki Widjaja
Galaxy Scientific Corporation

2:40 p.m. Human Factors in Maintenance and Engineering
Mr. Edward Rogan
Human Factors Manager, Engineering Quality & Training Services
British Airways

3:25 p.m. Break

3:45 p.m. Shift Work and Scheduling
Ted Baker, Ph.D.
President, Shift Work Systems Inc.

4:30 p.m. Adjourn

6:30 p.m. Reception

Wednesday, November 9, 1994

7:30 a.m. Continental Breakfast

8:30 a.m. The "Guide" - Exercise Introduction
Michael Maddox, Ph.D.

8:45 a.m. Group Work on the Guide

10:00 a.m. Break

10:20 a.m. Group Reports

Wednesday, November 9, 1994 cont.

11:30 a.m. Human Factors Guide Evaluation/Discussion
Michael Maddox, Ph.D.

11:45 a.m. Lunch (in Hotel/Hosted)

1:00 p.m. Performance Enhancement System (PENS): Update
Charles Layton, Ph.D.
Galaxy Scientific Corporation

1:30 p.m. CD-ROM #2 - A Demonstration
William Johnson, Ph.D.
Galaxy Scientific Corporation

1:50 p.m. Sandia NDI Research Overview
Patrick Walter, Ph.D.
NDI Validation Facility, Sandia Laboratory

2:20 p.m. Closing Comments
William T. Shepherd, Ph.D.
Office of Aviation Medicine, FAA

2:30 p.m. Bus trip to Aging Aircraft NDI Validation Facility

3:00 p.m. NDI Center Tours

4:30 p.m. Transit to Hotel

5:00 p.m. Adjourn

HUMAN FACTORS IN AVIATION MAINTENANCE

Dr. Jon L. Jordan,
Federal Air Surgeon

Aviation safety is dependent on the cooperation of operators, manufacturers, and the government (FAA). That triad is often referred to as "the three legged stool," with each leg representing one of these groups. I'm sure all of you have seen that stool depicted before in other seminars and workshops. The stool must have all three legs to be balanced and safe.

The Office of Aviation Medicine Human Factors in Maintenance Research Program bolsters the association and "the working together attitude" of government, manufacturers, and operators. Aviation Medicine does that through conferences like this one, through extensive publications, by distribution of CD-ROMs containing data and information, and from active participation in meetings worldwide.

Aviation Standards is proud of the 6 year history of the Human Factors in Aviation Maintenance Research program. As Associate Administrator, I appreciate the opportunity to be here, to speak with you, and to see first-hand why these Human Factors Workshops have become so popular.

The historical basis for embarking on this research program can, most likely, be attributed to the 1988 Aloha accident. The accident showed that human performance issues, are critical componets for safety, no different from adherence to Service Bulletins, use of proper inspection procedures, and maintenance training. The stark picture of the wrecked 737 moved Congress to quickly pass legislation that was already under consideration at the time. The Aviation Safety Act of 1988 specified that the Department of Transportation shall conduct safety research, which must attend to "human performance" not only in the cockpit but also in maintenance operations. That legislation was significant. It gave us the financial wherewithal to focus research on the aviation maintenance technician as the central and most critical part of the total aviation maintenance system.

The studies we have performed since 1988 have clearly shown that human performance in maintenance can have a strong impact on safety.

In 1991 the FAA published the National Plan for Aviation Human Factors. That plan, authored by a panel of 50 human factors professionals from industry, academia, and government, also emphasized the need for maintenance research. Recommendations from the National Plan have guided the Aviation Medicine research, but just as importantly, feedback you have given us at these workshops has shaped our program.

While safety is always our foremost concern at FAA, we cannot ignore the current tough economic times in the air transportation industry. We must work with industry to be sure that safety is never compromised by economics. This research program has been successful partly because of its attention to economics and to providing cost-effective research solutions and products that enhance human performance. The results, therefore, are improvements in efficiency while maintaining the high safety standards of our industry.

Six years of research, and now nine workshops, have already created a research legacy. I would like to briefly highlight a bit of history and a few of the milestones that have been achieved in our research program, and the contributions made by you and your colleagues in maintenance and in human factors research.

The first workshop, was held in the Fall of 1988. At that time we were formatting our research plans and establishing key industry liaisons. When I say "we" I mean not just FAA but all of us who have been working on maintenance human factors including you folks from industry, academia and other government agencies. I am really happy to say that "we" have been an effective team that has produced some solid results in the past few years. Please understand that very few of these results would have been achieved without your active participation.

The topic of Human Factors in Maintenance and Inspection was a new one at the time of the first meeting. While some maintenance research had been done in the US Military, Aviation Human Factors research was primarily a study of cockpit and air traffic control issues. Research in maintenance human factors was almost non-existent. A few key problems were identified at that first meeting. The topic that received the most attention was "communication," including just about every imaginable communication form ranging from design of job cards to use of understandable language in manuals, to holding workshops like this one. It was suggested at the first workshop that we have "at least one additional meeting of this kind....". This being the ninth meeting -- you certainly followed that recommendation! Meeting attendance has increased 300%, and would probably be greater if we did not limit the number of workshop participants.

In six years the research team has published over 150 articles and conference papers. For four years now the prestigious Human Factors and Ergonomics Society has dedicated a complete session to the Aviation Medicine Maintenance Human Factors program. We presented again this Fall at their meeting in Nashville. We have supported the International Civil Aviation Organization (ICAO), by lecturing at 9 Regional Seminars on Human Factors in Aviation Maintenance. The research team has participated in a variety of Air Transport Association and FAA meetings as well.

That first meeting produced some other recommendations about maintenance training, or the lack thereof, and FAA has paid attention to those recommendations. First, the Flight Standards Service modified FAR Part 147 dealing with curriculum in Aviation Maintenance Technicians Schools. Also, FAA established a Blue Ribbon Panel on the Shortage of Personnel for Aviation Occupations. Data from this human factors research program played a role in the conclusions and recommendations of the Blue Ribbon Panel. Likewise the panel provided ideas that have become topics of current human factors research. Our current study related to innovative maintenance certification practices is one such research example.

The program has conducted research ranging from basic scientific studies at the University level and at the Civil Aeromedical Institute, to applied development and evaluation in the airlines and schools.

In 1989 the team was introducing such terms as "intelligent tutoring, and expert system trainers" for aviation maintenance. You built, evaluated, and distributed such systems at training schools and with cooperating airlines. Much of the "advanced technology training" language this research team was innovating in 1989 has become common training language used today.

The 1988 meeting also placed importance on maintenance information. Your program has studied information collection, format, storage, retrieval and display. You have worked with airlines to redesign and evaluate job work cards. You have assisted the Flight Standards Service with design, development, and fielding of the pen computer-based **P**erformance **En**hancement **S**ystem, or "PENS" as it's known today. That work is continuing with a look at other types of electronic support systems both for airlines and FAA inspectors.

