

# **Meeting 7: Science, Technology, and Management: A Program Review**

## **Proceedings of the Seventh Meeting on Human Factors Issues in Aircraft Maintenance and Inspection**

Report of a Meeting

5 - 6 August, 1992

Atlanta, Georgia

Prepared by:

**Galaxy Scientific Corporation**

Information Division

Atlanta, Georgia

### **FOREWORD**

The Office of Aviation Medicine has now conducted seven workshops on Human Factors in Maintenance and Inspection. Participation began with approximately 30 participants in late 1988 to over 140 registrants at this meeting. The workshops have earned a reputation as a definitive source of reliable information about improving human performance in maintenance. The workshops have continued to provide a reasonable blend of human factors scientific principles with "real-world" maintenance practices. Thus, the meetings have served a broad range of personnel from academics to aviation maintenance technicians and their managers.

This meeting provided a progress report on the research including basic scientific studies, like hangar illumination, to practical applications, like development of a training simulation. Managers from U.S. airlines described their success stories on involving the workforce to define goals and develop processes to improve and measure maintenance productivity. The Department of Defense reported on Air Force automated performance support systems for maintenance technicians.

The meeting permitted a review of progress and helped to set priorities for future research. The Office of Aviation Medicine greatly acknowledges the technical guidance our research team

has received from FAA, DoD, other government agencies, and the aviation industry. Under such guidance and cooperation the research will continue to study and enhance human performance in aviation maintenance and inspection.

*William T. Shepherd, Ph.D.  
Office of Aviation Medicine  
Federal Aviation Administration*

## **EXECUTIVE SUMMARY**

The seventh in a series of two-day workshops on Human Factors in Maintenance and Inspection was held in Atlanta, Georgia in August 1992. The workshop theme was "Science, Technology, and Management". The workshop reviewed the research program of the FAA Office of Aviation Medicine. The majority of the workshop presentations were progress reports from various members of the research team. Industry and Department of Defense personnel also reported on topics related to the workshop theme.

### **Science**

The scientific reports were provided primarily by the University staff members of the research team. These reports covered topics related to human information processing and error classification, human factors of information display, an experimental evaluation of training for visual inspection, a field study of maintenance workplace illumination, and a case study of maintenance work control cards. There was also a presentation on development and evaluation of a real-time decision support system. The National Plan for Aviation Human Factors was also presented. The scientific research has provided sound principles upon which technology has been developed and tested.

### **Technology**

The technology reports described software and hardware systems that have been developed to support aviation maintenance and inspection. These reports covered topics related to the application of advanced technology for job aiding, training, and on-line information systems. The systems described provide support to the U.S. Air Force maintenance technicians, FAA electronics technicians, and airline environmental control maintenance technicians.

### **Management**

Innovations in management have had a positive impact on the effectiveness and efficiency of maintenance. Two airlines reported on programs that increased the participation of aviation maintenance technicians in planning and decision making. The programs and preliminary results

are also reported.

## INTRODUCTION

This report presents the proceedings of the seventh in a series of meetings sponsored by the Federal Aviation Administration (FAA). These meetings address issues of human factors in aviation maintenance and inspection. This two-day meeting, in August 1992, directed attention to "Science, Technology, and Management." This triad was addressed by eighteen speakers from industry, government, the Department of Defense, and academia. Many of the presentations served as a review of the Human Factors in Aviation Maintenance research program.

The Office of Aviation Medicine Human Factors in Aviation Maintenance research program has responded to many of the topics in the National Plan for Aviation Human Factors. The National Plan combines issues of science and technology with a management plan to define approaches to a broad range of human factors issues in aviation. The OAM's responses are presented herein. The responses address topics related to work environments, tools, procedures, training, documentation, and innovative maintenance management practices. The Aviation Medicine research is complimented by presentations from airline, manufacturers and Department of Defense personnel.

## HUMAN FACTORS IN AIRCRAFT MAINTENANCE

*Charles R. Foster*  
*Federal Aviation Administration, Retired*

### 1.0 INTRODUCTION

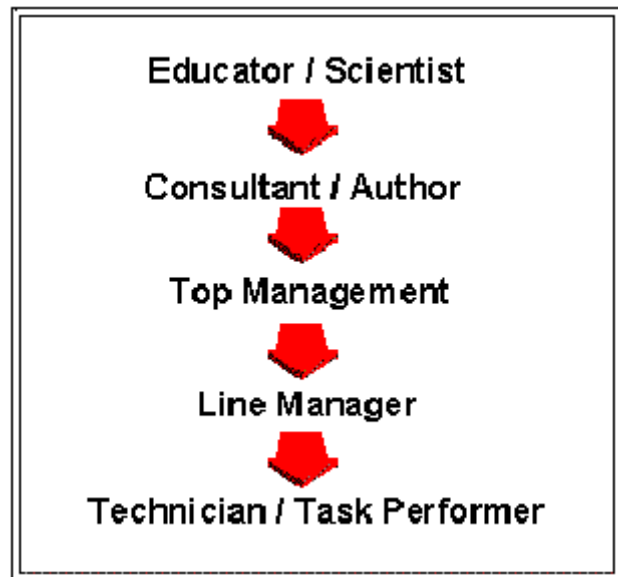
The aviation maintenance technician has a key, and often unheralded, responsibility for the availability of airworthy aircraft for efficient, reliable, and safe operation. Related to the FAA Aging Aircraft Program is the research program mandated by the Aviation Safety Research Act of 1988. This research program, which focuses on the Human Factor in Aircraft Maintenance, is conducted by the Office of Aviation Medicine. A jointly developed National Plan for Aviation Human Factors has identified major areas for research. They include Air Traffic Control, Flight Deck, Flight-Deck Integration, and Maintenance - of which Aircraft Maintenance is the subject of this meeting.

### 2.0 HUMAN FACTORS

We are all aware of the important role of human factors in the field of aviation. I wonder if anyone has ever compared the billions of dollars we spend each year in advancing our technological knowledge, to that spent advancing our understanding of human factors. Better

still what percent of the money spent in applying advanced technology is spent in the application of human factor principles?

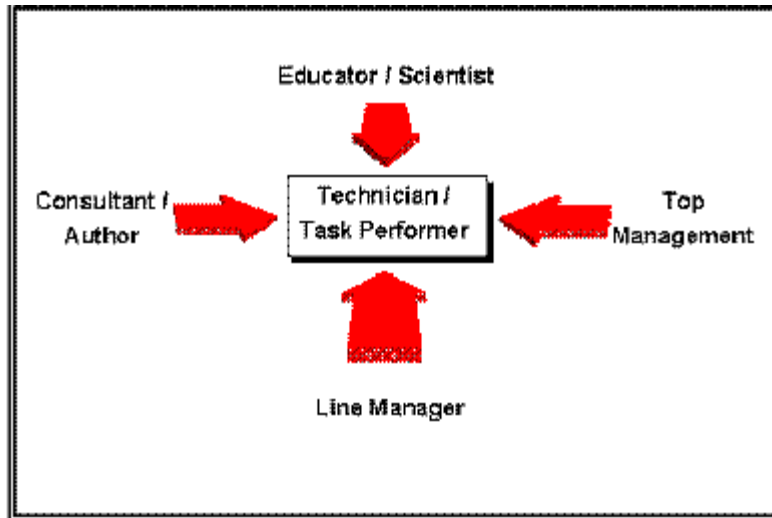
Human factor means many things to many people. The meaning can be related to a person's environment or their position. There is a different perception of the definition, value, and application of human factors in the arenas shown in **Figure 1**.



**Figure 1 Human Factors Arenas**

The Educator/Scientist is engaged in developing a better understanding of the basic principles of human factors and their application. The Consultant/Author is engaged in dissemination and communication of human factor information. Top management makes the decisions relating to the policy and support of human factors and the importance attached thereto. The line manager provides direction and assurance that established policy is implemented. The technician, or performer of the task, is often considered the primary focus for application of human factor principles and the bottom line is to enhance performance at this level.

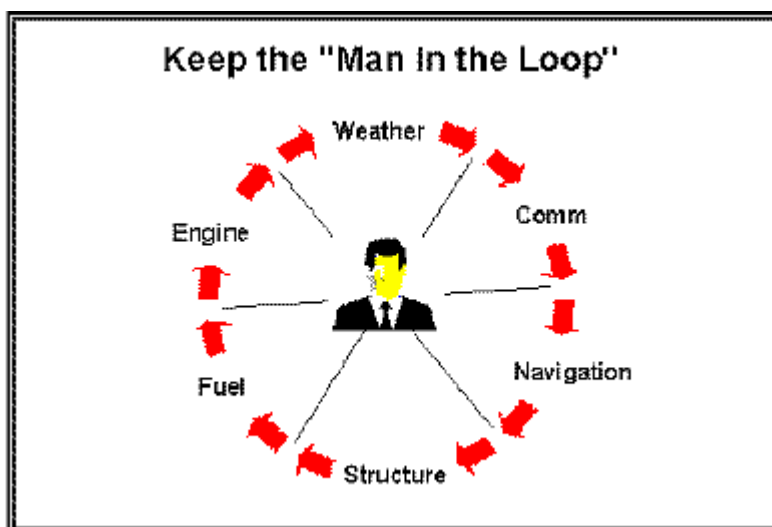
All too often, we concentrate intently on the individual and the immediate task (**Figure 2**). Each group relates to and engages in one-on-one communication with the Technician/Task Performer and endeavors to enhance the influence of human factors through this link. We ignore or do not integrate the other important influences that have a major effect upon the increased efficiency we look for through the application of human factor principles. Two of the other influences I am thinking about are motivation and leadership which tie all of these elements together.



**Figure 2 Concentration on the Task**

Although in each of the above groups there is some interface directly with the worker, the major influence does not come directly but follows a sequential path from the top to the bottom. It is in this chain of command and communications, as shown in **Figure 1**, that the elements of motivation and leadership play their most important role.

Forty years ago, this month in fact, at Wright-Patterson AFB, I was first made aware of the importance of human performance in aircraft operations. The thinking at that time was "KEEP THE MAN IN THE LOOP" (**Figure 3**). At that time, data on aircraft accident investigations assigned pilot error as the cause in some 65% of all accidents - not so different from the percent of human error contribution to aircraft accidents today. Many years later, discussing this with the then FAA Administrator, he stated " if the pilot causes 65% of all accidents, then we should look at how to get the pilot out of the loop to reduce aircraft accidents".



### **Figure 3 The 'Man in the Loop'**

Regardless of the problems or failures with engines, weather, structures, fuel, navigation, or communications - the then listed primary causes of aircraft accidents - man was there as the last or final fail-safe element of safety. Today, when we look at the Aloha and Iowa City accidents we see that after material failures occurred the human element in the system was the fail-safe component of last resort. There is no question that the "pilot in the loop" saved the day.

There appears, however, to be a dichotomy. We say the human is responsible for 65% or greater of the accidents, yet, the human is the most important and last safety element in the system. Just what is and what should be the role of the human in the system?

Aircraft flight operational experience provides an insight as to how the role of the human has changed quite dramatically. The first transoceanic aircraft had a flight deck-crew of five. There was the pilot, copilot, navigator, radio operator, and flight engineer. Today we fly the Boeing 747-400, our largest transport aircraft, with a flight-deck crew of two. Needless to say, there has been considerable human factor effort expended in the reduction of the crew size and the functions performed by crew members. We should build on this experience with crew members and apply the knowledge we have learned to aircraft technicians.

This brings up the question of just how we determine what the role of the human in the aviation maintenance system is. Maybe we should start with the original design and approval of the aircraft. The FAA chairs a Maintenance Review Board (MRB) for each new vehicle. For example, the Boeing 777 MRB is just starting to meet. This is where the manufacturer, airlines, component manufacturers, and the FAA address the maintenance program to be approved by the FAA before the aircraft can be fully certified and operated. The operator of the aircraft must establish a maintenance program for their particular operation and it must be consistent with the Approved Maintenance Manuals resulting from the MRB action. Human factor input should be made at this initial discussion of the maintenance programs for the new aircraft.

Many of the research activities that will be reported on at this workshop are directly related to the human factor issues and principles. Research teams have spent thousands of hours at maintenance sites and in airline training facilities talking with industry experts. They have learned much about airline maintenance and the human factors involved. Also, the airline maintenance partners in this research have a much better understanding of human factors issues. As I reviewed the list of attendees and look at this audience it is clear that you represent a cross-section of the scientists, managers, consultants, and workers I mentioned earlier as the principals involved in this process.

The Office of Aviation Medicine research program develops scientific theory and solid principles as well as practical guidelines for improved aircraft maintenance. The program has facilitated very effective communications among airlines, government, and the scientific community through different vehicles such as this workshop.

The research projects underway are vital to the development and application of improved principles and practices that will enhance our aircraft maintenance programs in numerous ways.

I am very excited about the innovations taking place in the development of computer hardware

and software as it is applied to enhanced concepts of computer-based training. Real world problems such as the design and use of job cards, improved environment for inspections, and similar tasks are being identified and new and more efficient solutions are being found.

Human performance in inspection, critical to the airworthiness of the aircraft in our aviation fleet, is a major area of study.

"Hypermedia" and "hypertext" are new words that identify a new and exciting technology. I am delighted that we will have a hypermedia product distributed at this workshop.

New management philosophies and management styles are included in the research effort and will be covered along with presentations on high technology "Job Aids".

### 3.0 SUMMARY

We are faced with the problem of enhancing human performance and efficiency in the design, manufacture, operation, and maintenance of our aircraft and the system in which they operate. Defining the role where technology can best be utilized, and applying that technology so human performance can be enhanced are both related to the research to be reported at this workshop.

We are all aware that research and development by its basic nature is an investment in the future. This meeting is indicative of the Federal commitment to that investment. The "hands on" applied research direction that Dr. William T. Shepherd has given this program, the airline participation, the technical expertise brought to bear, with the corporate commitment clearly evident, all speak well of the positive impact that can be expected in the future.

It is very obvious that the members of this audience are true research partners and not just the customer of the research results. With the guidance, expertise, and enthusiasm of this multi-disciplinary team, I am confident that you will enhance the efficiency and effectiveness of the key element in the aviation maintenance system - the performance of the aviation maintenance technician.

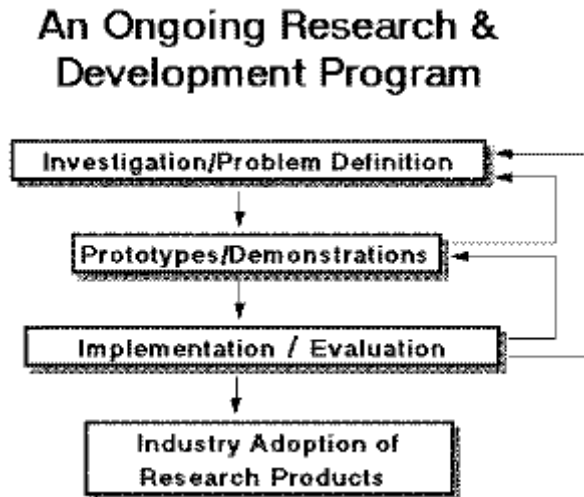
## HUMAN FACTORS IN AVIATION MAINTENANCE: PROGRAM OVERVIEW

*William T. Shepherd, Ph.D.  
Office of Aviation Medicine*

### 1.0 SUMMARY

This report details the second phase of the Office of Aviation Medicine research program on Human Factors in Aviation Maintenance. This on-going research program enhances human performance in the aviation maintenance system to ensure continuing flight safety and operational efficiency. The research program, as reported in the **Phase I report** (Shepherd, Johnson, Drury, Taylor, & Berninger, 1991) was initially planned to have 4 steps, with feedback

mechanisms as shown in **Figure 1**. Phase I focused on preliminary investigation and problem definition of human performance in airline maintenance environments. This report describes Phase II research that centers on the development of hardware and software prototypes with potential to enhance human performance in aircraft maintenance. (In this report the activities subsumed under "inspection" are considered to be part of "aircraft maintenance").



**Figure 1 The Research Program**

The research reported here was conducted by a multi-disciplinary team of scientists and engineers from industry and academia. The research team has worked in very close cooperation with the international aviation industry, mostly with US airlines and aviation manufacturers.