Your systems' analytic approach to the design and fielding of PENS has set an exemplary standard for new technology design development and implementation. The concept of "human-centered" design and extensive use of rapid prototypes have become very popular with users and with FAA management. Unequivocally, PENS is enhancing the work performance of Aviation Safety Inspectors.

With respect to information technologies, your program was the first to publish and distribute information on CD-ROM. CD-ROMs represent the cutting edge of information technologies. There is no question that they, and similar systems will be critical to the efficiency and quality of future Aviation Maintenance operations, not to mention the performance of our own FAA oversight activities.

While the Aviation Maintenance research program has compiled a good track record, it is you the people in this audience and your colleagues who deserve the credit. This research program is applied -- it is in tune with industry conditions and requirements. We feel that the industry has welcomed our input and has been very candid in reporting many opportunities for improvement.

The list of airlines cooperating with our research program, is pretty impressive. Atlantic Southeast, Continental, Delta, Northwest, US Air, United, Southwest, TWA, British Airways, and Lufthansa have all taken an active role as host sites for data collection or as speakers at these workshops. Numerous others have permitted on-site operations to allow observation and measurement, and provided personnel time and advice. Manufacturers have also been generous with their time and counsel.

The single most important characteristic of the research program is its attention to "real-world" aviation maintenance considerations. Again our thanks to you -- in industry -- for your help.

So much for the past; What about the Future of Maintenance Human Factors Research?

Have all the human performance issues been addressed? Is the system "fixed?" Is the work of this research program over? The answer to all of these is "No." There are still plenty of untouched opportunities to enhance human performance in maintenance.

As current or older technology aircraft continue to fly there must be increasing maintenance diligence and caution to ensure continuing airworthiness. These aircraft will require new maintenance practices and inspection procedures. These procedures will have to capitalize on new technology methods, which will come about through research.

New aircraft will require new skills. Technicians already accustomed to aircraft built-in-test equipment will have to convey this knowledge to their co-workers. Changes in FAR Part 147, and plans for changes to Part 65, already have placed emphasis on new electronics-oriented skills for the aviation maintenance technician. In fact we see this as one of the most important areas for our research. Terms such as "the information super highway" are familiar to all of you. These terms are especially pertinent in aircraft maintenance where it is crucial that proper information is exchanged. The volume of data and information needed to maintain today's air carrier fleet is even now approaching overwhelming proportions and it will become even larger in the future. If technicians are not to spend all of their time looking up or finding repair information, they must have assistance, electronic assistance, in getting the information needed to perform their jobs.

Technical information and the way it's provided are changing. There will be an increasing volume of technical data, available to the technician. Such data must be provided at the aircraft. Otherwise, technicians would spend too much time traveling around obtaining needed information. Portable maintenance access terminals, hand-held computers, and other such technologies promise to change the way technicians work. I think we are at the threshold of some dramatic changes in the way maintenance will be performed in the future. For the air carrier industry to stay safe, competitive and viable there will have to be some big improvements in efficiency of their operations across the board, but particularly in the realm of maintenance. We want our research to be on the forefront of this transition to help provide industry with the knowledge and tools needed to make their operations as safe as possible and also achieve new efficiencies.

The work of human factors researchers, obviously, must position the industry to maximize the performance of humans in the maintenance system. That job is never completed. The good news is that the FAA and Industry recognize the importance of the investment in human performance research and development. We are on the right path and we have participation, and great support from government, industry, operators, and academia. We must continue, on course, with the Aviation Medicine Human Factors in Maintenance research and other related endeavors.

For the next day and a half you'll be discussing a draft version of the Maintenance Human Factors Handbook. This handbook has been in preparation for the last few years and depends quite a bit on results obtained from the research program. We want the handbook to be a useful document for maintenance management. Typical research reports in scholarly journals are not of much use to people who work on the front lines in industry. These people have real world human factors problems they have to deal with every day and we've tried to aim our handbook at those types of problems. We want our handbook to be used, so during this meeting you're going to practice with some hypothetical human factors scenarios that might be found in a maintenance organization and show how the book can be put to good use. I hope the next couple of days will be rewarding and informative.

Again, I appreciate the opportunity to participate in this meeting with you. I look forward to continued involvement with the program.

HUMAN FACTORS IN MAINTENANCE AND ENGINEERING

Mr. Edward Rogan
November 8, 1994

Good afternoon, Ladies and Gentlemen. It really is a pleasure to be here and I would like to thank Bill for inviting me along to address the conference. As Bill said I am the Human Factors Manager Engineering at British Airways which is a fairly unique beast in our industry. The actual position was created in March of this year, so I'm a bit of a new kid on the block. Also from my introduction, you can see that career is all within aircraft engineering and maintenance and I have no psychology or Human Factors background. However, I am fortunate enough to have a Human Factors Consultant working with me who is very supportive in those areas engineers are traditionally very bad, you know, things like spelling, grammar and punctuation to mention but a few. Again from my introduction you would have seen my background has been primarily in what we call Technical Services. I think in the States you would call it Engineering. In that time as a development engineer, I was continually frustrated when involved in a quality lapse investigation to conclude that the cause of the incident was human error. I was therefore very pleased that Human Factors gave us the opportunity to go deeper into these investigations and look for the actual cause of the quality lapse not the consequence. So this was one of the reasons why I was attracted to the subject of Human Factors. I believe the appointment of a Human Factors Manager Engineering shows a lot of commitment to the subject by British Airways, our task now is turning that commitment into action. One thing I should mention is that we believe not one person can have complete responsibility for Human Factors, we see everyone in the organisation as having this responsibility. We see Human Factors in terms of organisational culture where everybody understands and has bought into it as well as owning it, very much like the current Total Quality ethos at BA.

So what am I going to talk about today? I would like to give a brief overview of some of the British Airways Human Factors initiatives with which we are currently involved or planning to do in the future. I would then like to concentrate on one particular initiative called MESH. I will describe what MESH is, where it came from and what it looks like, which means another computer simulation or demonstration. I'll talk a bit about the trial we have ongoing at the moment in British Airways. I'll just share some very early results and I wouldn't like anyone to read too much into these results. Finally, I would like to talk about where we're going with MESH in the future and then take any questions you may have for me.

So what Human Factors initiatives do we have at British Airways Engineering? First and most important of all, we need commitment from the top before we can change the culture of an organisation. It's a top-down approach. We have a Human Factors Steering Group which meets every two months and has done for the last two years and is attended by our General Managers. This high level involvement ripples through the organisation to say that we have commitment here and that is essential for others to see before they buy-in.

As I said before, we see an organisational culture change as a key element in any overall Human Factors programme. To change culture you must first make everyone aware of the subject and change some traditional attitudes towards human error.

We have started to produce a quarterly Human Factors magazine with a circulation of about fifteen hundred, the third issue is due to be published next month. These are distributed to staff in our Hangars, workshops and offices throughout Engineering. The magazine not only allows staff to learn from past mistakes and incidents but also make them more aware of the subject by introducing them to some of Prof. Jim Reason's (University of Manchester) theories on human error. The magazine also serves as a way of communicating the progress of some of the other Human Factors initiatives which I will be talking about later.

I would like to now talk about Human Factors education. We are currently involved with an education programme for managers which we call Emergent Leadership. This intensive programme encourages managers to re-examine many of their values (e.g., blame and fear free culture, openness and honesty, etc.) in order to change traditional attitudes and behaviour which should then lead to, what we would call, a Human Factors culture in the organisation. We are currently looking at a future programme for all grades similar to the CRM courses for flight crew.

On Quality Lapse investigations, we are working with Boeing on a process and database known as MEDA, Maintenance Error Decision Aid. This is basically a process to actually discover the root causes, and take away some of the blame from the individuals involved in quality lapses. The process is currently paper-based, however, the plan is to develop a world-wide computer database of maintenance error involving many airlines . We see this as a worthwhile project with which to be involved.

And finally MESH (Managing Engineering Safety Health), which we refer to as a proactive Human Factors tool as opposed to MEDA, which we term reactive because this is event-driven, i.e., an incident needs to have occurred before you can investigate it. MESH was conceived by Professor Jim Reason and his team from the University of Manchester. The system is an anonymous human factors computer-based evaluation or, if you prefer, a survey of staff's perceptions to Human Factors in their area. It is important to state that MESH is not a reporting tool and it is not intended to replace our current reporting processes. MESH is a proactive safety management tool, the results from which can be used to identify and prioritise the human factors issues in a particular area. It's not, however, just a management tool. With the Total Quality culture that we have at BA Engineering, we see it very much as everyone getting involved and resolving their own local issues. Of course, there will be large, long term issues that affect the whole organisation which cannot be addressed locally. We must therefore also analyse the results from an organisational point of view.

MESH looks at two types of factors, which we term Local and Organisational Factors. Local Factors, or LFs, are those factors that affect staff at the sharp end of the operation. These factors are actually specific to the area and have been selected by staff in that work area; typical examples of LFs are things like Parts Availability, Fatigue, Tools and Equipment, Knowledge, Skills and Experience, etc. Organisational Factors, or OFs, are constant throughout the engineering organisation, and although these affect everyone in the organisation, they are more visible to management. Organisational Factors are therefore rated by management grades; typical examples of OFs are training and selection, people management, provisions of tools and equipment, building and equipment maintenance, etc.

WHAT IS MESH?

"Managing Engineering Safety Health"

- Based on theory conceived by Prof. Jim Reason (Manchester University, England)
- Anonymous Human Factors computer based evaluation
- Proactive survey of staff's perceptions of Human Factors in their workplace
- Results used to identify and prioritise Human Factors issues in the workplace

MESH

- Local and Orginisational Factors
    - Local Factors (LFs):
    - Affect those at the sharp end.
    - Specific to an area and selected by users.
    - Eg., Parts Availablility and Fatigue.
- Organisational Factors (OFs):
    - Affect Everyone, but more visible to management.
    - Standard questions throughout organisation.
    - Eg., Training and Selection and People Management.

I would like to now give a demonstration of the MESH software. Here's a scenario. One week ago, a licensed avionics engineer waited for seven hours for a spare part. The aircraft departed on time, but the installation of the part and the subsequent function tests needed to be done extremely quickly. The licensed aircraft engineer is rostered to do his MESH input today. You can see MESH has been designed to be used in the Windows environment. It is extremely user friendly. Not all of our technicians and aircraft engineers are actually PC literate, so we wanted to make it as simple as possible, this was an important specification for the system. Using the mouse, the licensed aircraft engineer would click on the MESH icon. The first question I'm asked is my Grade. Okay, I'm a Licensed Aircraft Engineer. All the grades in the list are particular to that area, so as I said before MESH is defined and designed for that area. The next question I am asked is my trade - in my case Avionics. The final personal question is what shift am I on - let's say A shift. Again the shifts are all applicable to this one area. I've used it though, I would like some more questions. The next screen also ask several questions but this time they are related to the task. The system first asks you to think of a task in the last week that did not go to plan and which may have caused frustration or put pressure on the individual to complete. It then asks for the Date - last week. ATA chapter - instruments. Airline operator - BA in this case. Source of work - let's say it was an AMS item.

Now, because I have told the system that I am an aircraft engineer, the Local Factors evaluation appears. If I had said that I was a line manager then the Organisational Factors would have appeared. The first factor I am asked to rate is Knowledge, Skills and Experience. But what does this mean to me? By clicking on the example box next to the factor gives typical examples. These examples have been again derived by staff in that area and are therefore normally pertinent to typical tasks performed in that area. In this case Knowledge Skills and Experience wasn't a problem, so I click on No Problem. The next factors Morale, Fatigue, Time of Day, Manuals and Procedures and Tools and Equipment were not a problem in my example, so again I click on No Problem. Parts and Spares - well, this was my problem and by clicking on the example box, the system prompts me to think whether it was a quality, location, availability or delivery problem. In my case it was the time taken for delivery of the part. So for Parts I would rate this as quite a problem. The remaining factors were also not a problem in my case except maybe operational pressure which I will rate as a Nuisance. So the next screen that appears is the Anonymous Comment facility. The initial version of MESH didn't have this. This facility makes it easier to determine the real issues behind the MESH Profiles when these are analysed at a later date. In our case, you would normally put in something like - waited for seven hours for a NAV receiver, Pt No. 123ABC from SPUD stores. That's probably BA speak, but you would try and be specific as you can and the information is then stored in the data base along with all the other comments from that area.

Now, it's important that feedback is given to the user, so we have the facility here that not only shows the Local Factors Profile for the individual's input but also for the whole area over the last month. I can also look at the Organisational Factor Profile for the month. I hope I have shown you how easy and quick the system is to use. There is, however, a Help facility for those who have forgotten how to use the system. The Help screens also give information regarding human error theory, again this has been based Prof. Reason's work.

I am now going to click on the MESH Analysis icon. This tool is used by whoever is responsible for looking at the profiles and identifying the issues behind them. We plan to modify this part of the software over the next few months, however, I will demonstrate the software that we have been using over the last year. The Analysis tool gives us the ability to sort the collected MESH data in order that we may compare different time periods, work areas, shifts, trades etc. We can then use these results for trending purposes. Okay, let me exit the analysis tool and I'd like to now talk about the actual MESH trial at BA Engineering.