## **1.1 CONTINUING RATIONALE**

**Shepherd et.al** (1991) and **Shepherd & Johnson** (1991), offered an extensive description of the rationale for the research program. These reports described the complexity of the total aviation maintenance system and the role of the human within the system. Increased maintenance workload, caused in part by an increased level of air carrier operations, is one reason to focus on improving aviation maintenance technician (AMT) performance. The challenge of providing continuing air worthiness of the aging fleet while developing knowledge and skills for maintaining new technology aircraft places a burden on airline maintenance organizations.

Phase I research investigated methods for enhancing human performance in aircraft maintenance. There are ample reasons for continuing these investigations. For example, operations will continue to increase. Airlines will fly more hours with the same fleet sizes. Thus, there will be less time for maintenance and greater stress on the fleet. Therefore, enhancing human performance in maintenance continues to be an important priority.

Resources are finite. Airlines, during 1991-92, have not been profitable. Since the **Phase I report** was published, major air carriers like Pan Am have gone out of business. Regional carriers, like Midway Airlines, have also shut down. Other carriers have suffered record



financial losses and face uncertain futures. Airlines recognize the criticality of cost control in every aspect of their operation. However, cost control cannot jeopardize safety. This research program recognizes that the enhancement of human performance in maintenance is critical to the safety and efficiency of air carrier operations.

### 1.1.1 Integration of Human Factors Research

Research to enhance human performance in aircraft maintenance can focus on several dimensions, such as the human, the tools, the work place, work procedures, and management philosophies, as examples. The research must be useful to maintenance practitioners, as well as to the human factors research community. This report, therefore, has practical as well as scientific value.

Each major body of research is summarized below.

## 1.2 ADVANCED TECHNOLOGY TRAINING

Advanced technology training combines artificial intelligence technology with conventional computer- based training. The technology was described extensively in the **Phase I report** (Shepherd, et. at, 1991) and elsewhere (Johnson & Norton, 1991 and Johnson & Norton, in press).

During Phase II this effort converted a Phase I training prototype to a fully operational advanced technology training system for the Boeing 767-300 environmental control system (ECS). The system is simulation-based in that it permits the user to access and operate all panels, controls, and built-in-test equipment of the ECS. **Figure 2** shows the human-computer interface for the ECS.

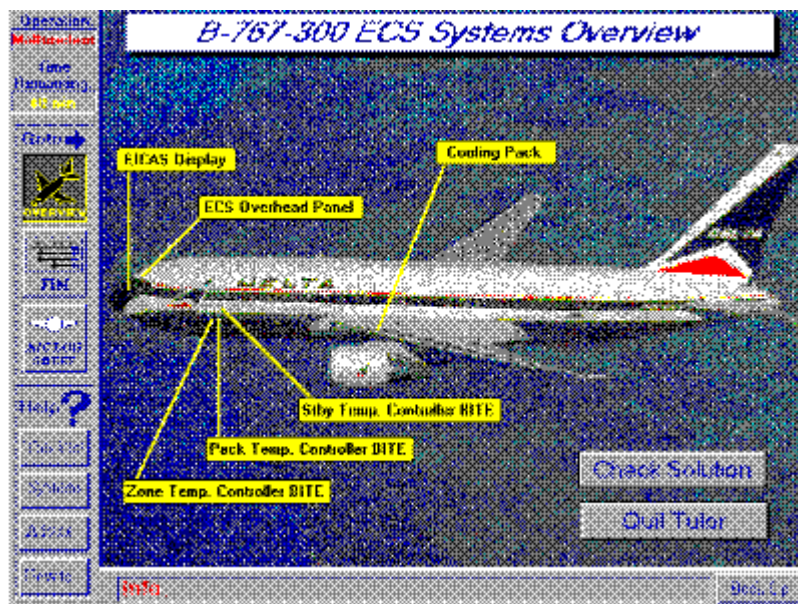


Figure 2 Environmental Control System Tutor

The ECS trainer is unique not only because of the simulation but also because of the robust software used for modeling student performance and providing feedback, explanation, and remediation. These modeling features are described in this conference by **Norton**.

In addition to providing simulation, the ECS Tutor provides on-line access to the training manual for the ECS. The software makes it easy for the student to use the manual during training. This research is preparing for development of an integrated information system which can provide not only training but also real-time job aiding and maintenance documentation. Research related to the concept of on-line documentation is described by **Johnson, Norton, and Utsman** in this conference.

The research used a process of formative evaluation that took place as the training systems underwent many iterations with software engineers and training professionals at Delta Air Lines and at Clayton State College. Continuing research will conduct a substantive training effectiveness evaluation at Delta.

### **1.3 ADVANCED TECHNOLOGY MAINTENANCE JOB AIDS**

This research effort addressed existing approaches to job aiding in maintenance, the drawbacks to such approaches, the prospects for using emerging technologies to develop maintenance job aiding systems, and the impact of emerging technologies on human performance. There were two major themes to the research: 1) many previous attempts at building maintenance job aids consisted of trying to replace human expertise with machine expertise; and, 2) problems with such approaches have led to a reconsideration of the skills and abilities of human operators and ways to capitalize on them.

Accordingly, the research calls for a 'cooperative system' approach to designing such systems; a cooperative system is one in which a human and a computer are actively involved in the problem solving process. Findings present a study which used this approach in developing a job aid. Some of the results of the study that are relevant to designing maintenance job aids and integrated information systems (Johnson & Norton, 1992 a & b) are also presented. Finally, a research and development plan for building a maintenance job aid for aircraft maintenance was created.

#### **1.3.1 Human Performance Implications of Artificial Intelligence Approaches**

The bulk of the job aiding systems encountered in a literature review used artificial intelligence and expert systems techniques. While artificial intelligence techniques can provide a computer with powerful problem solving abilities, job aiding systems which rely solely on such techniques often meet with limited operational success. One of the reasons for such limited success is that the computer is supposed to embody the knowledge and abilities of a human expert, when, in fact, such systems are necessarily incomplete. Because builders of expert systems cannot capture all of the human expert's knowledge about a task, such systems often draw erroneous conclusions. Therefore, the operator must have enough expertise to realize that the computer is wrong; the problem is that the operator will not develop such expertise unless he/she is actively

involved in the problem solving process. However, these problems do not exclude artificial intelligence techniques from use in operational job aids. Rather, the question is one of emphasis: instead of using artificial intelligence techniques as the foundation for a job aid, they should be used in conjunction with other methods of performance aiding (eg., representation aiding).

### 1.3.2 Human Performance with a Cooperative System

A research study (Layton, 1992) which investigated human performance with three forms of a cooperative system provided some interesting insights into how such systems affect human behavior. This system was designed to assist commercial airline pilots and dispatchers in enroute flight planning. (**Figure 3** depicts a portion of the system displays and controls.) This research has provided some interesting insights into the ways in which job aiding tools affect human performance. The software will be described by **Layton** at this meeting.

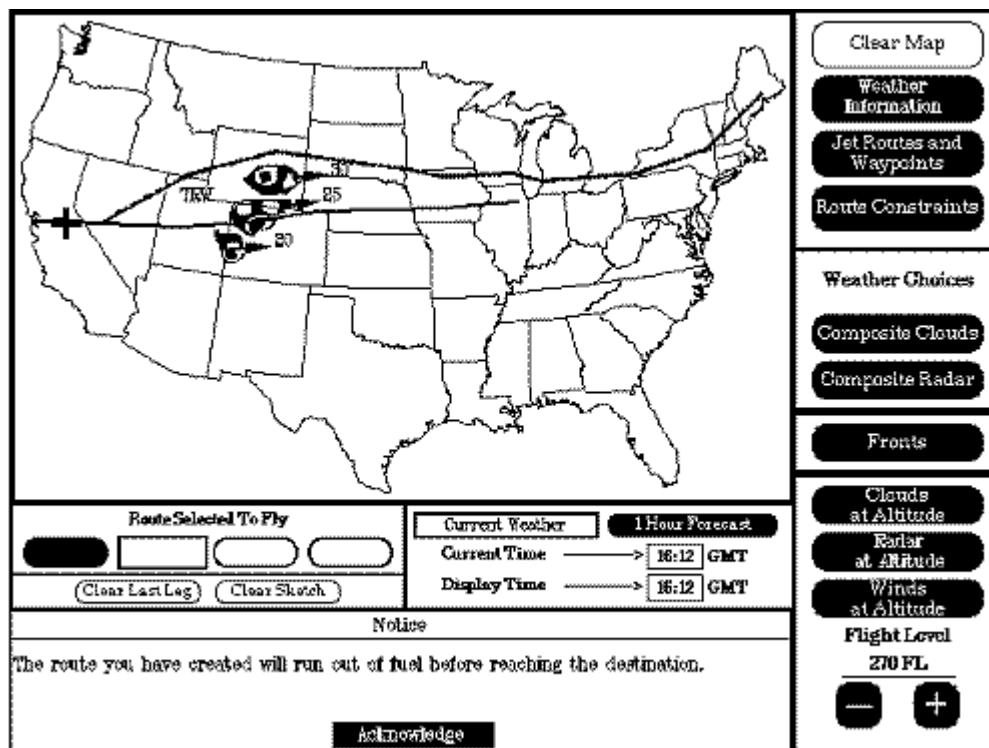


Figure 3 Enroute flight planning cooperative system

### 1.3.3 Research and Development Plan

A three-phase plan for developing a maintenance job aid using cooperative system techniques was developed. Initial interactions with the participating airline suggest that the job aid will assist maintenance technicians in using the Structural Repair Manual (SRM). The SRM specifies methods for repairing structural faults in aircraft and it indicates the regulatory forms that need to be filled out when undertaking such repairs. The SRM supersedes all previous methods and manuals for aircraft structural repair and is becoming a regulatory tool.

Unfortunately, the SRM appears to be cumbersome. The job aid will likely provide technicians with strategies for using the SRM, examples of SRM use, and, possibly, an on-line version of the SRM. Thus, the SRM job aid will provide the three central components of an integrated information system.

## 1.4 DIGITAL DOCUMENTATION

Maintenance personnel are often overwhelmed with the amount of technical documentation necessary to accomplish a given task. The information comes from a variety of sources including company and manufacturer's manuals, and government documents, like advisory circulars or regulations. Currently most maintenance documentation exists as hard copy or microfiche. The task of keeping these databases current is very time consuming and expensive.

This research task, called the Hypermedia Information System, (HIS) shown in **Figure 4**, studies advanced technology software and hardware techniques for information storage and retrieval. The primary products of this research will be techniques for the development and use of large information sources on small portable computer systems.



**Figure 4 Hypermedia Information System**

The term "hypermedia" refers to a combination of text, graphics, animation, audio, and video to convey information. Such information-bases are designed to be accessed easily, usually in a non-linear fashion. This hypermedia research will make it possible for a technician to access a manual for all media and information to complete a job. The research fosters co-development of integrated information systems (Johnson & Norton 1992, a & b) that provide training, job-aiding, and on-line documentation.

A by-product of the research is the development of a hypermedia information system for all technical publications from the Aviation Medicine Human Factors in Aviation Maintenance research program. Ultimately this digital source of information will be published on a CD-ROM

(Compact Disc-Read Only Memory).

One of the first six conferences on aviation maintenance human factors has already been prepared for distribution as a digital document. The seventh conference is the first time that the meeting proceedings will be distributed in digital format at the meeting. The software developed through this research effort has facilitated the timely publication of such digital documentation.

## **1.5 HUMAN RELIABILITY IN AIRCRAFT INSPECTION**

The research related to improving human reliability in aircraft inspection built upon the solid task analytic foundation derived under Phase I. Drury describes two studies at this meeting: one study related to the re-design of workcards for inspection and the other a study of the lighting environment for inspection. Both studies offer practical human factors guidelines applicable to these topics. The research team also describes a plan to consider human-computer interface issues applicable to computer-based maintenance aids.

Building on Phase I research, a series of laboratory experiments evaluated the effects of time pressure on inspection and the improvement of training techniques for visual inspection. The research team will describe a study of the classification of human error in inspection. The classification is particularly valuable in its review of many scientific studies of human error. These studies form the basis for the team's development and presentation of system models of human error in inspection. These models provide the means to understand, predict, report and manage inspection errors.

Inspection is information processing. The chapter reports research on the design of information flow in the inspection environment. The research helps to determine what, when, and how to present information to the inspector. Experimental results are presented regarding optimal methods of information presentation in inspection tasks.

The research team will also describe a joint study of inspection practices in the UK and USA. The comparative study observed that management structures of maintenance and inspection are more closely intermeshed in the UK than in the US. Other differences and rationales are reported.

## **1.6 GUIDELINES FOR HUMAN FACTORS IN MAINTENANCE**

Human Factors principles are often derived in laboratory studies of procedures, equipment, effects of time, temperature, lighting and other variables. Much of the information derived from these studies is reported for scientists, psychologist, and engineers for academic applications. This task is reviewing the human factors literature from a wide variety of parallel and similar areas to aircraft maintenance. Also all of the research results from the Aviation Medicine Aircraft Maintenance Human Factors program will be combined with this information base to produce a Human Factors Guide for Aircraft Maintenance. This guide promises to be useful to airline maintenance management system designers, FAA oversight personnel, and others as they strive to improve human performance in the maintenance system. Parker will show an example chapter from the Human Factors Guide.



## 1.7 CREW RESOURCE MANAGEMENT FOR MAINTENANCE: EVALUATION OF A TRAINING PROGRAM

**Phase I** (Shepherd, et. al. 1991) reported on management-worker communications in the aviation maintenance environment. Phase II research has shifted focus to the effects of crew resource management (CRM) training in an airline maintenance environment. The research has concentrated on communication among maintenance crews. The researcher participated in the evaluation of the effectiveness of a particular airline's CRM training for maintenance personnel and in the post-training performance effects on maintenance managers and technicians.

The CRM course acceptance has been very high. In fact maintenance crews have demonstrated greater acceptance of the CRM principles than have flight crews. The research indicates that relevant attitudes about CRM improved immediately after training. Course attendees have reported that the CRM principles have caused them to be more actively involved in all maintenance decision making.

The CRM evaluation research is valuable in that it has created instruments and criteria to measure post- training maintenance performance. These measures will be helpful to assess the training and cost effectiveness of such human performance enhancement courses.

## 1.8 CONTINUED COMMUNICATION

The seven workshops that have been conducted to date under the Aviation Medicine research program have facilitated communication between researchers and industry. The immediate application of some of the research activities described above will allow the industry to increase reliability and lower costs. The Office of Aviation Medicine intends to continue sponsorship of the workshops throughout the duration of the research program.

The participation and cooperation of the airline industry has been instrumental to the OAM research program. Air carriers, manufacturers, and schools have been extremely cooperative and helpful. This cooperation is gratefully acknowledged.

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## **NATIONAL PLAN FOR AVIATION HUMAN FACTORS: PROGRESS REPORT**

*Phyllis Kayten, Ph.D.  
Deputy Scientific Advisor for Human Factors  
Federal Aviation Administration*

This document is not available for viewing, but is available in the printed proceedings.

## **JOB AIDING RESEARCH IN THE U.S. AIR FORCE**

*Bertram W. Cream  
Chief, Logistics Research Division  
Armstrong Labs*

This document is not available for viewing, but is available in the printed proceedings.