MESH is currently installed in five work areas; two hangars, one workshop and two engineering offices. These are very different environments and this is one of the reasons for allowing the local area to define its own requirements for the system; what works in Hangar X probably will not work in Office Y. We have two MESH Champions per work area who train staff in the area on how to use the system. They also analyse MESH data from their area using the MESH analysis tool which I have just demonstrated. Existing computer hardware has been utilised in all these areas. More and more PCs are appearing in the hangars and other areas and therefore there shouldn't be any hardware costs associated with installing MESH. We have a monthly MESH Progress meeting to coordinate the trial, which is attended by all the champions, myself, the human factors consultant and my General Manager.

The local process for managing MESH data is left to the local areas to develop, although, I do give a number of guidelines based on our experience to date; such as target number of MESH inputs per month. How they achieve this is very much up to them, because as I said before, all the environments are different and they know best how their staff need to be encouraged to use the system. For hangar areas, we found it best to go for a twenty percent sample. We would, therefore, ask a random sample of twenty percent of the workforce to enter data once a month for three months, and then they wouldn't have to enter data for another year. Then, there would be another group of staff who would do it for three months, and so it goes on. In areas where there isn't large numbers of staff employed, we normally ask everyone to input once a month in order to achieve a significant sample.

I mentioned before that we don't see this as just a management tool and we actively encourage local TQ working groups to use MESH results in order to resolve Human Factors issues in their area. In some areas, the monthly MESH profiles are on the agenda of existing local TQ forums. MESH profiles make a very good agenda item, identifying and prioritising issues to talk about and, most importantly, resolve. I think it is important that we don't identify hundreds of issues and never get around to resolving any of them. MESH allows us to prioritise our efforts, concentrating on resolving maybe two or three issues identified as contributing to the high bar of the MESH profile. Feedback to MESH users is very, very important in order to motivate staff to use the system. Actions taken and resolutions must regularly fed back and even if you can't take any action, it is important to say why not. If used correctly, MESH should help communication within an area. For example, MESH has identified a deep rooted problem which will take the organisation two years to resolve. By feeding back to staff information on what the organisation is planning to do about the problem and when can influence the attitude of staff and have a positive influence on the MESH profiles. The method of feedback varies according to the area, but is generally given in either newsletters, notice boards or the human factors magazine. We are considering giving feedback electronically, by having another icon in the MESH box saying, for example, MESH Feedback, so that a monthly update on MESH issues can be accessed by staff using the MESH PC. Another important use of MESH Profiles is looking at the effectiveness of past resolutions. Profiles can be used to support business cases to show not only that a problem exists, but also we now have a way of monitoring in the future the effectiveness of the resolution proposed in the business case.

Now, I have stated that MESH is basically a local tool, but obviously there are going to be issues that affect the whole organisation. There are going to be times when Hangar A and Hangar B have the same problems and it would be a waste of their effort if they tried to resolve these individually. Therefore, we use our existing "quality forums" to monitor MESH profiles from an organisational point of view. In the future we hope to combine local profiles so that the highest forum in our organisation, the EQMRB (Engineering Quality Maintenance Review Board), can actually see what each business unit (or department) looks like. We think that such information will be very useful high level decisions.

So, what do we have planned for MESH in the

MESH TRIAL

Local Process

- All users individually trained
    - Monthly MESH Input Roster
    - 20% sample of hangar staff
    - All workshop and office staff
- MESH Results
    - Analysed by Champions in TQ groups
    - Issues identified/prioritized from MESH Profiles and Comments
    - Actions fed back to users - newsletters, noticeboards
    - Past resolutions of issues monitored for effectiveness

future? Well, it's not the best time to give this presentation at this moment because I'm actually in the process of analysing results from the trial over the last six months, and will be presenting my findings to our Human Factors Steering Group next month. As I stated before we are looking at a number of software modifications especially to the Analysis tool.

We are also looking at networking the system, because at the moment we to collect MESH data from each area on disk and combine it on my PC. Obviously, that's not an efficient way of doing it. Also once MEDA (Human Factors Investigation tool) is producing results, I would like to see both systems working together as an integrated Human Factors tool, using proactive and reactive data.

I think that it's clear that we've got to change some of the traditional engineering attitudes to human error. However, I think there is one engineering attitude or tradition that I would like to keep and that is - we are pretty good as a profession at turning theory into practice. I see that as my job, turning Human Factors theory into practical applications. I believe that the Human Factors Guide that you have been working on over the past few years will be useful by giving practical advice on a misunderstood subject and I believe all our efforts will pay dividends in aircraft safety, quality and costs in the future. Thank you.

OVERVIEW OF FAA NDI RESEARCH AT SANDIA LABS

Patrick Walter, PH.D.
November 9, 1994

Has anyone told you what Sandia means? In Spanish, it translates as *watermelon*. The mountain range to the north is the Sandias. The mountain range to the south is the Monsontos, which translates as *apple*. When the sun's setting at the right position, the mountains turn a pinkish hue for about thirty seconds every night. The mountains are full of deer, mountain lions, coyote, and bear.

Just to orient you, Sandia National Labs is a Department of Energy Laboratory. Sandia's history has been one of designing nuclear weapons, doing underground nuclear testing, and maintaining the nuclear weapons stockpile. Actually, we're fairly busy today. One of the things we're doing is helping the Russians dismantle their stockpile of nuclear weapons. There's a segment of the program at our laboratory that works for other government agencies. Sandia's big customer is the Department of Defense. The FAA came to Sandia after Congress passed the 1988 Aviation Safety Act to ask if we would get involved with the inspection portion of their Aging Aircraft Program. We did.

Last week, we hosted a meeting both of the ATA Inspection Network and its NDT Forum with about four hundred people attending, including fifty-one airlines from twenty-seven countries. What I'm going to do today is to go through the same presentation I gave at the forum a week ago today. There are a lot of human factors elements that tie into your programs and other things I think will interest you. I am going to deviate from my previous presentation only in style to point out things that I believe relate to your interests.

Our program's objective is to provide the FAA with a tool for independent and quantitative performance and cost assessments of aircraft structural inspection techniques. If you want to introduce new inspection technologies to airlines today, economics is a big part of the process. I will point where I think we are saving the aviation industry some dollars, but the program's overall goal is to encourage NDI technique development and validation. We have test beds in a hangar that you are going to visit during the tour this afternoon.

I am not going to give you a lot of verbiage; I am going to show you some pictures of our work activities. We were funded in September 1991, and for our first seventeen months we were essentially a facility organization. We acquired a hangar, probably a small hangar by most of your standards. Our hangar has 28,000 square feet. When we got it, the roof was caving in and the floor would not hold a transport aircraft. We leased the hangar, then rehabbed it and acquired test beds. We installed support equipment, scaffolding, and a catwalk so that we could walk along the top of our transport airplane. Since the FAA is responsible for the inspection program under the National Aging Aircraft Program, we worked with them to define some program infrastructure so that research could be focused towards Albuquerque. We wanted essentially to function as the hand-off to the aviation industry, so we defined items such as a validation process and procedures. In February 1993, we opened our facility doors. Soon after, researchers wanted to come and start working on our test beds. People came from industry and from universities with graduate students, so we had to next implement safety procedures.