## **A FRAMEWORK FOR HUMAN RELIABILITY IN AIRCRAFT INSPECTION**

*Kara A. Latorella  
and  
Colin G. Drury  
State University of New York at Buffalo  
Department of Industrial Engineering*

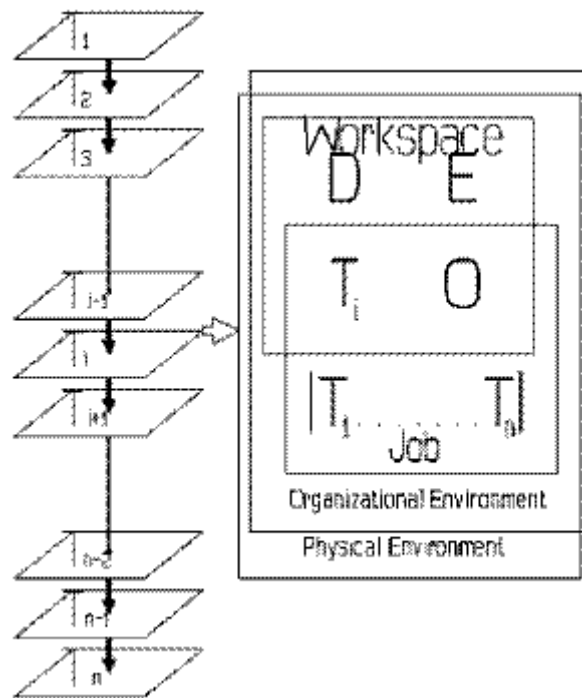
## 1.0 INTRODUCTION

Maintaining civil aircraft air-worthiness requires the reliability of a complex, socio-technic system. This system's reliability is dependent on the reliability of its components (i.e., equipment, inspectors, the physical environment), and on how reliably these components interact. Error is the measurement counterpart of reliability, and most, if not all, errors can be classified at some stages as human errors. This paper uses the data collected from the task analyses of many inspection tasks (Shepherd, et al., 1991), and the human factors literature on human errors to derive an overall framework for error studies in inspection. This framework interprets the hangar-floor observations in terms of current theories of human error causation, and then uses this interpretation to list strategies for reducing or eliminating errors. The ultimate aim of this work is to ensure that data and theories of human error from other fields (e.g., nuclear power, chemical plants, transportation systems) can contribute to reducing the error potential of aviation maintenance and inspection.

The assessment of human error in complex systems is currently undergoing somewhat of a renaissance (Brown and Groeger, 1990). Classification schemes of errors have expanded from the early "omission/commission" classification (Swain and Guttman, 1983 and Meister, 1971) to more behavioral- based classifications (e.g. Norman, 1981; Rasmussen, 1982; Rouse and Rouse, 1983, and Reason, 1990). While error classifications based on task characteristics may provide a convenient descriptive format for errors, error models based on human behavior can define causal mechanisms of errors. Identification of causal mechanisms and catalytic factors is necessary for predicting errors and thereby designing error tolerant systems for preventing errors. The approach taken here is to use a behavioral-based and system- based human error classification scheme to identify, predict, prevent or reduce, and report errors in aircraft inspection and maintenance. Operators may cause errors outright or, more likely, human frailties and characteristics may be "catalytic" factors (Rouse and Rouse, 1983); combining with other component characters to evolve "sneak paths" (Rasmussen, 1982) to error situations.

Whereas previous research in aircraft inspection and maintenance has utilized various empirical human factors techniques, this effort uses a behavioral-based human error modeling approach, housed in a conceptual aircraft inspection and maintenance system model (Figure 1). The system model provides a framework for error classification and therefore, a basis for improved error management. The following section describes the system model of aircraft inspection and maintenance. The final section details how the model can be useful for managing aircraft inspection and maintenance errors.





**Figure 1 System Model**

## 2.0 SYSTEM MODEL FOR HUMAN ERROR IN MAINTENANCE AND INSPECTION

The fact that errors emerge from, and are defined by, the interaction of system characteristics indicates the necessity of a system approach to the description and control of these errors. Such a system view of aircraft inspection and maintenance includes not only the traditional interaction of the operator and task requirements, but also includes operator interactions with equipment, documentation, and other personnel within the constraints imposed by the environment. The system model (Latorella and Drury, 1991) contains four components: operators (personnel), equipment, documentation, and task requirements. These components are subject to constraints of both the physical environment and the social environment. The job component can also be considered as a subset of the organizational environment in which tasks are defined. Similarly, the workspace component is a subset of the physical environment. This conceptual model is two-dimensional (**Figure 1**). The temporal sequence of the individual tasks

**Operators.** Aircraft maintenance and inspection **operators (O)** differ between organizations but belong to the same basic categories: inspectors (perhaps distinguished as either visual or **NDT**), maintenance, utility, lead inspectors, lead maintenance, inspection foremen, maintenance foremen, production foremen, and engineers. In addition to carrying out sequences of activities, personnel serve as informational resources to each other. Communication between personnel can be viewed as an information processing task similar to referencing a document. The

organizational structure of the system imposes constraints on the amount of, format of, and the personnel likely to engage in, collaborative problem-solving communications.

**Equipment.** Both visual and **NDT** inspection use **equipment (E)**. There is specialized equipment for different types of NDT, including: eddy current, ultrasonic, magnetic resonance, X-Ray, and dye penetrant. Visual inspection requires flashlights, mirrors, and rulers. Use of this equipment requires specialized knowledge of its operating principles, and equally specialized knowledge for the interpretation of its output. Interpretation of visual stimuli or NDT output necessarily requires information processing by the operator, but may also require communication with other personnel.

**Documents.** A variety of **documents (D)** is required for inspection and maintenance. Workcards, which may include graphics and references to more comprehensive standards manuals, specify the task to be performed. Forms (shift turnovers, **NRRs**) are used to communicate between personnel and to document procedures, while additional documentation is used for training and retraining purposes. Physical characteristics of forms, documents and graphics affect the legibility of information and therefore, impact the ability to accurately perceive this information. Issues of comprehension are important for understanding the content of documents. Issues of representation are central to ensuring that graphics are appropriate and useful.

**Task.** A **task (Ti)** is defined as the actions and elements of one workcard or similar task order. Task characteristics which have been found to influence inspection include: defect probability, physical characteristics of the defect, the number of serial inspections, feedforward and feedback availability, and whether standards are used (Rodgers, 1983). These aspects of the task necessarily interact with personnel, organizational, job and environmental characteristics. Personal information processing biases may interact with the task structure and present problems such as searching in the wrong area.

**Job.** **Jobs (J)** are defined by the collection of tasks that an individual is expected to perform. However, there are many characteristics of the job which can not be described by the characteristics of its individual tasks. Job factors are derivative of the organizational environment and provide constraints for tasks (e.g., shift durations, work/rest cycles, day/night shifts, job rotation policies). These can further impact personnel physical (e.g., fatigue, eyestrain), affective (e.g., motivation, job satisfaction), and information processing (e.g., attention allocation) characteristics.

**Workspace.** The workspace, a subset of the physical environment, contains the task and the equipment, documentation and personnel required to perform the task. While illumination is an attribute of the physical environment in general, task lighting (such as a flashlight) is an attribute of the workspace. The degree of physical access afforded by the workspace is an important constraint on performance. Both these issues are currently being researched under continued funding on this contract (Drury, et al., 1992, and Gramopadhye, Reynolds and Drury, 1992).

**Physical Environment.** The physical environment is described by several parameters: temperature, noise level and type of noises, lighting level and light characteristics, and electrical and chemical sources. While some of these factors can either enhance or degrade performance, others indicate potentially hazardous conditions. The level and spectral characteristics of

lighting affect the perception of fault indications. Impulse noises interrupt tasks and may result in skipped or unnecessarily repeated procedures. The level and frequency characteristics of noise affect the ability to communicate. Examples of hazardous conditions in the physical environment are exposure to X-rays emitted during X-ray **NDT** and fuel fumes encountered when inspecting the inside of a fuel tank.

**Organizational Environment.** The organizational environment, often ignored in the analyses of maintenance systems, has been shown to be influential in the patterns of work (Taylor, 1990) and therefore, possibly in the patterns of errors. Factors which have been identified as important include: the organization of work groups (or conversely, the isolation of workers), reporting structures, payoff structures associated with task performance, trust within one class of personnel, trust between classes of personnel and levels of personnel, selection/placement strategies, and human-machine function allocation of control and responsibility.

**Using the System Model.** The model in **Figure 1** is useful for depicting the goals of the system and therefore the functions that should be supported. The goals of the system are defined by the requirements of the personnel component in isolation and in conjunction with other system components. The personnel component is primarily described in terms of information processing characteristics and limitations. These characteristics influence the behavior of individuals' and their experience with other system components. The functions associated with the performance of tasks, use of equipment, and communication with co- workers are subject to error and are therefore of primary concern. These functions are then considered within the constraints of environmental factors which may affect error formation and/or propagation. Drury, Prabhu and Gramopadhye (1990) have compiled a generic function description of the maintenance inspection task requirements. The desired outcome for each of the task functions (Drury, 1991) which can be considered as the task's goal can be stated and, following Drury (1991), decomposed into the steps taken to accomplish the desired outcome. Note that the use of equipment has been included within these task descriptions and therefore would not be considered separately.

Errors must be described in the situational context in which they occur in order to identify contributing factors. **Table 1** shows some relevant characteristics of system components with which the individual may interact for the initiate task. Relevant characteristics of each system component can be identified for observed errors. The effect of these factors on performance has been suggested in many studies, however, the manner in which performance is affected, especially by combinations of factors, requires additional empirical investigation.

**Table 1 System Component Influencing Factors**

<b>1.0 Personnel</b> 1.1 Physiological 1.2 Psychological 1.3 Personality <b>2.0 Equipment</b> 2.1 Hand Tools 2.2 Displays 2.3 Control <b>3.0 Documentation</b> 3.1 Type of Information Included 3.2 Style (Intelligibility) 3.3 Formatting (Visual Clarity) 3.4 Content (Usefulness, Appropriateness, Veridical) 3.5 Legibility (Physical) <b>4.0 Task</b> 4.1 Physical Requirements 4.2 Informational Requirements 4.3 Characteristics	<b>5.0 Job</b> 5.1 Physical Factors 5.2 Social and Organizational Factors <b>6.0 Organizational/Social</b> 6.1 Structure 6.2 Goals 6.3 Trust 6.4 Motivational Climate/Incentives 6.5 Function Allocation/Job Design 6.6 Training/Selection Methods <b>7.0 Physical Environment</b> 7.1 Lighting 7.2 Noise 7.3 Temperature/Ventilation 7.4 Chemical Hazards 7.5 Vibration 7.6 Electrical Shock Hazards <b>8.0 Workspace</b> 8.1 Proximity 8.2 Anthropometrical Constraints
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## 3.0 AIRCRAFT INSPECTION AND MAINTENANCE ERROR MANAGEMENT

Error management may be considered as a three part objective. Errors which are evident in an operational system (error phenotypes) must be identified and controlled. Secondly, in order to reduce the likelihood of unanticipated error situations, errors must be predicted and systems must be designed to be error tolerant. Thirdly, error reporting systems must provide error and contextual information in a form which is appropriate as feedback to personnel. Operators may then use this information to adjust their error control and prevention strategies or alter environmental characteristics. This section presents strategies for error control, prevention through error-tolerant systems, and finally the need for a context-sensitive error reporting scheme.

Error phenotypes (Hollnagel, 1989), the specific, observable errors in a system, provide the foundation for error control. Error prevention and the development of design principles for error avoidance rely on genotype identification (Hollnagel, 1989), associated behavioral mechanisms and their interaction with system characteristics (Rasmussen and Vicente, 1989). Here, error phenotypes are obtained empirically and from a failure-mode-and-effects analysis of task and communication models. These phenotypes are considered in light of their ability to be self-correcting and the type of error which they represent. They are further characterized by the relevant aspects of the system components with which they interact. The resulting list of phenotypes, their error correctability and type, and the pertinent situational factors allow designers to recognize these errors and design control mechanisms to mitigate their effects. Rasmussen and Vicente's (1989) methodology is used to identify genotypes associated with each phenotype. This yields mechanisms of error formation within the task context.

### 3.1 ERROR CONTROL AND PREVENTION

Error control strategies can be derived by classifying error phenotypes according to components of the system model (**Figure 1**) and Rasmussen and Vicente's (1989) systemic error mechanisms. This classification framework aids in suggesting intervention strategies appropriate to the error and the system components involved. The system model provides a useful means of classifying observed errors for this purpose and relating them to specific human factors interventions. There are a number of personnel factors of general importance to controlling errors. Personnel interactions are extremely important aspects of the performance of the inspection and maintenance tasks. Equipment should be designed to support task requirements and accommodate human information processing characteristics. The physical and organizational environments should be designed to enhance task performance and ensure the safety and motivation of personnel.

Various intervention strategies have been suggested for the control and prevention of errors. Rouse (1985) identifies five general interventions and proposes a mathematical model for describing optimal resource allocation among the strategies. These five general categories are also reflected in the more detailed listing of intervention strategies proffered by Drury, et al., (1990). These interventions have been tailored to the aircraft inspection context and were classified as either short-term or long-term strategies. The intervention strategies from these two sources are described below in detail in **Table 2** and **Table 3**. **Table 2** presents a compilation of the intervention strategies and design guidelines proposed by Rasmussen and Vicente (1989), Drury, et al., (1990), and Rouse (1985).

**Table 2 Error Management Strategies**

### **SHORT-TERM INTERVENTIONS (Shepherd, et al, 1991)**

1. Worksheet design
2. NDI equipment calibration procedures
3. NDI equipment interface
4. NDI equipment labelling of standards
5. Support stands
6. Area localization aids
7. Stands/areas for NDI equipment
8. Improved lighting
9. Optical enhancement
10. Improved NDI templates
11. Standards available at the workplace
12. Pattern recognition, job aids
13. Improved defect recording
14. Hands-free defect recording
15. Prevention of serial responding (inadvertent signoff)
16. Integrated inspection/repair/buy-back - improve written communication
17. Integrated inspection/repair/buy-back - improve verbal communication

### **LONG-TERM INTERVENTIONS (Shepherd, et al, 1991 and Rouse, 1985)**

18. Identification of errors - error reporting
19. Integrated information systems (feedback, feedforward, directive)
20. Training
21. Selection/placement

### **ERROR REDUCTION RESOURCES (Rouse, 1985) (also notes training and selection)**

22. Equipment design
23. Job design
24. Aiding

### **RASMUSSEN'S "COPING" GUIDELINES (Rasmussen and Vicente, 1989)**

25. Make limits of acceptable performance visible while still reversible.
26. Provide feedback on the effects of actions to cope with time delay.
27. Make latent conditional constraints on actions visible.
28. Make cues for action, put only convenient signs, but also represent the necessary preconditions for their validity (symbolic).
29. Supply operators with tools to make experiments and test hypotheses.
30. Allow monitoring of activities by overview displays.
31. Cues for action should be integrated patterns based on determining attributes (symbolic representations).
32. Support memory with externalization of effective mental models.
33. Present information at level most appropriate for decision making.
34. Present information embedded in a structure that can serve as an externalized mental model.
35. Support memory of items, acts and data which are not integrated into the task.

**Table 3 Error Management Strategies**

Systemic Errors	Levels of Cognitive Control	SYSTEM ELEMENTS							
		Task	Personnel	Job	Workspace	Equipment	Documentation	Physical Environ.	Organiza Environ.
LEARNING	Skill	6,11,12	20		6	6,22,24,25	6,24	25	
	Rule	11,28	20			11,22,24,28	1,2,24,28		
	Knowledge	13,19,28	16,17,18,20	16,17,26,29		13,19,22,24,26,27,29	1,16,19,24		17,18,29
INTERFERENCE	Skill	12,14		23,30		14,24,30	24		
	Rule	11	20	23		3,11,22,24,31	24		
	Knowledge	18,32	16,17,20	15,16,17,23,32		3,19	1,16,19,24,32		15,17,32
LACK OF RESOURCES	Skill					33			
	Rule					33	33,34		
	Knowledge	18,19,34	16,17,20,21	16,17,23,34		34,18,19,22,24,33,34	1,16,19,24,33,34		17
STOCHASTIC VARIANCE	Skill	6,12,14	16,17,20,21,35	23	5,6,7,8	3,5,6,7,9,10,14,22,24,35	6,24	8	
	Rule	11	16,17,20,21,35			11,22,24,35	2,24,35		
	Knowledge		16,17,20,21,35	16,17		4,22,35	16,35		17

Error genotypes, rather than the aforementioned phenotypes, are classified according to the system model, using Rasmussen and Vicente's (1989) systemic error categories and Rasmussen's levels of cognitive control (Skill, Rule, Knowledge). This characterization of error genotypes allows prediction of possible, but so far unanticipated, error phenotypes. Unanticipated errors can be predicted by considering tasks at each level of cognitive control and each error mechanisms' possible perturbation of performance within the context of the specific system components involved. Given an error genotype cell, intervention strategies (which also have been classified by system component, systemic error mechanism, and cognitive control level (**Table 3**) can be identified for its control.