Researchers were making a lot of samples of flaws typically occurring in aircraft structure. We pooled all the information together and archived it. If FAA researchers were looking for specific flaw samples, we could tell them where samples were available. We formalized an FAA Sample Defect Library which is published and routed as a DOT document. We also developed a database. All experimenters acquire data, and the common result of most advanced inspection techniques is an image. Visual inspection is not about just a flashlight and mirror; in its broadest sense, it can encompass someone looking at an image of some NDT-determined flaw on a screen. When experimenters left our facility, they provided floppy disks containing inspection results. We archived these floppies into a database.

We began our work with reliability experiments. I will subsequently tell you about work we are doing in reliability and then touch on human factors. We integrated economics into our program early on, and an economist works with us. We are initiating a program to assess results of experimentation in our facility to date. Thus far, when an experimenter has come to our facility, it has been a somewhat informal process. We are now developing rigorous protocols and acquiring blind samples we need to fill our Sample Defect Library. The core of any program has to be blind samples; *blind* implies unknown to the experimenters. We also work for the FAA in areas such as information systems and structural activities. We routinely interact with Boeing and Douglas. If you are here from an airline, chances are, I have been to your facility. The lab is going to get formal industry feedback as to results of our structured experiments.

When I make a presentation at one of these meetings, I am typically asked: "Where's the beef?" What I want to do is to show you some things we've completed to date. In November 1992, we got our first test specimen for the Sample Defect Library (Figure A.1). It is Sample 100 and is from a Boeing 737. It's from the same series as the Aloha, which means it has the cold bond joints and that terminating actions have not been performed on it. It's relatively low cycle, 46,000 cycles, 38,000 hours. We acquired it from Miranda, Arizona, and it was flown here for its last flight.