## 3.2 ERROR REPORTING IN AIRCRAFT INSPECTION AND MAINTENANCE

Currently, error reports are primarily used for documenting error situations for administrative purposes; internal or external regulatory agencies. There are many different regulatory mechanisms for reporting errors to the FAA. In addition, the Air Transport Association (ATA) has proposed modifications to those. All of these reporting systems have the following common features:

1. They are event driven. The system only captures data when a difficulty arises or a defect is found.
2. Aircraft type and structure serve as the classification parameters for reporting.
3. Expert judgements of error criticality are used to further classify data and determine its urgency.
4. To some extent in all systems, the feedback of digested data to users is not well-

engineered. Thus, for the end-user level, the data collection effort is largely for naught.

Error reports in maintenance and inspection produced for administrative purposes are typically concerned with establishing accountability for an error and its consequences rather than understanding the causal factors and situational context of the error. This type of information is not appropriate for use as performance feedback to inspectors or maintenance personnel, nor is it helpful information for error tolerant system design. Error reporting schemes are developed from within an organization and therefore vary greatly among organizations. The framework of these error reporting schemes is event driven and developed iteratively, thus additions are made only with the occurrence of a new error situation.

To alleviate the difficulties of inconsistency, and provide an appropriate and useful structure for error data collection, an error reporting scheme should be developed from a general theory of the task and the factors which shape how the task is performed; principally, the behavioral characteristics of the operator, but ideally also organizational environment, job definition, workspace design, and the operators' physical, intellectual and effective characteristics. Effective error categorization systems are not only descriptive but are prescriptive, providing information for specific intervention strategies (i.e. Langan-Fox and Empson, 1985 and Kinney, et al., 1977).

## 4.0 SUMMARY

In the preceding sections a framework has been provided for the classification and control of human error in aircraft inspection. The proposed system model of aircraft inspection and maintenance recognizes the fact that the interaction of the task with the human and the environment is the basis of most human errors. Thus an attempt is made to shift the attention from the task to these interactions. Based on the system model, the S-R-K framework of Rasmussen (1983) and the systemic error categories of Rasmussen and Vicente (1989), a methodology for identifying intervention strategies has been proposed.

As Rasmussen, Duncan, and Leplat (1987) note, it is necessary to shift the focus of analysis from the task to the interaction of the task and the operator for classifying errors. Furthermore, taxonomies of human error must encompass the analysis of not only the task characteristics but also the information processing mechanisms associated with the subtasks. It is apparent that other situational characteristics (i.e., environmental conditions) are also useful for the sensitive classification of errors (Stager and Hameluck, 1990).

Both the taxonomic approach of Drury and Prabhu (1991) and the taxonomy for error management strategies developed here can be used as a basis for formulating error reporting schemes. Upon occurrence, errors can be classified by level of cognitive control, type of systemic error, and by causal or catalytic elements of the system. As previously mentioned, the categories of system elements can be refined as illustrated in **Table 3** to provide a more descriptive error characterization. Identification of these parameters will likely involve detailed investigation of the error situation including extensive operator interviewing. This data store can be analyzed for trends in error sequences, effects of different intervention strategies on error-type



frequency, and for the efficacy of intervention strategies over all types of errors.

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## A FRAMEWORK FOR THE DESIGN OF THE AIRCRAFT INSPECTION INFORMATION ENVIRONMENT

Prasad Prabhu  
and  
Colin G. Drury  
State University of New York at Buffalo  
Department of Industrial Engineering

### 1.0 INTRODUCTION

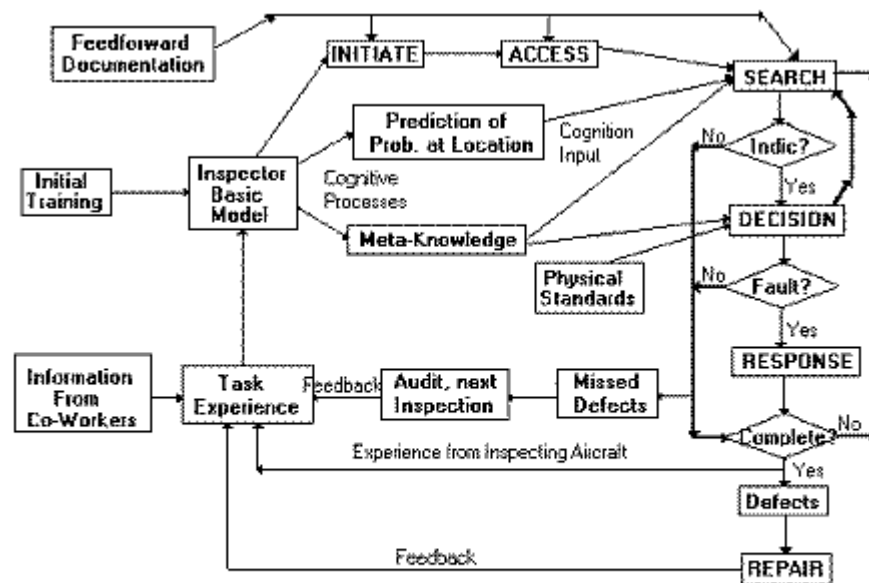
From the extensive series of task analyses performed during site visits to aircraft inspection operations (**Shepherd, et al., 1991**) it became clear that supplying the inspector with appropriate information was a key contribution to inspector reliability. Information reaches the inspector through a variety of pathways, such as documentation, training and job aids which are subject to separate studies within the FAA/OAM program. For example, at this conference there are papers on training (**Drury and Gramopadhye, 1992**) and workcard design (**Patel, Prabhu, and**

**Drury, 1992**). The design issues are similar for any information system:

- What information to present (issues of information sufficiency)
- When to present this information (temporal issues)
- How to present this information (information display issues) so that there are gains to be made by ensuring consistency across information sources. Hence this paper provides a framework for research in all areas of information design. In particular it combines concepts from the human factors knowledge base with specific needs of aircraft inspection. Specifically, it starts with the classification from **Drury (1990)** of aircraft inspection information into two sources: feedforward information and feedback information. Feedforward includes relatively general command information, and aircraft specific feedforward information.

## 2.0 A MODEL OF INFORMATION FLOW IN AIRCRAFT INSPECTION

The proposed model represents both the physical work flow as well as the information flow. It also highlights the cognitive aspects of the inspection task. It is a descriptive model in the sense that it represents the current state of the information flow in commercial aviation aircraft inspection. It is a general representation of how the aircraft inspector gathers, receives and uses information during the task and as such, is not specific to any particular aircraft operator's inspection system.



**Figure 1 Model of Information Flow in Maintenance and Aircraft Inspection**

## **2.1 FEEDFORWARD INFORMATION**

From the model (**Figure 1**), feedforward information to the inspector is seen to come from the following sources:

1. Initial Training
2. Manufacturer/FAA/Airline Operator documents.
3. On-the-Job experience on a particular aircraft.
4. Information gathered from co-workers.
5. Command information in the form of standards.
6. Utilization of understanding about the fault causation mechanism in aircraft.

Initial Training. Taylor (1990) found that the current hangar maintenance organization has a bi-modal experience distribution of 30 plus years and three or fewer years. The inspection group is expected to have a similar distribution with three to five years added to the lower value. No formal inspection training programs were observed or reported at any of the airlines. Typically, inspectors hold an A and P license and have maintenance experience. Most of the training is on the job where an experienced inspector puts the novice through his paces and shows him the various aspects of inspection.

Documentation. There is an immense amount of potentially useful information available both in paper (hard copies) and paperless (computer, microfiches) form. The documents are generated by a triad consisting of the Federal Aviation Administration (FAA), aircraft manufacturers and aircraft operators. There is a complex, multi-dimensional interaction in the flow of data between these three.

Experience on a Specific Aircraft Type. Aircraft at a maintenance facility are serviced over various lengths of time depending on the type of service. The transfer of an aircraft to a different facility (other than the one it normally goes to) is very rare and occurs in case of contingencies or in case of heavy workload at the regular facility. Similarly, movement of personnel between different facilities is very low. Thus, most maintenance and inspection personnel accumulate experience on a particular type of aircraft. The effect of such job specialization on the occasional inspection of a different aircraft type has not been studied. Knowledge about the aircraft is accumulated over a period of time through on-the-job work. Experienced inspectors gradually develop an understanding of the cause-effect relationship of defects and also know what to look for and where.

Information from Co-Workers. Airline inspectors typically work independently and occasionally in teams of two. The frequency of formal meetings amongst inspectors varies from airline to airline. Drury, Prabhu, and Gramopadhye, (1990) during the task analysis of inspection in the airline industry found few formal meetings of mechanics or inspectors despite frequent informal contact among inspectors, and less frequent contact between inspectors and mechanics. The mechanics and inspectors contact each other for buy-back or for the approval of a repair. Mechanics finding faults during scheduled maintenance tell inspectors about this. This contact

for advice/instruction is at times the only formal information exchange between the inspector and the mechanic.

Comparative Standards. There seems to be almost no standards that are accessible to inspectors at the worksite for defects like corrosion, cracks, dished/pouched rivets, wear, component play, etc. A small subset of standards does exist with the manufacturer, FAA, etc. but these have not been organized into a scheme for utilizing comparative standards on the job. The closest inspectors come to a standard in visual inspection is to use adjacent areas to make a comparison, which is not a reliable method (**Drury, 1990**).

Understanding Fault Causation Mechanisms in Aircraft. Inspection of aircraft is largely composed of pure search activities followed by decision-making tasks whose output is of the form of "acceptable/non-acceptable." However, some areas of inspection involve utilization of cues, knowledge of how faults are caused, and knowledge of how the behavior of one particular aircraft component indicates behavior of related components. Examples are: dirt streaks around a rivet on the fuselage indicate a loose rivet, bulging of the paint on the aircraft skin indicates underlying corrosion, scraped paint at the fairings indicates underlying fairings are rubbing, play at the flap vanes points to worn out bearings or tracks, etc. Use of such indirect evidence is a powerful technique to enhance detection and discovery of a fault, particularly where faults are not directly accessible to pure visual/auditory/tactile search.

## 2.2 FEEDBACK INFORMATION

From the model, it is seen that feedback can be either on the job or in training. Use of feedback on the job has been found to reduce the number of false alarms as well as reduce missed defects. Training schemes implementing feedback have been used to improve learning rates, to develop schemes, and for the efficient transfer of training skills to on-the-job performance.

On-The-Job Feedback. There seems to be no systematic and obvious system in place that provides feedback to the inspector. Feedback in search/decision making comes when the inspector talks to a supervisor or a fellow inspector to confirm a borderline case, although this occurs rarely. Also rare is the feedback that could come from the repairer or the buy-back inspector who both have potential data on the fault. There is very little feedback on any defect that the inspector misses. This feedback can only occur through audits and quality control inspections, but these systems do not ensure a consistent feedback to all inspectors on a regular basis.

Feedback in Training. As explained in the earlier section, the feedback in aircraft inspection is relatively scarce and on the occasions that the inspector gets it (e.g., audit) it is delayed in time. Delayed feedback makes learning by practice alone difficult (Woods, 1989). The current state of training is that much emphasis is placed on both the procedural aspects of the task (e.g., how to set up for an X-ray inspection of an aileron), and on the diagnosis of the causes of problems from symptoms (e.g., troubleshooting an elevator control circuit). However, the inspectors we have studied in our task analysis work have been less well trained in the cognitive aspects of visual inspection itself. How do you search an array of rivets -- by columns, by rows, by blocks? How do you judge whether corrosion is severe enough to be reported?

## 3.0 ANALYSIS OF INFORMATION REQUIREMENTS: AN S-R-K BASED APPROACH

For effective use of feedforward and feedback information, the information requirements of human inspection have to be identified for both the expert and novice whose needs may be very different. Thus, we can posit that studying the behavior of the human inspector interacting with the system (while performing the inspection) will help identify possible information support points as well as providing guidance to the type of information (either feedforward or feedback) that is needed at these points. The skill-rule-knowledge based hierarchy of Rasmussen (1983) affords us a robust framework within which this analysis can be carried out, and will be mapped onto both visual inspection and NDI.

### 3.1 VISUAL INSPECTION

Search and decision making form the critical components of visual inspection. The search component can be further decomposed into pre-attentive search, and a detailed search consisting of foveal (pure search or search plus decision making) and extra-foveal processes. Identification of the behaviors associated with each of these subtasks results in a many to many mapping as seen in **Table 1**. These mappings have been identified for an expert inspector. An interesting aspect of these mappings is the existence of relatively few knowledge-based behaviors exhibited by the expert inspector. This seems logical since there is less problem-solving or active reasoning in aircraft inspection and more detection, identification and classification.

**Table 1 Mapping a Visual Inspection Task to Cognitive Behavior for Expert Inspector**

Visual Inspection Processes	Behavior Categories		
	Skill-Based	Rule-Based	Knowledge-Based
Pre-Attentive Search	Scan and Detect		
Foveal (Pure Search)	Fixate and Detect		
Foveal Decision		Identify and Classify	
Extra-Foveal Search	Trigger move to next area		
Decision-Making (Outside of Search)		Move to next area, Rules of what to look for	Reason and Decide

The SRK framework aids understanding of how behavior will be qualitatively modified as the inspector goes from a novice to an expert. Thus, although both the novice and the expert exhibit, say, rule-based behavior, the behavior of the expert will be qualitatively different from the novice (Sanderson and Harwood, 1988). In **Table 2** we have mapped a specific visual inspection

task (inspection of rivets) to the SRK framework, to represent the performance of an expert inspector. We can expect that some of the defects identified at the skill-based and rule-based levels by the expert will be identified at the rule-based and knowledge-based levels by the novice, indicating a rightward shift on **Table 2** corresponding to an upward movement on the SRK hierarchy. Thus, this analysis points to the need for different levels of information support for the expert and the novice inspector. It can also provide guidelines to define training requirements for novice inspectors based on identifying expert inspector behaviors.

**Table 2 Visual Inspection of Rivets: Cognitive Behaviors for Different Defect Types**

- |                          |                           |                                   |
|--------------------------|---------------------------|-----------------------------------|
| <b>1. Missing Rivets</b> | <b>4. Cracks</b>          | <b>7. Pooched or Dished Rivet</b> |
| <b>2. Hole in Skin</b>   | <b>5. Ripples in Skin</b> | <b>8. Wear</b>                    |
| <b>3. Dents</b>          | <b>6. Loose Rivets</b>    | <b>9. Corrosion</b>               |

VISUAL INSPECTION PROCESSES	BEHAVIOR CATEGORIES		
	SKILL-BASED	RULE-BASED	KNOWLEDGE-BASED
PRE-ATTENTIVE SEARCH	* Missing rivet * Hole in skin		
FOVEAL (PURE SEARCH)	* Missing rivet * Hole in skin * Deep dents * Large cracks * Prominent corrosion		
FOVEAL DECISION		* Borderline corrosion * Slight wear * Dished rivets * Ripples in skin * Small cracks	
EXTRA-FOVEAL SEARCH	* Chipped paint in periphery leads to next fixation		
DECISION-MAKING (OUTSIDE OF SEARCH)		* Streaks around rivets trigger inspection for loose rivets * Powdery contamination triggers search for corrosion * Borderline defects	* Defect type not listed * Use of meta-knowledge

**Table 1** and **Table 2** also indicate the large role that skill-based and rule-based behaviors play in visual inspection. The visual search part of visual inspection is seen to be entirely skill and rule-based for the expert inspector (or after training to criteria). The skill-based behavior can be associated to the scanning, fixating and detection activities (see **Table 1**). Since skill-based



performance is essentially unconscious and feedforward controlled, we can conclude that the information aid for this part of the visual search should be something that does not require active conscious use by the inspector. This points to visual environment changes (better lighting, improved contrast), and improving human detection capabilities (increasing visual lobe, increasing target conspicuity). At the same time, this also indicates training as a critical need to attain satisfactory sensory performance.

**Table 1** and **Table 2** also highlight rule-based behavior as a significant mode of visual inspection, resulting in the identification and classification of defects. Thus, finding corrosion, wear, small cracks and similar difficult defects takes place due to rule-based behavior. It is pertinent to note at this point that the work card system used in the aircraft industry to control aircraft maintenance and inspection relies heavily on a linear procedural approach (Drury, 1991; Drury, Prabhu and Gramopadhye, 1990). Rule-based behavior also accounts for search strategy based on past experience and work card instructions. Thus, we reach the conclusion that it is very important to develop procedural knowledge (workcard design), checklists and comparison standards to support this behavior.