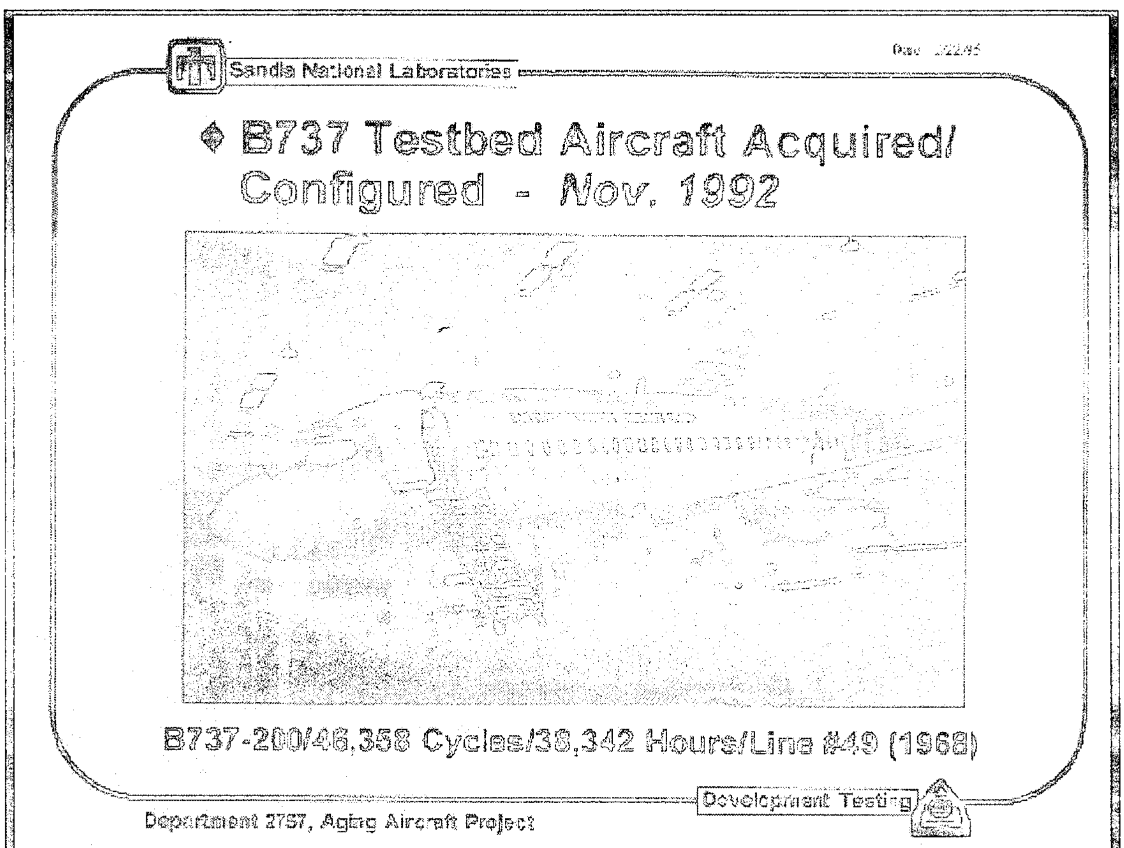


Figure A.1

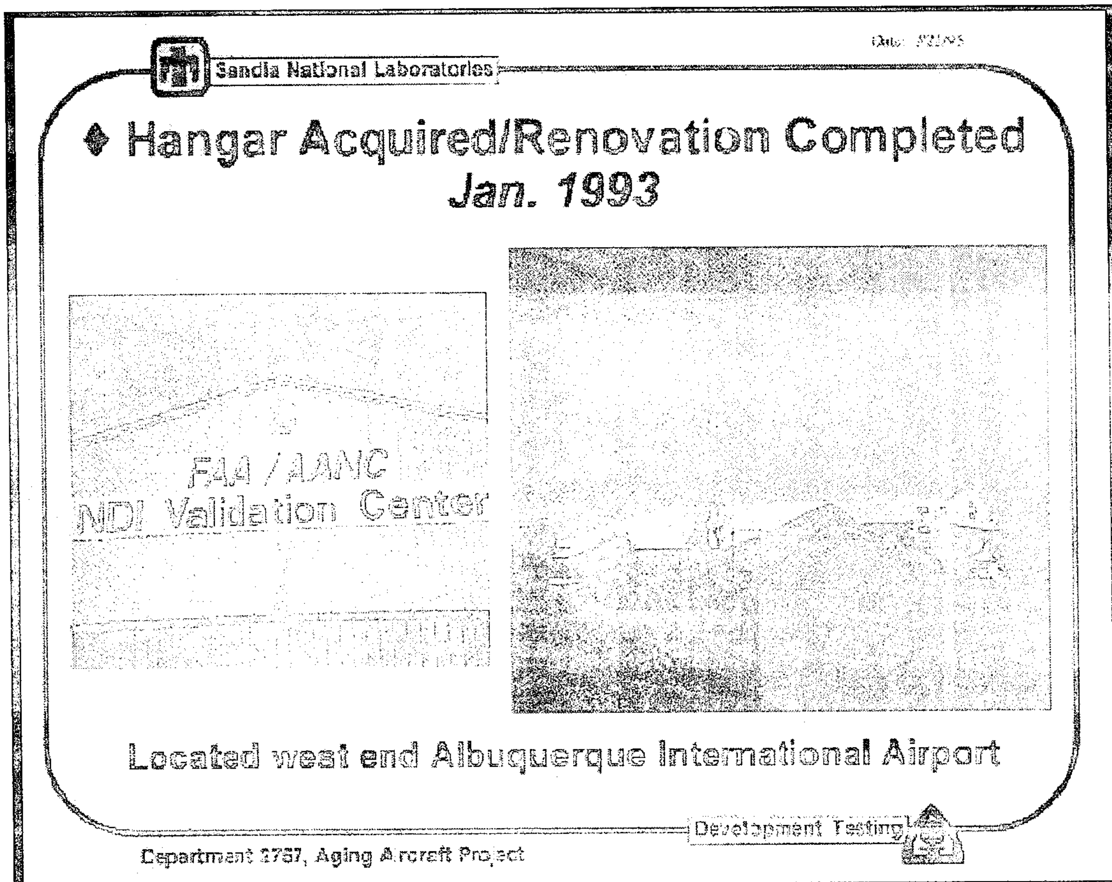


Figure A.2

Since you're going to be visiting our hangar later this afternoon, I can share a little humor (Figure A.2). When we acquired the Boeing airplane, there was still a lot of emotion from the Aloha accident. You can imagine how Boeing appreciated that there was a hangar in the airport for Aging Aircraft, and there was a Boeing airplane. Soon after, we brought in some Douglas DC-9 fuselage sections because there are some known problems around the bulkhead and with cracking around the windows. This also created a balance among manufacturers.

At the 8th FAA/AAM Meeting on Human Factors Issues in Aviation Maintenance last year, Floyd Spencer presented the results of an eddy current reliability experiment to you, so I am going to mention it only briefly (Figure A.3, next page). When you go to the hangar, you are going to see the panels. Floyd is going to be standing by them in case you have any questions. One question that came up after Aloha was, "How well is inspection being done in airline maintenance facilities?" The way this system works is that fatigue modeling of the airframe is performed. Predictive crack row models are used, and assigned inspection intervals must be frequent enough for one to find a crack before it gets to a critical length. On the Aloha plane's lap splices, cracks emanated from under the rivets, and so the question came up, "How well is eddy current lap splice inspection being done in aviation maintenance facilities today?" No one had ever quantified an answer before. The U. S. Air Force, through its 'have cracks, will travel' program, made a round robin in DOD facilities a number of years ago. Typically, Boeing and Douglas develops a predictive probability of detection (POD) model. They then take the ninety percent POD and shift it to fifty percent to include degradation they assume will incur in going from their facility to American Airlines, Tramco, Dalfort, United or whomever. They degrade their curve conservatively to account for differences between their results and those they believe will occur in maintenance facilities.

However, the question is: "How good is industry doing?: We have just completed a $1.5 million experiment for the FAA during which we visited nine maintenance facilities. When we called the facilities,

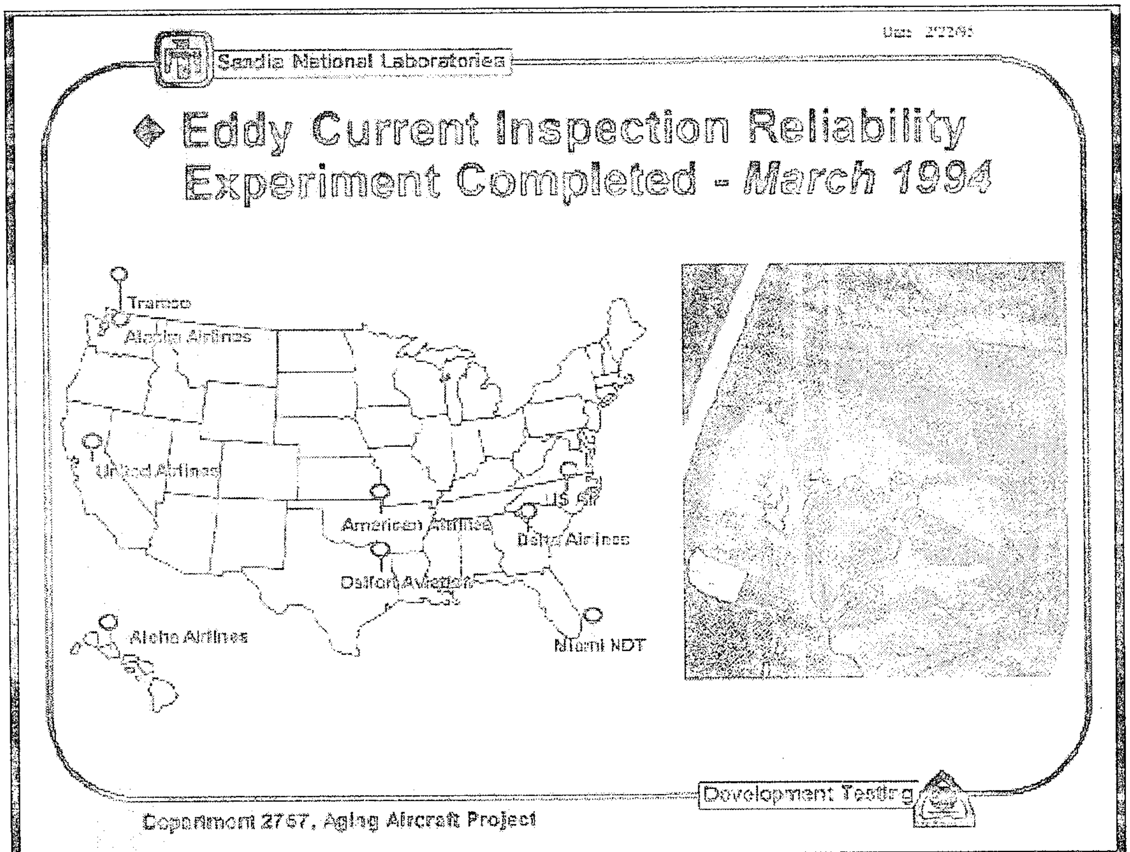


Figure A.3

they really welcomed us. The concept of Sandia Labs being neutral on a three-legged stool–airline, OEM, FAA–appears to have been accepted. People in the field clearly distinguish among us, the FAA, the OEMs, and the airlines. There have been three DOT volumes published supporting this experiment. The last, which is full of human factors information, is at the FAA Tech Center right now awaiting publication.

The experimental parameters in this experiment include a Boeing 737 structure with enough inspection sites to keep an inspector working six to eight hours, day shifts, night shifts, crack angles, painted versus unpainted surfaces, accessibility, etc. We went into a facility, set up, followed developed protocols, and asked the inspector to pull a job card and go to work.