Knowledge-based behavior is often a slow and error prone process, besides creating cognitive workload for the human. Often in such circumstances the human will try to minimize cognitive strain by using shortcuts in the reasoning and decision making process, which can lead to suboptimal performance. Thus, we should try to design the system and the information environment to minimize the need to indulge in knowledge-based behavior. Knowledge-based behavior in visual inspection will be more evident in a novice inspector, providing a strong impetus to the design of adequate training programs to bring the novice to expert levels and thus minimize knowledge-based behavior. Once a certain level of expertise is attained the knowledge-based behavior will be needed only in case of unfamiliar work situations. This can, for example, happen if an inspector who normally works only a specific part of the aircraft (e.g., the wing section) is asked to inspect a cargo door. Thus, it becomes important that the workcard (feedforward environment) be designed for usability as well as have the information needed to make a smooth transition to an unfamiliar task. Feedback information from a buddy system, and efficient communication lines with the supervisor also has to be considered. Also important is the development of the knowledge about the spatial and functional aspects of the aircraft, which is partly built through the years of prior experience of the inspector as an aviation mechanic. This is normally five years, but is decreasing due to a shortage of inspectors, with some inspectors having as little as three years of maintenance experience. There are cognitive error implications in too rapid a promotion system.

## 3.2 NON-DESTRUCTIVE INSPECTION

NDI can be decomposed into three broad stages -- calibration, probe movement, and display interpretation (**Table 3**). Skill-based behavior is indulged in while using the probe and is a sensorimotor, feedback-controlled movement. This indicates the need for manual control training on tracking tasks (e.g., circle drawing, tracking) which transfer to this movement control task. Similarly, thought should be given to providing tracing paths (e.g., circles around rivets) which provide adequate feedback information. Templates can be and are being used (although



some inspectors do not like to use them due to handling difficulties) and the improved design and use of such aids should be encouraged. The rule-based behavior component of calibration points to the necessity of developing adequate and well designed checklists along with procedural knowledge for reliable performance. Swain and Weston (1988) point out that during the calibration procedures, powerplant technicians who very often have followed written steps, rely on memory and this increases the probability of omissions. This points to calibration process design that is capable of providing cues to the next step on the display screen as well as detecting wrong inputs by the operator. Where calibration can be rigidly defined, the checklist is the obvious cognitive aid, already extensively used in aviation. Those calibration tasks which have some flexibility must be clearly delineated for separate treatment.

**Table 3 Mapping a NDI Process to Cognitive Behavior for Expert Instructor**

NDI PROCESSES	BEHAVIOR CATEGORIES		
	SKILL-BASED	RULE-BASED	KNOWLEDGE-BASED
CALIBRATION	Probe Movement over test specimen	Calibration Procedures	
PROBE MOVEMENT	Tracking Along Desired Path	Supportive Mode Identifying Boundary Conditions	
DISPLAY INTERPRETATION		Interpreting Familiar Signal	Interpreting Unfamiliar, Unanticipated Signals

Display interpretation forms the critical portion part of NDI and as such can be either rule-based or knowledge-based or both. The information environment should thus support both these behaviors while trying to ensure through system design and training that the need for knowledge-based behavior is minimized. Since rule-based behavior is based on signs which trigger stored patterns which in turn control our choices, Rasmussen and Vicente (1989) suggest that the design of the display should be such as to provide action cues as signs which also have symbolic content, thus supporting both rule and knowledge- based performances. Display screens for NDI that allow comparisons of the current pattern (curve) with known defect curves for comparative decision making should be considered for viability utilizing the human's ability to compare complex patterns presented together. Also, the knowledge-based component found during display interpretation indicates the need to develop feedforward information (training and documentation) to provide technology knowledge, instrument knowledge, and aircraft defect history.

From the discussion above, it is evident that the mapping of the inspection processes to the SRK framework provides useful guidelines for, and a better understanding of, the type of information that has to be provided for aircraft inspection. This has been compiled in **Table 4** where the information categories (feedforward and feedback) identified in the aircraft inspection information model (**Figure 1**) have been assigned to the various inspection subtasks based on the

type of behavior they would logically support.

**Table 4 Information Requirements Identified from Mapping Inspection Processes to SRK Framework for Two Examples**

INSPECTION PROCESSES	INFORMATION ENVIRONMENT	
	FEEDFORWARD	FEEDBACK
1. VISUAL (e.g. Rivet Inspection)		
o Pre-Attentive	o Training	
o Foveal Search	o Training	o Output Feedback
o Foveal Decision	o Training o Procedural Knowledge o Comparison Standards	o Cognitive Feedback o Buddy System
o Extra-Foveal	o Knowledge of Cues	o Feedback of Results
o Decision Making	o Co-Worker Information o Functional System Knowledge o Fault Causation Knowledge o Aircraft History (Defects)	o Communication Links o Buddy System o Cognitive Feedback
2. NDI (e.g. Eddy Current)		
o Calibration	o Checklists, Display Design	
o Probe Movement	o Training on Tracking and Accurate Movement Control	o Probing Aids (Templates or Markings Around Rivets)
o Display Interpretation	o Display Design o Functional System Knowledge o Technical Instrument Knowledge o Aircraft History	o Cognitive Feedback

## 4.0 SUMMARY

In the preceding sections we have presented a general descriptive model of information flow in aircraft inspection, and a methodology (using the S-R-K framework) to identify the information requirements of the aircraft inspector.

We need to develop training procedures for the search and decision making components of aircraft inspection using human factors techniques that include use of cueing, feedback, active training and progressive part training as suggested by **Drury and Gramopadhye (1990)**. It has been found that off-line controlled training successfully transfers to the more complex on-the-job

environment. We see that there is a great deal of research support to indicate that use of feedback in initial training is beneficial. From the airline inspection context this points to the necessity of developing a training methodology that incorporates performance feedback. **Drury and Gramopadhye (1990)** have demonstrated a training scheme for gamma ray inspection of a nozzle guide vane area of a JT9D engine.

We have to understand the problems created by the mismatches between the needs of the inspector (who is looking for information) and the design of the documents (that present data). There is a critical need for usable knowledge, which gets translated to utilized information, on the job. From a document design viewpoint we have to focus on creating usable documents. Information flow design and system design should ensure the availability of documents at the right place at the right time. The demonstration project on workcard design presented elsewhere in this proceedings is an example of applying such document design principles.

It has been known for many years that if comparison standards are available at the work point, more accurate inspection will result. Yet in many cases such standards are not available to the aircraft inspector. If the maximum allowable depth of a wear mark is given as 0.010 inches, there is neither a convenient way to measure this, nor a readily available standard for comparison. Other examples are play in bearings and cable runs, areas of corrosion, or looseness of rivets. All are considered to be "judgement calls" by the inspector, but simple job aids, perhaps as part of the worksheet, or standard inspection tools, would remove a source of uncertainty. Leaving standards to unaided human memory may be expeditious, but it is also unreliable.

There is a necessity to gather the meta knowledge required for this indirect fault indication from experienced inspectors (through knowledge of engineering) who understand the utilization of such cues. There is also a need to identify the mappings between defects and fault causation mechanisms for a wide variety of such defects. The decision-making activity can then be converted to a rule-based, procedural type of task. Rules thus formed can be used in an effective training scheme to help inspectors increase the efficiency of the search and decision making process. This approach can be extended further to form an inspection data base which can be continually revised and updated to reflect the distributed knowledge that exists not only in a specific airline but across all airlines. Such a global knowledge-base would thus receive its input from experienced inspectors all over the aviation industry, thus consistently benefitting all users. It is also conceivable that an expert system could be developed that makes use of such a data base and supports decision-making tasks.

The information components identified in the model are connected to a particular task component using the methodology. In other words, task specific information needs are identified. We have to develop the information components identified by the model so that the cognitive behaviors that are needed for an inspection task are supported.

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## **NEW TECHNOLOGY FOR THE SCHOOLHOUSE AND FLIGHTLINE MAINTENANCE ENVIRONMENTS**

*William B. Johnson, Ph.D.  
Jeffrey E. Norton  
and*

## **1.0 INTRODUCTION**

Resource requirements are high to develop computer-based training or automated job aides. It is also expensive to develop on-line documentation. A cost vs. benefit analysis is more likely to favor new technology when the same system can be used across multiple functions within a technical environment. The integration of training, job aiding, and on-line information is discussed in this paper. The software technologies of intelligent tutoring, expert-system job aiding, and multimedia information storage/retrieval will be described. Example systems are from the aviation and electric power generation maintenance environments.

## **2.0 INTEGRATED INFORMATION**

There are specific knowledge, skills, attitudes and other characteristics necessary for a human to perform a job task. While certain human characteristics necessary for job performance are innate, most are developed through training, experience, or merely by the worker asking "how to do the job." An integrated information system (IIS) (Johnson, et al, 1992) can provide training/experience, real-time job-aiding, and also offer a manual so that the worker can "look-up" the information as appropriate.

Integrated information systems should make the worker oblivious to the differences between training and the work environment. To accomplish this, IISs must share the same sources of knowledge for training and for working. The worker must consider IISs as "information", not as either training or job aiding.

IISs must be developed by a multi-disciplinary team comprised of researchers with experience in training, job aiding, and information retrieval. Therefore IIS design and development must involve such disciplines as training, industrial/systems engineering, human factors, logistics, information retrieval, and appropriate subject matter expertise.

### **2.1 COST JUSTIFICATION**

Multiple use of information helps to amortize the information development and maintenance costs. The Air Transport Association (ATA) Maintenance Training Committee has recognized this fact. Currently each airline creates a "Training Manual" from the manufacturers' "Description and Operation Manual." ATA insists that the major manufacturers supply an "Information Manual" that will fulfill training and operation requirements. The manufacturers are preparing such documentation in digital and hardcopy format.

The fault trees included in the manufacturers' Fault Isolation Manuals (FIMs) show the kind of rule-based information that can be used for real-time job aiding and for training. Using the FIMs on-line, for training and for aiding, ensures that technicians are familiar with the

procedures and with the computer. Thus, when the information is needed, under the time pressure of the job, the technician will know how to access information quickly.

Another IIS cost savings can be found in how personnel are used. The IIS technology can multiply the potential of the technician. Generalists can access the information formerly known only to the specialist. Also, less experienced personnel will have access to job aids, thus increasing their capability.

### 3.0 HYPERMEDIA: PROVIDING CONTINUITY BETWEEN TRAINING AND JOB AIDING

Whether on the job or in the training environment, the aviation maintenance technician typically requires an assortment of documentation: fault isolation manuals, description and operation manuals, maintenance manuals, parts lists, etc. Frequently, the mechanic must jump from one manual to the next, folding and unfolding schematics along the way. Hypermedia information systems can integrate all of these information sources into a seamless document.

Hypermedia systems combine text, graphics, audio, and video into the same system. The technician can electronically jump from manual to manual, avoiding the cumbersome task of marking previous locations in each document. With the press of a button, the technician can see schematics or line drawings. Hypermedia systems also provide various ways to access information. The technician may access a document from an index or table of contents, as well as via a direct link from another document. Section 3.2 provides an example of a hypermedia system with many of these characteristics.

Hypermedia provides a critical link between training and job aiding. A shared hypermedia information source provides continuity for the students as they move from the classroom to the flightline.

### 4.0 EXAMPLES OF INTEGRATED INFORMATION

Advances in hardware and software technology have enabled developers to combine training, aiding, and information retrieval technology in the same system. **Table 1** shows projects that strive to integrate these technologies. A description of each of these systems follows. While the examples are specific to selected domains, the technology approaches are generic and broadly applicable to any training, aiding, or information system.

**Table 1. Integrated Information Systems in Development**

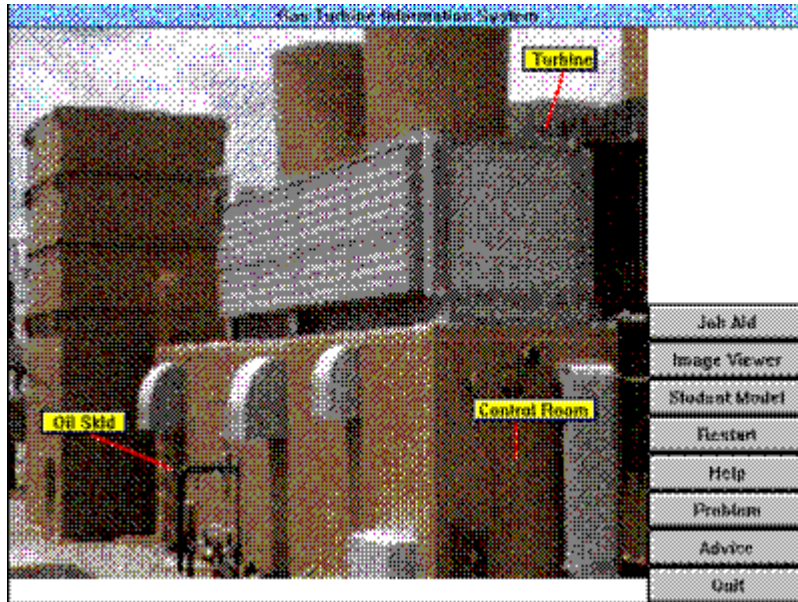
<b>System Name</b>	<b>User</b>	<b>Type of Information</b>	<b>Sponsor</b>
Gas Turbine Information Systems	Electric Plant Technicians	Manuals, Training Simulation, Expert System Job Aid	Electric Power Research Institute
Aviation Human Factors Publications	Engineers, Scientists	FAA Human Factors Publications, System Training, Hypermedia, Information Sources	FAA Office of Aviation Medicine
Environmental Control Simulation	Aircraft Technicians	Intelligent Simulation, Diagnostics Advice, Technical Documentation	FAA Office of Aviation Medicine
Radar Simulation	Airway Facilities Technicians	Intelligent Simulation, Diagnostics Advice, Technical Documentation	FAA Airways Facilities
Automatic Valve Simulation	Nuclear Power Plant Technicians	Intelligent Simulation, Diagnostic Advice, Technical Documentation	Electric Power Research Institute (Nuclear)

## 4.1 GAS TURBINE INFORMATION SYSTEM

The Gas Turbine Generation Division of the Electric Power Research Institute (EPRI) created a robust expert system job aid from 1988-91 (Bloom, 1989). The system provided real-time job aiding for troubleshooting gas turbines during start-up. Unfortunately, the technicians did not train with this job aid. Thus, in stressful emergency situations they did not have time to learn how to use the job aid. Therefore, even though the job aid contained useful knowledge, the technicians rarely used the system.

The Gas Turbine Information System (GTIS) redesigns the original job aid to provide training, aiding, and on-line documentation. **Figure 1** shows a screen from the GTIS. The system operates on a dual 80386 processor. One of the processors is dedicated to delivery of digital video interactive (DVI) information. The DVI is used mostly to deliver training information about general gas turbine principles and other engine-specific information. The second processor delivers the simulation, tutoring, job aiding, and the technical manual.





**Figure 1 GTIS Student Interface**

GTIS permits the user to simulate operation of the gas turbine for diagnostic training. The simulation is "intelligent" in that it creates a model of the users actions as needed. Since the users become familiar with the system during training, it is very natural for them to switch the system to a real-time job aid when needed for plant troubleshooting.

GTIS research and development addresses on-line documentation. When completed, the system will contain a complete set of technical manuals with a hypermedia interface.

## **4.2 AVIATION HUMAN FACTORS PUBLICATION**

The Federal Aviation Administration, Office of Aviation Medicine (OAM), is developing a hypermedia information system for all documents published in the three-year history of the program. **Figure 2** shows a screen from that information system. The hypermedia system contains links to figures, tables, photographs, and other documents. The OAM hypermedia information research has been instrumental in software design for other integrated information systems being developed at Galaxy Scientific Corporation. At the end of the project, this complete hypermedia, research system will be distributed on a CD-ROM. The project has resulted in specifications for delivery of text and graphical information and the creation of the hypermedia display and linking system.



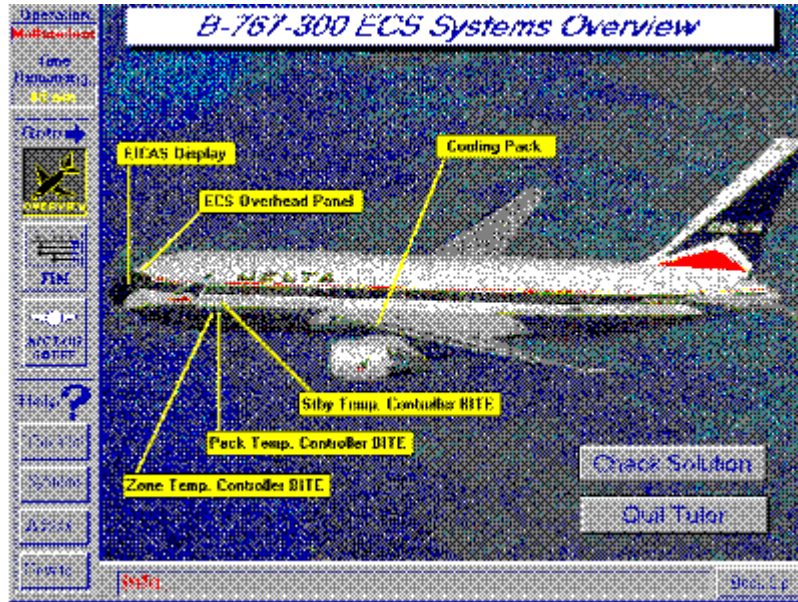


Figure 2 FAA Hypermedia System

Even though the current effort concentrates on the integration of research papers, the hypermedia system has also been used to access aircraft maintenance documents. The system is also being used to distribute 4 on-line papers, including this one, at the 1992 Annual Meeting of the Human Factors Society.

### 4.3 ENVIRONMENTAL CONTROL SIMULATION

The environmental control simulation (ECS), also developed for the Office of Aviation Medicine, demonstrates intelligent tutoring systems and, more importantly, intelligent simulation (Johnson, 1990). The ECS models the Boeing 767 air conditioning system. From the main menu, shown in **Figure 3**, the user can access all instrumentation and hardware available in the aircraft.



**Figure 3 ECS Main Screen**

Applying intelligent tutoring system design (Polson & Richardson, 1989, Massey, et al, 1988) to a simulation environment has resulted in an intelligent simulation. The system observes user interaction with the simulation to provide appropriate feedback and advice. As shown in **Figure 4**, the system also permits the user to access the fault isolation manuals from the computer. The ECS has integrated training and information system functionality, but has not yet attempted the transition to job aiding. This transition can be accomplished with relative ease due to the software design of the current system. As previously discussed, this aircraft-specific example is generalizable to many maintenance training applications.

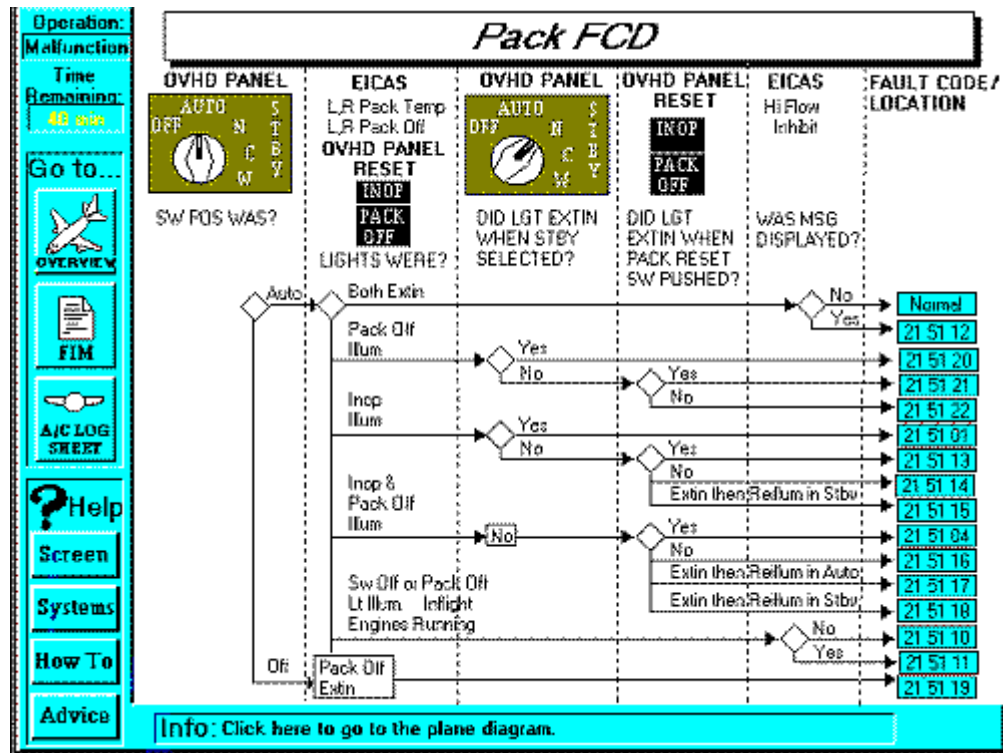


Figure 4 ECS Fault Isolation Manual

## 4.4 MICROCOMPUTER INTELLIGENCE FOR TECHNICAL TRAINING (MITT)

Microcomputer Intelligence for Technical Training (MITT) has been described extensively elsewhere (Wiederholt, et al. (1992), Johnson, et al. (1988)). The MITT tutor design and the MITT Writer authoring system, sponsored by the US Air Force Armstrong Laboratory, has resulted in the development of numerous intelligent tutors for technical training. The tutors described in the following two sections are advanced technology derivatives of MITT.

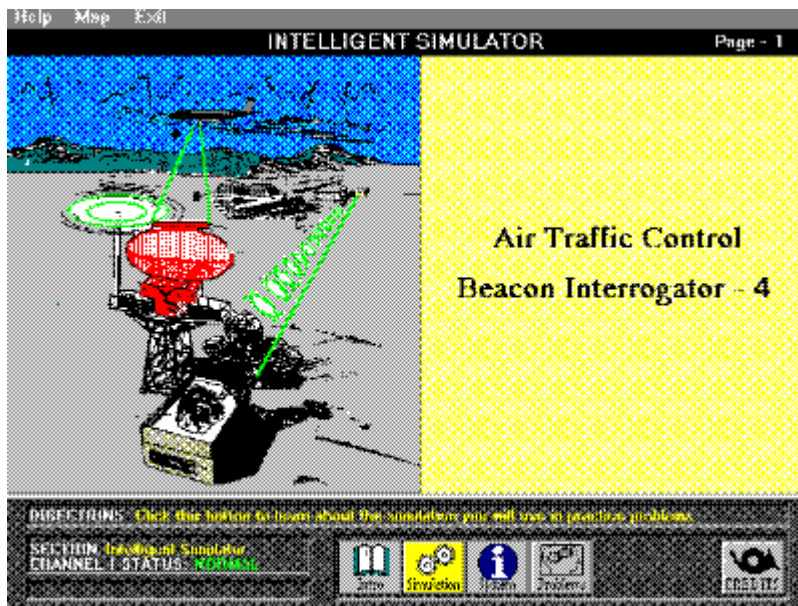
### 4.4.1 Radar Simulation Tutor

The FAA Technical Center, in Atlantic City, New Jersey has a charter to apply Advanced Technology to training and aiding of Airway Facilities (AF) technicians. The radar tutor is a direct response to that charter (**Jones & Jackson**, in press).

The population of AF technicians is very senior. In many FAA facilities, most of the technicians are eligible for retirement. New technicians are often overwhelmed by the variety and volume of systems for which they must be trained. In most cases new technicians spend 75% of their first year, away from home, training at the FAA Academy in Oklahoma City. Upon return from training, continuing training is needed to ensure readiness.

The Radar Simulation tutor, pictured in **Figure 5**, permits the user to operate the system for

maintenance in a simulation environment. The system was originally designed to use the MITT tutor format, but has evolved to provide additional interface, feedback, and on-line information system capabilities within a Microsoft Windows environment.



**Figure 5 Radar Simulation Screen**

The Radar Simulation tutor permits the student to perform tests and to seek advice. System design will permit the entire tutor to operate on the Pen computer for future application as a job-aid.

#### **4.4.2 Automatic Valve Simulator**

Motor-operated valves (MOV) have been a continuing operational and maintenance problem in US Nuclear electric power plants (NRC, 1989). The MOV Tutor, shown in **Figure 6**, which uses the MITT technology, permits the user to see and learn about MOVs. The trainer also simulates diagnostic scenarios on which the technician may practice. Finally, the system contains all necessary MOV documentation to ensure real time job aiding as needed. As a part of this research a specification for a Microsoft Windows- based authoring system is also in development.

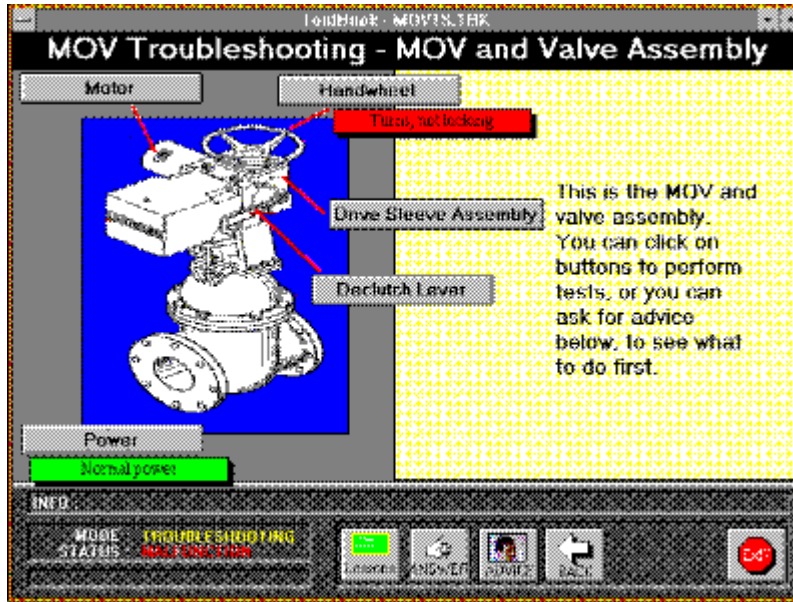


Figure 6 MOV Screen

## 5.0 SUMMARY

Current and future job and equipment design increases the numbers of workers that will require simultaneous training, aiding, and information retrieval. Therefore, designers and developers, using readily available hardware and software, must create integrated information systems. As described previously, the integration of these three capabilities will justify the time and cost of development.

This paper has described five systems that demonstrate the feasibility of integrated systems. The result has been very successful. Sources of funding support have increased considerably since the user base has increased and will continue to grow. All customers, including trainers, and in-plant personnel are able to multiply their capability with these tools. The systems are closing the gap between "resident" training and "on-the-job" training. Clearly this positive trend is indicative of the future.

## 6.0 ACKNOWLEDGEMENTS

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## INTELLIGENT SIMULATION FOR MAINTENANCE TRAINING

Jeffrey E. Norton  
Galaxy Scientific Corporation

## 1.0 ABSTRACT

Over the past decade, computer hardware and software advances have been astounding. As these hardware and software systems become more sophisticated, so do the expectations of the computer users. To be accepted, training systems must provide sufficient fidelity to satisfy users' expectations. This paper describes how Intelligent Simulations and Intelligent Tutoring Systems attempt to provide sufficient simulation and interface fidelity. It also provides pragmatic examples of training systems that effectively use varying levels of fidelity.

## 2.0 INTRODUCTION

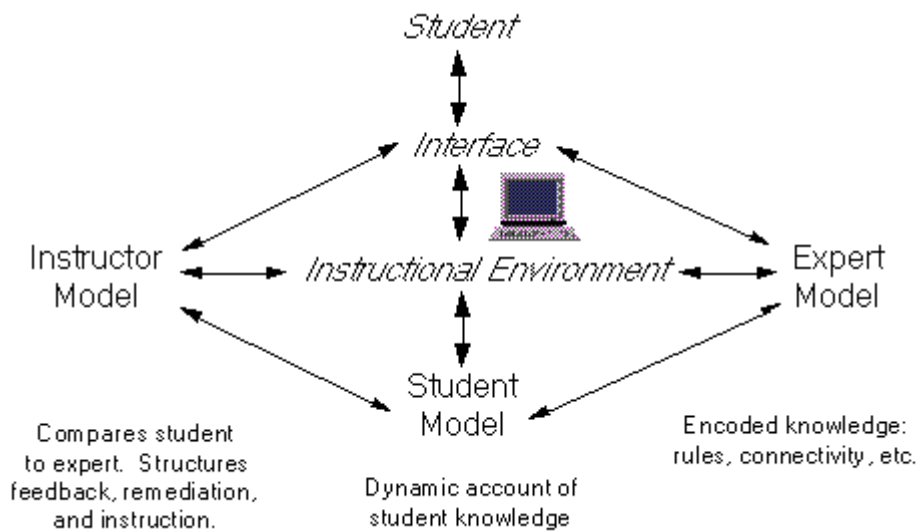
Computer users are becoming increasingly sophisticated. They interact with high-technology devices daily such as compact disc players, camcorders and cellular telephones. They also play interactive video games with high resolution graphics. As a result, they are bored by anything that doesn't have the same "curb appeal". Training and job aiding for technical devices should provide sufficient visual appeal to capture the user's attention.

However, a flashy interface is not enough. Once the user accepts the visual appeal of the system, the training system must be engaging enough to keep the user's attention. Without adequate simulation and remediation, the student is not motivated to learn. Intelligent Tutoring Systems and Intelligent Simulations provide a framework in which students can learn by doing.

## 3.0 INTELLIGENT TUTORING SYSTEMS AND INTELLIGENT SIMULATION

The term "Intelligent Tutoring System" (ITS) gained popularity in the eighties (Sleeman and Brown, 1982, Polson and Richardson, 1988, Psotka, et al, 1988). It describes an architecture around which training systems are built. As shown in **Figure 1**, an ITS contains an instructional environment, interface, and models of the student, expert and instructor.





**Figure 1 Intelligent Tutoring Systems**

The instructional environment is at the heart of the diagram. This environment can range from drill and practice to tutorials to complex mathematical simulations (or any combination thereof). This paper concentrates on the use of simulation as the instructional environment for troubleshooting in technical domains.

The student sees the output of the instructional environment via the interface. The interface media can range from only text, to text and graphics, to digital photographs, to video and sound. Obviously, the type of interface depends upon the limitations of the computer hardware. Later sections will show how varying levels of interface presentation can be effective.

The "intelligent" portion of ITS revolves around models of the instructor, student, and expert. The ITS keeps tracks of the current state of the student's knowledge and actions (the student model). The ITS compares this model with what an expert would do (the expert model), and provides appropriate remediation to the student (the instructor model).

Intelligent Simulation (Johnson and Norton, 1991) still uses the ITS framework, but places greater emphasis on the simulation and the interface. While the student, instructor, and expert models are still very important, the *perceived* fidelity of the simulation and interface is equally important. The term "perceived" is significant here. The *actual* complexity of the simulation is insignificant, as long as the student *perceives* it to be adequate. For example, data values that appear on a test panel can originate from a complex simulation or a simple look-up table. As long as the data values are timely and accurate, the student does not care how they were generated.

Research indicates that the required level of fidelity varies depending on the type of task being taught (Hays and Singer, 1989). The intelligent simulations described below are generally more concerned with the cognitive tasks of troubleshooting, rather than with the psychomotor skills. Therefore, these simulations require more functional fidelity than physical fidelity.

## 4.0 PRAGMATIC EXAMPLES OF INTELLIGENT SIMULATIONS

The author and his colleagues have developed a wide spectrum of intelligent simulations over the past decade. This section will identify several training applications that adhere to the ITS and Intelligent Simulation structure. It will describe how each training system effectively integrates various levels of fidelity in each application.

### 4.1 ENVIRONMENTAL CONTROL SYSTEM (ECS) TUTOR

The Environmental Control System (ECS) Tutor is an intelligent simulation for maintenance training of the ECS on the Boeing 767-300, as shown in **Figure 2**. The ECS Tutor, developed for the FAA Office of Aviation Medicine, lets the student troubleshoot malfunctions of the air conditioning portion of the ECS.



**Figure 2 The ECS Tutor**

The instructional environment and interface present the student with an interactive simulation of the aircraft maintenance environment. The student accesses the Overhead Panel to affect changes that are then shown on the Engine Indicating Crew Alerting System (EICAS) Display, as shown in **Figures 3** and **4**. The student also accesses the Fault Isolation Manual (FIM) during the simulation. The FIM is the aircraft mechanic's decision tree during troubleshooting.