Within the program, we have addressed some structural issues, and we have made some structural assessment on our B-737 airframe. I can tie in some human factors observations. The scanners make an X-Y scan; depending on the sensing technique, they paint an image of an aircraft's structure and its condition at the location being inspected (Figure A.4). Some people came in wearing backpacks and with visual displays. Some would set up their equipment and after ten minutes, it would be on the floor, and their experiment was over. Other people were successful in adapting commercially available equipment to airframe structure. Some of it worked remarkably well. We did time trials, assessed the efficacy of inspection results, etc. Our results are available as a DOT report.

As a byproduct of some of our work, the Coast Guard has asked to join our program. Their HU25A aircraft is a Falcon 20 derivative (Figure A.5, next page). This particular plane did a lot of reconnaissance over Haiti. The Coast Guard, like everybody else, is running short of money, and they cannot afford to maintain their entire fleet. They have park nine of their forty-one planes, so they donated one to us. The plane is made by Dessault. The American representative is Falcon Jet. There's an SSIP (Supplemental Structural Inspection Program) coming on this aircraft, and SSIP's draft indicates that it will cost the Coast Guard a large sum of money. Dessault has met with us, and we think there is real potential for knocking the cost down by integrating some advanced inspection techniques.

As I mentioned, we defined the deliverable from our validation process to be an inspection technique's reliability and cost-effectiveness. When we went around the country to various maintenance facilities with our eddy current inspection experiment, people used their own inspection equipment in-house. For example, when we went to United, we knocked on the door and asked if we could come in and take hangar space and use your inspectors on day shifts, night shifts, etc. We said the we would need forklifts and that it really would be an inconvenience. To their credit, they said that it was okay, that they wanted us there, and that they would give us a week's worth of time, as we needed it. And then we said, "Well, listen,

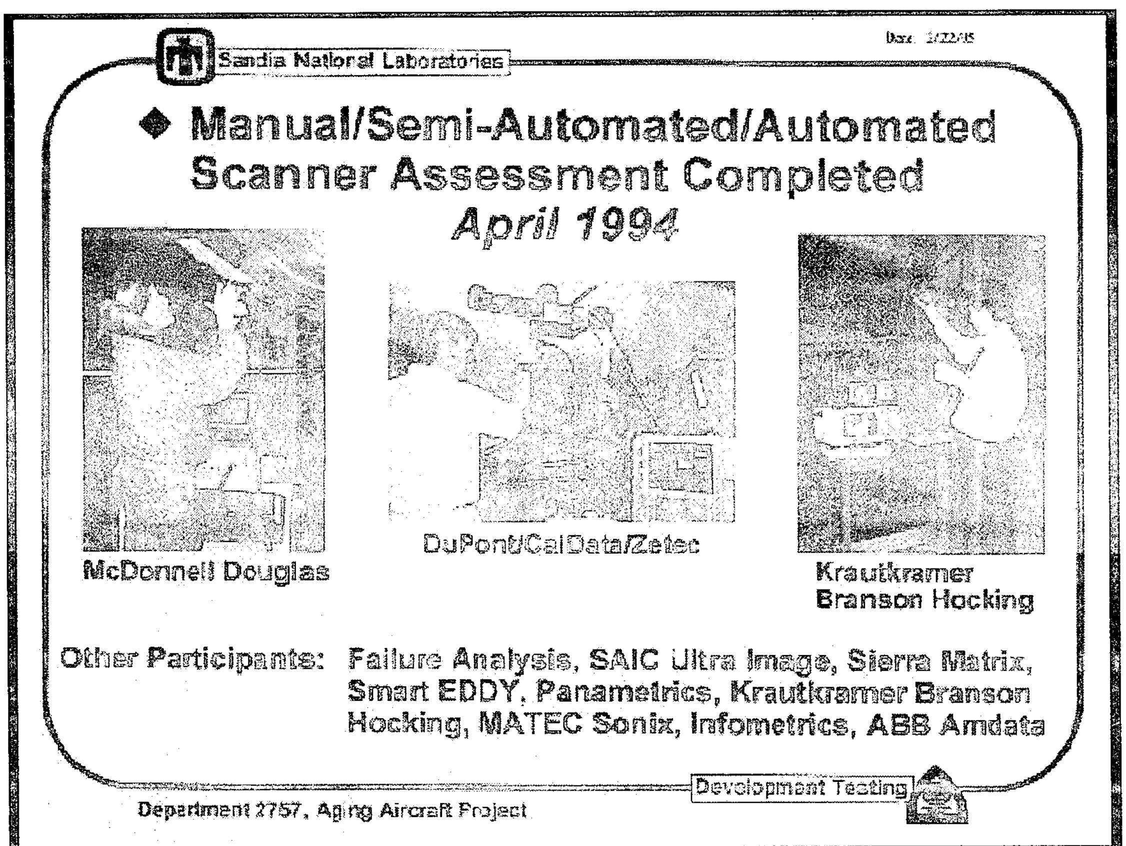


Figure A.4

Figure A.5

let us ask you something else. Here's a new piece of equipment, the MOI. It's designed to do the same type of inspection work as the eddy current equipment, but it works a little differently. Instead of looking at a meter on impedance plane, it gives a visual image of the magnetic field. It might have some advantages in terms of reliability or cost-effectiveness. If you want, we will provide a one-day training program. Then you can try it for another week, but then you will have to repeat the whole experiment, go through this whole process again, so now it is going to take two weeks of your time."

Without exception United and everyone else said, "We want to give you another week's worth of our time." We put together a training program. They repeated the experiments, and we acquired field reliability for this instrument to compare against the existing eddy current technique. We then worked with the Transportation Center at Northwestern University to perform a cost-benefit analysis. We presented it at the ATA meeting, and a report is coming out on this now. The report shows that if you can defer paint stripping, you can come up with some non-trivial economic advantages.

Another question that came up in using the B-737 as a test bed was, "What was its condition?" We transformed our facility into a maintenance facility and performed a heavy check on that airplane. Our procedure was to pick out structural elements of the heavy check that we thought we needed to incorporate into our assessment, to initiate a cost estimate, and to identify the SIDS and supplementation inspections we wanted to incorporate. Then, we contacted some ex-airline employees who comprised a consulting company–ex-United, FedEx, and Continental folks–and brought them in The group included a retired foreman who had thirty years' experience. This company was Tech Ops. We acquired visual inspectors from Albuquerque Airport; they had twenty to twenty-five years' experience and had bounced around in the industry, spending their career working on transport aircraft. Then, we went down to Miami and hired a commercial NDT firm, Miami NDT, who contracts to third-party maintenance facilities and has a large presence in NDT inspections in the Miami area. We brought all these people together, transformed one of our rooms into a maintenance planning room, put together a hundred and thirty-five job cards, and performed what we call a baseline of that airplane. This means that we inspected as well as can be done with the tools present in civil aviation today. This means a lot of visual inspection and a little bit of fairly simple NDT. Tech Ops held the "baton" during the entire process.