Figure 3 The ECS Overhead Panel

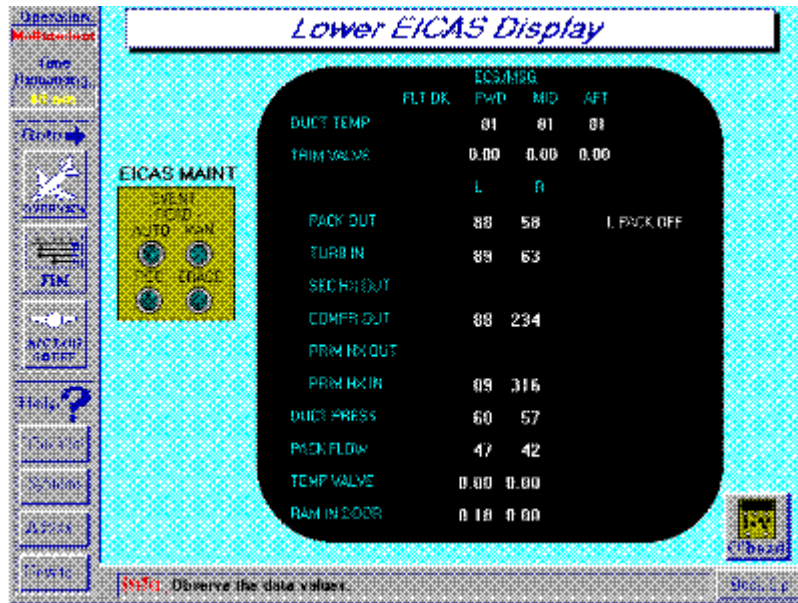


Figure 4 The ECS EICAS Display

The student may ask for troubleshooting advice at any time. Also, the system detects when the student appears to be floundering, and offers unsolicited advice. The system gradually gives more specific help each time it recognizes that the student needs help in the same area. For example, the unsolicited advice may first suggest that the overheating problem may be caused by a problem in the control system. If the student still has trouble, the system may then suggest that the student look at the temperature control valve.

The simulation of the ECS focuses on the inputs and outputs of each component. If a component

fails, it produces an erroneous output value. Each subsequent component propagates this error through the system. The student interacts with the EICAS display and the Overhead Panel to see the effects on the air conditioning system. If the student replaces a malfunctioning component, the data values on the EICAS display immediately reflect the correction.

The student may choose to solve the problems by using the FIM exclusively, by using a schematic of the cooling pack, or both. Regardless of the method chosen, the simulation reacts as described above. Solving the problem via the FIM forces the student to go "by the book". Solving the problem via the schematic allows more flexibility for more proficient students. Both methods give the student access to various troubleshooting tools and procedures (e.g. visual inspection, voltmeters, built-in test equipment, replacement, etc.).

Preliminary evaluations of the ECS Tutor, with an airline and an aircraft maintenance school, have been very favorable. In order to obtain "hard" numbers, the ECS Tutor will undergo a complete cost- effectiveness and training-effectiveness evaluation in the Summer of 1992.

## **4.2 AIR TRAFFIC CONTROL BEACON INTERROGATOR (ATCBI-4) TUTOR**

The Air Traffic Control Beacon Interrogator (ATCBI-4), shown in **Figure 5**, is a complex electronics system used by air traffic controllers. The ATCBI-4 Tutor, sponsored by the FAA Technical Center, allows Airways Facilities maintenance technicians to troubleshoot simulated malfunctions with the help of an expert advisor.

The simulation of the ATCBI-4 represents each component in the system via different operating states. When a malfunction is introduced to the system, the simulation determines whether each component is normal or abnormal - based upon the functional connectivity of components in the system. Each component has default data values for both a "normal" state and an "abnormal" state. If required, the simulation may override the default "abnormal" data values with values that are more specific to a given malfunction.

The ATCBI-4 Tutor also allows the student a variety of ways in which to troubleshoot the system. The student may use either functional flow diagrams or simulation displays. The student uses functional flow diagrams to get a solid theoretical basis for troubleshooting. These diagrams present the information about components in the most basic form: normal or abnormal.

Once students establish a baseline proficiency, they may opt to interact with the simulation displays for a more realistic, interactive instructional environment. The student accesses displays which represent oscilloscope wave forms and instrument panels. Simulation displays replicate the physical troubleshooting environment more realistically than the logical troubleshooting environment.

## **4.3 GAS TURBINE INFORMATION SYSTEM (GTIS)**

The Gas Turbine Information System (GTIS), sponsored by the Electric Power Research Institute (EPRI), is an Integrated Information System for gas turbines, as shown in **Figure 6**. This system combines training, job aiding, and intelligent information retrieval. The intelligent

tutoring system lets the student diagnose failures on a gas turbine engine. The job aid assists with on-the-job troubleshooting. The GTIS information retrieval system provides access to schematic diagrams and other system information.

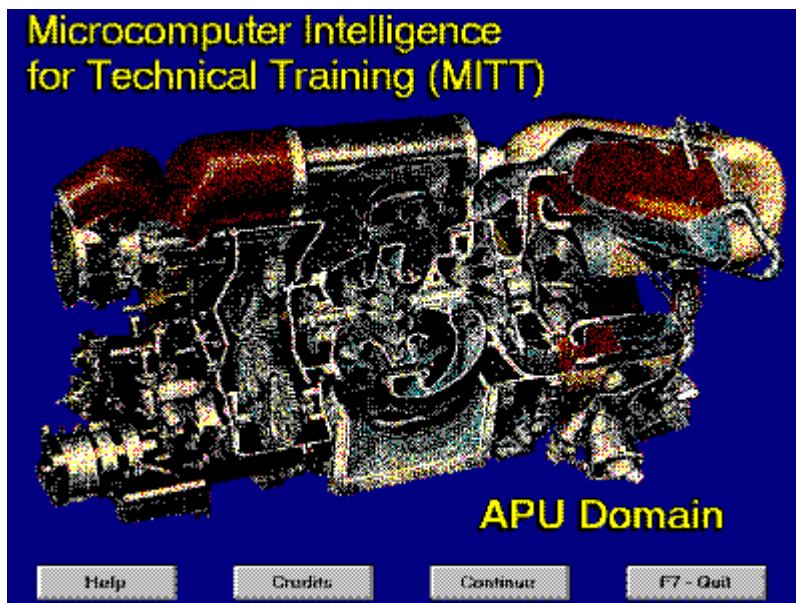
The GTIS simulation uses a static "look-up table" scheme to generate data values. Data values are pre-defined for each malfunction. The simulation uses a "snapshot" of the state of the gas turbine at the time of the failure for data values.

The GTIS student obtains diagnostic information via tests, observations, calibrations and replacements. The GTIS uses still digital photographs of the equipment while troubleshooting, but uses digital video interactive (DVI) sequences to describe equipment and to teach general gas turbine principles.

#### 4.4 MICROCOMPUTER INTELLIGENCE FOR TECHNICAL TRAINING (MITT)

Microcomputer Intelligence for Technical Training (MITT) permits technicians to operate and diagnose technical systems. It tracks trainee's actions and provides feedback using an embedded expert system. MITT runs on 80286-based DOS machines with the default 640K of memory (Norton, et al, 1992).

The MITT Writer Authoring System permits training developers to build expert system-based tutors (MITT Tutors) without the use of a programming language. The developer simply enters a description of the training domain. The developer may make changes to this training description as modifications to the target system warrant. To date, some of the MITT Tutors include: Auxiliary Power Unit (APU) Tutor (see **Figure 7**), Message Processing System (for Minuteman Missile) Tutor, Electric Power Distribution System for the Space Shuttle (Fuel Cell) Tutor, and Automobile Engine Tutor.





## Figure 7 MITT APU Tutor

The MITT Tutor simulation relies on a simple, but effective "look-up table" to supply necessary data values to the student. With MITT Writer, the training developer provides a description of sensor behavior for each malfunction. The training developer specifies discrete data points for the duration of the malfunction. By using this method, the MITT Tutor supports dynamic data values. The simulation also extrapolates from data point to data point to give the student the effect of a continuous simulation.

## 5.0 CONCLUSION

The Intelligent Simulations just outlined encompass the spectrum of simulation fidelity and visual appeal. The ECS Tutor uses a deep simulation model, while MITT uses a dynamic look-up table. GTIS uses a surface-level, static simulation. These systems also use a host of interactive displays: from EGA, scanned graphics in MITT, to digital photographs in ATCBI-4, to digital video interactive in the GTIS.

Each of these technologies requires different levels of resources for development. While many people always want the highest fidelity simulations and greatest resolution images, it is impractical, and also unnecessary, for every system to require such parameters. The systems described above show that different combinations of fidelity can be quite effective.

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# EMERGING TECHNOLOGIES FOR MAINTENANCE JOB AIDS

*Charles F. Layton, Ph.D.  
Galaxy Scientific Corporation*

## 1.0 INTRODUCTION

Maintenance is fast becoming one of the most frequent applications of computer-based job aiding. Maintenance job aids range from automatic preventive maintenance schedulers, to systems that monitor equipment status and recommend maintenance, to systems that aid in fault diagnosis and repair. Application domains range from production equipment (e.g., clutch assembly machines), to process equipment (e.g., turbine generators), to high technology specialized equipment (e.g., fighter aircraft). There is a range of methodologies employed, including algorithmic approaches for preventive maintenance schedulers to expert systems for fault diagnosis and repair. The technologies employed encompass a range from mini computers to desktop microcomputers linked to video disks. This paper addresses extant approaches to job aiding in maintenance, the prospects for using emerging technologies for such systems, and the impact of emerging technologies on human performance, particularly in aviation maintenance applications. It also calls for a new design philosophy in building job aids. A study which used this philosophy and compared three different levels of aiding on a task is also discussed. Some of the results of the study and their applicability to maintenance job aids are presented.

This chapter is similar to a previous review of job aids (see **Chapter 5** of Shepherd, W. T., Johnson, W. B., Drury, C. G., Taylor, J. C., & Berninger, D., 1991), in that many of the systems encountered were concerned with technological developments, rather than performance achievements. Whereas that previous work identified some of the difficulties with introducing advanced technology job aids into an operational environment, this discussion addresses some of the fundamental problems with past approaches to job aids and presents a design philosophy which capitalizes on the skills and abilities of the operator in order to produce a combined human-computer system that attains increased performance.

## 2.0 SURVEY OF MAINTENANCE JOB AIDS

A survey of academic, industrial, and popular literature revealed a wide variety of approaches to building maintenance job aids. These differing approaches include both hardware and methodological considerations, ranging from stand-alone, automatic scheduling systems to portable, interactive troubleshooting systems. The hardware aspects are addressed first, followed by a discussion of some of the different methods used.

### 2.1 HARDWARE EMPLOYED



The following systems exemplify the variety of hardware approaches used for maintenance job aids.

Folley and Hritz (1987) describe an expert system that assists in troubleshooting clutch assembly machines on a production line. Fault lamps above the machine stations indicate which stations are malfunctioning. A technician takes a maintenance cart to the malfunctioning station. The cart carries a two-button control and a monitor and the technician connects these to a junction box at the station. This junction box links the monitor and control to a remote computer and video disk player. The technician uses the control to move through a menu system to specify the faulty station. The computer then specifies the tests to be performed, along with graphic displays of the equipment, and the technician enters the results of the tests. In this way, the computer guides the technician through troubleshooting and repairing the malfunctioning equipment.

A similar system developed by the Electric Power Research Institute (EPRI) also uses a video disk player for displaying maintenance information and procedures for gas-turbine power plants. This system uses a dual processor computer system. One processor manages an expert system, while another controls a video disk player. The EPRI also uses voice recognition and synthesis for input and output, respectively.

General Motors developed an expert system to assist in vibration analysis of production machinery (cf. "GM unveils `Charley'..."). Named after a retiring technician with many years of experience, `Charley' was intended to help less experienced technicians locate parts that needed repair in production equipment with rotating components. Charley stores a signature file for each properly operating piece of equipment; technicians record the vibration signature of a problematic piece of equipment with a special data recorder and then connect the recorder into a Sun workstation. Charley compares the newly recorded signature with the database and begins diagnosing the problem. Charley guides interactions, may ask the technician for additional information, and explains its troubleshooting strategies. Charley can also be used as a consultant and allow a technician to explore `what if' questions. Finally, Charley is also used to train new technicians. The emphasis of the system is on preventive maintenance, rather than repair of failed equipment.

McDonnell Douglas developed the `Avionics Integrated Maintenance Expert System' (AIMES) for use on F/A-18 fighter aircraft (cf. "McDonnell Douglas flight tests..."). AIMES is a self-contained on-board box which contains a microprocessor and records flight avionics data on a cassette for later analysis. During this off-line analysis, production rules detect and isolate avionic failures at the electronic card level. AIMES generates queries and tests based on data and concludes whether a fault is present. If there is a fault, AIMES supplies the fault data, the card name, and the reasoning that led to the fault isolation conclusion.

The telecommunications industry is a large user of advanced technology maintenance aids, particularly in network switch and cable analysis (cf. "Expert system from AT&T..."). For example, the `Automated Cable Expertise' system runs automatically each night to detect trouble spots in cables. Upon identifying a problem, it reports the repair history of the area and suggests corrective action.

## 2.2 METHODS EMPLOYED

The following systems exemplify the range of software methodologies employed in maintenance job aids.

Berthouex, Lai, and Darjatmoko (1989) discuss a system for determining daily operations for a wastewater treatment plant. This system is billed as an 'expert system', although it was developed using standard spreadsheet (Lotus 1-2-3) and database software (d-Base III), rather than one of the many production system shells. (Expert systems have historically been written using production rules, if-then clauses, in one of many languages specifically designed for that purpose, for example OPS5 or LISP. Popularization of the term 'expert system' has led to decreasing precision of use.)

'Process Diagnosis System' (PDS) was developed by the Westinghouse Research and Development Center and Carnegie Mellon University for maintenance of steam generators. PDS is a condition monitoring system for preventive maintenance in order to alleviate both breakdown maintenance and unnecessary maintenance. The system is designed to detect deterioration early and predict the duration of safe operation. PDS also recommends specific preventive maintenance for regularly scheduled down times.

Vanpelt and Ashe (1989) describe the 'Plant Radiological Status' (PRS) system for nuclear power plants. The PRS system presents a three dimensional model of the power station and equipment so that maintenance teams may plan maintenance tasks in advance. The PRS system facilitates access to and interpretation of radiological conditions by identifying hotspots and contaminated areas, as well as identifying obstructions and available workspace. The goals of the PRS system are to reduce maintenance time and radiation exposure.

Several systems for supporting operations and maintenance were reviewed by Bretz (1990). One of the systems was developed by Chubu Electric Power Company and Mitsubishi Heavy Industries, Ltd. in Japan. This comprehensive expert system assists in power plant boiler failure analysis and maintenance planning. The failure diagnosis reports the most probable causes for failure, guidelines for inspection, the items to be investigated, repair methods, and suggested preventive maintenance. The maintenance planning subsystem automatically prepares daily repair schedules, a work estimation plan, and work specifications.

The distinction is sometimes made between 'deep' and 'shallow' knowledge in expert systems. The knowledge typically represented in production systems is considered shallow knowledge because it contains only antecedent-consequent relationships without any information as to why one thing follows from the other. Deep knowledge, on the other hand, captures the functional and causal relationships between the components of the object or system being modeled; thus, 'modeled-based reasoning' is often used to describe this approach. Atwood, Brooks, and Radlinski (1986) call 'causal models,' which use components functions as the basis for their reasoning, the next generation of expert systems. Clancy (1987) describes a system for diagnosing switch mode power supplies which uses a model of the component level of the electronics for its diagnosis. Whereas one can test for signal presence at the module level of the electronics, the component level is concerned with the way in which a signal changes as it passes

through the components. Finally, a system developed for Britain's Central Electricity Governing Board uses a model of the cause and effect relationships inherent in turbine generators for diagnosis and maintenance (see "Expert system probes..."). This expert system monitors and analyzes the vibration patterns of the equipment in its analysis.