Over the past year, fifty groups have worked in the facility. When you go over today, there will be two groups working, and those of you that have been in the inspection industry will be kind of interested. NASA Langley has four people here doing thermal wave imaging by putting heat pulses into airplanes and looking at temperature differences on the surface to detect corrosion and disbonds. They're also doing some ultrasonic work. There is also a commercial firm, Holographics, Inc., who are putting some vibratory inputs into our aircraft. They are able to use laser detection for things like subsurface structural damage, cracked frames, stringers, clips missing, etc. They want to rehearse this technique and ultimately give the FAA and industry the opportunity to assess it.

The FAA, in setting up our center, also funded a number of other locations across the country. They put up two principal centers, the one here in Albuquerque and a university consortium at Iowa State University. The other researchers undertake basic and applied research, and we have the role of technology transfer to industry, i.e., the industry hand-off. Based on industry feedback and FAA review, nine tasks at Iowa State's consortium look like they have the potential to contribute to the aviation industry. We're working with them to make working prototypes that we can demonstrate to industry in our center. Industry then has the opportunity to express its interest and state whether it wants this research to proceed.

I don't know how many of you have heard about widespread fatigue damage, but it is a topic a number of folks are actively discussing right now. It involves small generalized cracking in airframes and has the potential to lower an airframe's capability to be damage-tolerant. I'm not here to debate that issue. TOGO (Technical Oversight Group On Aging Aircraft) an FAA/industry review group, has this issue as one of their concerns. We have been asked to be able better to assess technologies for detecting small cracks in airframes. The typical crack, at least around a rivet, an inspector looks for now is nominally a tenth of an inch, but interest has been expressed in looking at cracks in the forty and fifty mil range. To reach that goal, we need both blind specimens and industry and FAA researchers coming in to have their technologies assessed. Every task we are working on has an industry linkage. Concerning subsurface flaws, i.e., cracking in second and third layer structures, a requirement again exists for blind samples. We are working cooperatively with Boeing and Douglas to design those samples, and Northrop is also a player. Northrop represents the military side, but they also do R&D on improved inspection techniques. It looks like their technology will well lend itself to the civilian side.

As you are aware, to inspect commercial transports, you open them up and go in with a flashlight and a mirror to visually inspect for corrosion. The Air Force is actively pursuing wide area and local nondestructive inspection techniques to detect corrosion. It is tremendous what service lives are predicted for Air Force planes. For example, the KC 135 has to fly until the year 2030. Their cycle time is low, and the fatigue problem is not accentuated if you can prevent corrosion. The Air Force places a lot of emphasis on corrosion detection. We are leveraged with them for cooperation between our FAA program and their Air Force program.

Visual experimentation is another activity at our facility. We have continuous requests to assess how well visual experimentation occurs in industry today. Colin Drury, who spoke earlier, is working on this task with us. On the earlier eddy current reliability experiment that I talked about, we were linked to the OAM through Bob Blanchard over at CAMI. We have tried to keep an involvement with this audience. Concerning the visual experimentation, the ATA (Air Transport Association) has appointed an advisory group, including five airline people. We're planning a program over the next four to six months so that we should have between twenty-four and thirty-six airline inspectors through our facility. We are putting together a standard visual inspector's tool box to normalize the inspectors' tools, and we will complete experimentation on the transport aircraft before moving into the commuter area over the next year. We appreciate the ATA's support.

Halon bottles are another interesting topic. The ATA has asked us to work in this area. American recently estimated a $10 million dollar savings for the industry in the next year if we are successful. Halon bottles in aircraft must be hydro-tested: there is a DOT regulation about it. The bottles are collected and sent to one of three centralized locations. The halon is captured, and the bottles are hydro-tested, reloaded, shipped back to the airline, and reinstalled. We think it's going to be–I don't want to say easy–certainly not difficult to heat the bottle by about forty degrees and to avoid disassembly and shipping by looking at acoustic emissions.

A DC-9 wingbox inspection is another work activity. When I first became involved with this program, I went to an inspection facility and worked with inspectors for several days, crawling through the airplanes. The head of maintenance told me that if I wanted to serve the industry, I needed to assume that the average inspector has a minimum of a ninth-grade education and wants to do a good job. We have to design tools for the inspector. I believe another variable is if one can save someone enough money, some constraints can lessen. In the case of the DC-9, Northwest Airlines expressed interest. In the DC-9's wingbox, there is a potential problem due to stress, corrosion, and cracking. The inspection procedure involves an extensive teardown. If the wingbox T-cap is in good shape, the unit can be reassembled. By working cooperatively with the technique's inventor, Northwestern University, we think we have an ultrasonic technique that can potentially replace a teardown with a forty-hour inspection, a savings of hundreds of hours per airplane. Since Northwest has a fleet of something like a 109 DC-9s, potential savings are in the millions of dollars. We hope soon to have a service bulletin revision from Douglas, who is fully cooperating in this project.

The Air Force uses boron epoxy bonded repairs on a lot of their planes. Boron epoxy has some unique properties. It is directional in nature and has very high stiffness. We were interested in supporting the FAA by doing some work with boron epoxy, and the FAA supported a workshop at our facility. There were concerns about who would be the initial customer. Delta volunteered, and Lockheed expressed interest in issuing a service bulletin concerning the use of boron epoxy as a structural reinforcement. We now have a joint program with Delta and Lockheed on the L-1011. Our parking lot at the hangar has some big slabs of L-1011 we have cut out and hauled in. We are also working cooperatively with the Atlanta ACO. Textron is the boron epoxy supplier, and Warner Robbins AFB is also participating.

Most of the program's focus to date has been on transports. Commuters can certainly benefit from this program, especially since some commuters contain inaccessible structure. We are going to bring a commuter airplane into our hangar in the next six months. By the time we finish the visual inspection on the transport, we will be ready to move to the commuter and use it as a test bed for other activities.

Candidly, when we started this program a few years ago, we thought we had some tools to contribute, but the nature of that contribution was not totally clear. Now, we feel like we are delivering products to the aviation industry. I do not say that out of arrogance, but because the industry is indicating that we are contributing. The FAA is negotiating with us to expand our program and to acquire more access to other areas of Sandia.

We feel we are coordinating well with Douglas and Boeing. As time goes by, we hope to work more with GE and Pratt to place more emphasis on engines in our program. We feel that we work well with individual airlines. We routinely have airline personnel in our facility, and we encourage and appreciate that. What we would like to do is to set up a more structured interface with the ATA and are talking with them about how we might develop an optimal interface. We need to get more involved in commuter issues; our commuter aircraft is coming in. As I told participants at the ATA Forum, we're trying to listen to everybody, and it is a big industry.

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