The most sophisticated system encountered in the survey is the 'Testing Operations Provisioning Administration System' (TOPAS) developed by AT&T. Clancy (1987) describes TOPAS as a real-time, distributed, multi-tasking expert system for switched circuit maintenance. TOPAS performs trouble analysis, localization, and referral of network troubles. Clancy claims that TOPAS "does network maintenance without human intervention or consultation" (p. 103). If this is true, then TOPAS is not really a job aid, because it performs the job itself.

## **3.0 THE USE OF ARTIFICIAL INTELLIGENCE IN JOB AIDS**

The methods and design philosophies used in building job performance aids vary with the designer(s). While some of the systems surveyed placed the technician in charge of the troubleshooting and maintenance, the majority of the approaches relied on artificial intelligence. The following describes various artificial intelligence approaches and their impact on human performance.

### **3.1 EXPERT SYSTEMS**

Expert systems typically have three components: a rule base, a knowledge base, and an inference engine. The rule base contains the problem solving strategies of an expert in the domain for which the system was developed. The rule base is made up of production rules (if-then clauses). The knowledge base contains the history and the current data of the object under consideration (this object may be anything from an aircraft engine to a medical patient). The inference engine is responsible for determining what rules get activated and when the system has solved the problem or is at an impasse. Expert systems are typically written in a programming language specifically designed for such use, such as LISP or OPS5.

Typically, the human expert is not the person who builds the expert system, rather he/she interacts with a 'knowledge engineer' who is responsible for extracting the expert's expertise. One difficulty with expert systems has frequently been referred to as the 'knowledge engineering bottleneck'; it can be difficult to access and program the knowledge of the expert into the expert system. For instance, the expert may not even be aware of what he/she does to solve a particular problem. Furthermore, it is impossible to guarantee that the rule base contains all of the knowledge of the expert.

### **3.2 KNOWLEDGE-BASED SYSTEMS**

Knowledge-based systems place less emphasis on production rules as a way of representing knowledge, and more emphasis on using a large database of information. This database may consist of information such as vibration patterns of equipment, as in the 'Charley' system

discussed above, or it may consist of typical hardware configurations, for instance. The point of knowledge-based systems is that they rely on a large body of readily-available information for the bulk of their processing.

### 3.3 MODEL-BASED SYSTEMS

Model-based systems are an attempt to produce more robust problem solving systems by relying on 'deep' representations of a domain. The models depend on a description of the functionality and relationships of the components that make up the domain. Model-based systems are concerned with not only how a component functions, but why it functions that way. Developers of model-based systems believe that these systems will be able to solve novel problems, whereas expert systems can only solve problems with which an expert is familiar.

## 4.0 HUMAN PERFORMANCE IMPLICATIONS OF ARTIFICIAL INTELLIGENCE APPROACHES

The human performance implications of using an artificial intelligence-based problem solver are many. All of these systems revolve around the 'machine expert' paradigm, in which the computer controls all problem-solving activities. One problem with the machine expert paradigm is that because computers do not have access to the 'world', they must rely on a person to supply all relevant data about the world. Thus, the machine expert directs tests to be run and requests the results of those tests. Based on these data, the computer requests more information or reaches a conclusion, and that conclusion may be erroneous. In the words of one cognitive engineering researcher, the human is reduced to a "data gatherer and solution filter" for the machine.

One problem associated with this lack of environmental access is that the person may have knowledge that the computer does not. Since the computer directs the problem solving, it may never ask for information that may be critical to successfully solving the problem. Furthermore, there is usually no provision for the operator to volunteer such information. The person may even have different goals than the machine or may not know what the machine's goals are when it is attempting to solve a particular problem. Additional difficulties arise when the human operator accidentally enters the wrong data or when he/she misinterprets a request from the computer. Suchman (1987) discusses the problems of human machine communication at length.

Probably the biggest problem associated with expert systems is that they are brittle. As mentioned above, expert systems can only solve problems that the human expert has seen or remembers to discuss with the knowledge engineer. People (either experts or expert system designers) simply cannot anticipate all of the environmental variability encountered in the world. This leads to the tragic irony of such systems: expert systems are most needed when a problem is difficult, and that is precisely when the expert systems fail. The upshot is that the human operator is left to solve a difficult problem without the benefit of having developed expertise through solving other problems, because those were handled by the expert system!

All of these problems and more arose in a study by Roth, Bennett, and Woods (1987), in which the authors observed technicians using an expert system to troubleshoot an electro-mechanical device. One of the major findings of the study was that only those technicians who were actively involved in the problem solving process and performed activities beyond those requested by the expert system were able to complete the tasks. The technicians who passively performed only those activities requested by the expert system were unable to reach solutions on any but the most trivial tasks.

The above should not be interpreted as a condemnation of all uses of artificial intelligence techniques, however. Indeed, artificial intelligence has greatly advanced our understanding of the capabilities, as well as the limitations, of computational tools. Prudent use of such techniques can greatly enhance the ability of a cognitive engineer to provide operators with powerful problem solving tools.

## **5.0 EMERGING TECHNOLOGIES**

Continued advances in hardware and software technologies will further increase the cognitive engineer's design repertoire. Indeed, there are many emerging technologies that could be profitably used in maintenance job aids. Advances in computer hardware, display hardware, and object modeling all have great potential to improve job aiding capabilities. Each of these is discussed below.

### **5.1 ADVANCES IN COMPUTER HARDWARE**

As computer hardware has become smaller and more powerful, there has been a progression to smaller, more portable job aids. Whereas earlier job aids ran on minicomputers, then workstations and personal computers, newer job aids are being designed using laptops. There is no reason to believe that the laptop computer is the smallest, lightest computer that will be developed, however. Indeed, the NCR NotePad has recently been introduced. This computer is pen-based; that is, all input is performed via a pen stylus, rather than through a keyboard or mouse. The NotePad is light enough that it can be easily held in one hand, which greatly facilitates taking it to the maintenance site. The NotePad is relatively quick, it has reasonably large storage capacity, and it has limited handwriting recognition abilities.

An aviation industry working group is currently defining the standards for a 'Portable Maintenance Access Terminal' (PMAT) for use in commercial aviation. As currently conceived, the PMAT would connect to the 'Onboard Maintenance Systems' of current aircraft and would be used for troubleshooting. Because the emphasis is on portability, it is likely that something similar to the NotePad or a standard laptop computer will be specified.

Another emerging hardware technology is the use of 'built-in test equipment' (BITE) in engineered systems, no doubt due in part to the widespread use of microprocessors. BITE likely does not eliminate the maintenance technician, however, because it may be difficult to implement such equipment in mechanical systems or in very complex systems. Indeed, BITE may introduce additional problems for maintenance people because there is a lack of

standardization on how BITE should operate; thus, there may be confusion when dealing with similar, but different, BITE. Further complications may arise due to issues of granularity in BITE; BITE may simply indicate that a piece of equipment is not functioning properly, without indicating the specific nature of the malfunction or without indicating which component must be repaired or replaced.

## **5.2 ADVANCES IN DISPLAY HARDWARE**

One of the surveyed systems used a personal computer to control a slide projector for displaying maintenance graphics. Several of the systems used a computer-controlled video disk for such displays. With the advent of digital cameras and compact disc-interactive (CDI) technology, systems with higher fidelity and portability can be achieved. Appropriately designed CDI systems could store many views of the object(s) being serviced, as well as maintenance procedures and information. Indeed, what graphics were displayed would depend on the fault manifestations. Furthermore, well-designed CDI systems would allow the technician to troubleshoot by hypothesizing a failed component and watching how a simulation of the system performed. Similarly, the technician could replace a component in the simulation and see the results. In this manner, the technician could develop expertise more quickly than learning on-the-job (because the technician would have control over what aspects he was learning, rather than relying on whatever malfunction happened to occur).

## **5.3 ADVANCES IN OBJECT MODELING**

An extension of the three-dimensional model discussed above is virtual reality. Virtual reality has received a lot of attention as a result of the Defense Advanced Research Project Agency's development of the 'Pilot's Associate Program' and consists of replacing an operator's view of the 'real world' with a simulated view of that world. Thus, real world objects are replaced with simulations of those objects. One possible use of virtual reality would be to allow the maintenance technician to 'stand' inside a device, such as an engine, and watch how it functions, both normally and with failed components. The technician could also see the effects of replacing components, similar to the CDI system above, but with the benefit of observing the effects more directly. As with CDI, the technician need not replace the actual system components, but may replace components in the simulation of that system. The uses of virtual reality appear to be limited only by the job aid designer's imagination.

# **6.0 HUMAN PERFORMANCE IMPLICATIONS OF EMERGING TECHNOLOGIES**

While many past approaches to job performance aids sought to replace human expertise with machine expertise, there is a growing appreciation for the importance of human skill. The machine expert paradigm sought to overcome human information processing 'limitations' with a computer prosthesis. However, even computers are limited resource processors. A more enlightened approach is to view computers as tools to amplify human capabilities, not overcome

limitations. In this sense, computers can be seen to be like other tools, such as telescopes or automobiles: they are instruments which provide additional resources for achieving our needs and desires. Woods and Roth (1988) discussed the above issues and addressed many more cognitive engineering issues inherent to developing systems that have powerful computational abilities.

Technology is not a panacea; each new technology brings with it significant drawbacks, as well as benefits. The challenge to designers is to use emerging technologies to build cooperative systems, in which both the human and the computer are actively involved in the problem solving process. Humans can no longer be regarded as passive 'users' of technology, but as competent domain practitioners with knowledge and abilities which are difficult to replace. The following section discusses a study which addressed just such issues.

## **7.0 A STUDY OF HUMAN PERFORMANCE WITH A COOPERATIVE SYSTEM**

A study which addressed some of the human performance issues discussed above was carried out as part of the author's graduate program (Layton, 1992). This study compared three different levels of computer support on the basis of their effects on human performance. Although the domain for which the systems were developed was enroute flight planning, the general principles behind the alternative designs can be applied to developing aviation maintenance aids, as well. The following is a discussion of enroute flight planning, the design concepts behind the three levels of computer support, the method employed for comparing the various systems, the general outcomes of the study, and the implications of those outcomes for developing aircraft maintenance job aids.

### **7.1 ENROUTE FLIGHT PLANNING**

Enroute flight planning consists of modifying the flight plan of an airborne aircraft in response to changes in the capabilities of the aircraft, to crew or passenger emergencies, to changes in weather conditions, and/or to problems at the destination airport. The study focused on flight plan adaptation in response to changes in weather conditions. From a pilot's perspective, the components important to enroute flight planning include the airplane, possible flight routes, weather conditions, and airline company dispatchers. The pilot is concerned with getting from a given origin to a given destination on time, with a minimum of fuel consumed, while maintaining flight safety. He/she must consider what routes to take (these routes consist of waypoints, or navigational points, and jet routes, the so-called "highways in the sky"), what altitudes to fly, what weather to avoid, and the ever-changing capabilities of the aircraft (e.g., the weight of the plane decreases with fuel consumption; the lighter the plane, the higher it can fly, within limits).

The initial flight plan is rarely followed exactly, due to unforeseen events occurring while enroute. Indeed, minor changes in flight plans are frequently made and major changes are fairly common. These amendments to the original result from the dynamic, unpredictable nature of the



`world' in which the plans are carried out. Weather patterns do not always develop as predicted, resulting in unexpected areas of turbulence, less favorable winds, or storms that must be avoided. Air traffic congestion may delay take-off or restrict the plane to lower-than-planned altitudes. Airport or runway closures can cause major disruptions, not just for one aircraft, but for everyone planning on landing at that airport. Mechanical failures, medical emergencies, or other critical problems may delay take-off or may force an airborne plane to divert to a nearby airport. Furthermore, there are several constraints on the flight plans that can be developed. Planes must maintain a certain separation distance between each other and between thunderstorm cells, as specified in the Federal Air Regulations. Planes must fly along the jet routes. They are also limited to certain altitudes. Over the continental United States, for example, 33,000 feet is an 'eastbound only' altitude. There are also physical limitations: the plane can't fly if it is out of fuel and it can't land at an airport with runways that are too short. Some of these constraints are actually 'soft', in that they may be violated in some circumstances. If, for instance, there is no eastbound traffic, Air Traffic Control (ATC) may allow a plane to fly west at an 'eastbound only' altitude. Similarly, ATC may approve a vector that deviates from the jet routes in order to avoid a storm or to save fuel.

## 7.2 SYSTEM DESIGN CONCEPTS

It is clear that enroute flight planning is a complex activity, but it is not clear how humans deal with these complexities or how one might program a computer to choose the `optimum' solution to any given problem. For instance, how does one make tradeoffs between fuel conservation, flight safety, and prompt arrival at the destination? Because pilots make such tradeoffs on a routine basis, one goal of the study was to develop a system to support them in making such decisions. There is a heavy emphasis, therefore, on allowing the pilots to explore "what if" types of questions so that they could gain feedback on the impact of a planning decision on flight parameters.

FLIGHT PLANNER, an enroute flight planning software testbed, used three levels of computer support which corresponded to successively greater flight planning power. Common to all three systems were: 1. a map display which consisted of the continental United States, the aircraft, and flight routes; 2. a representation of a flight log, which included the flight route and altitudes; and, 3. a display of flight parameters. These three items were displayed on two monitors.

**Figure 1** depicts the map displays and controls, and **Figure 2** depicts the flight log display and controls and the flight parameter display. The pilot could elect to display weather data, waypoints, and jet routes on the map display. The lowest level of enroute flight planning support provided the pilot with the ability to sketch proposed flight plans on the map, in accordance with the waypoint and jet route structure. The latter condition required a pilot to sketch routes one waypoint at a time. Once the pilot completed a proposed flight plan, in terms of geographic location, the computer responded with various flight parameters, such as time of arrival and fuel remaining at the destination. The computer also indicated whether the flight was predicted to encounter any turbulence and the severity of that turbulence. The computer also proposed the most fuel efficient vertical flight profile for the proposed route. This form of support encouraged the pilots to propose options and see their effects on flight parameters. This form of support is

referred to as the 'sketching only' system.

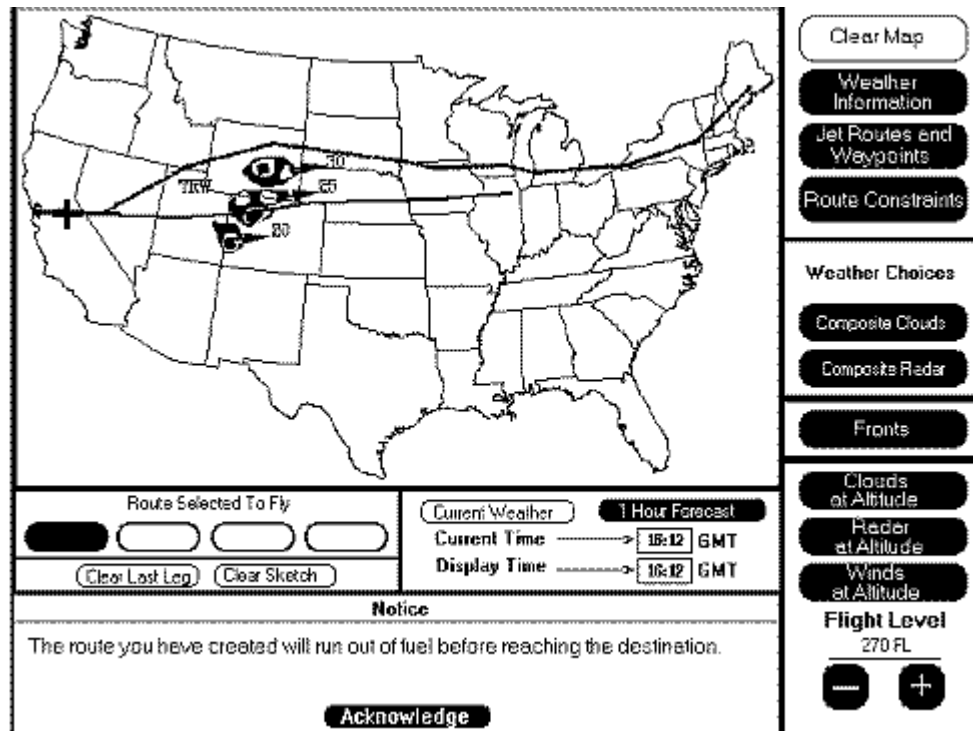


Figure 1 Left Monitor Displays and Controls

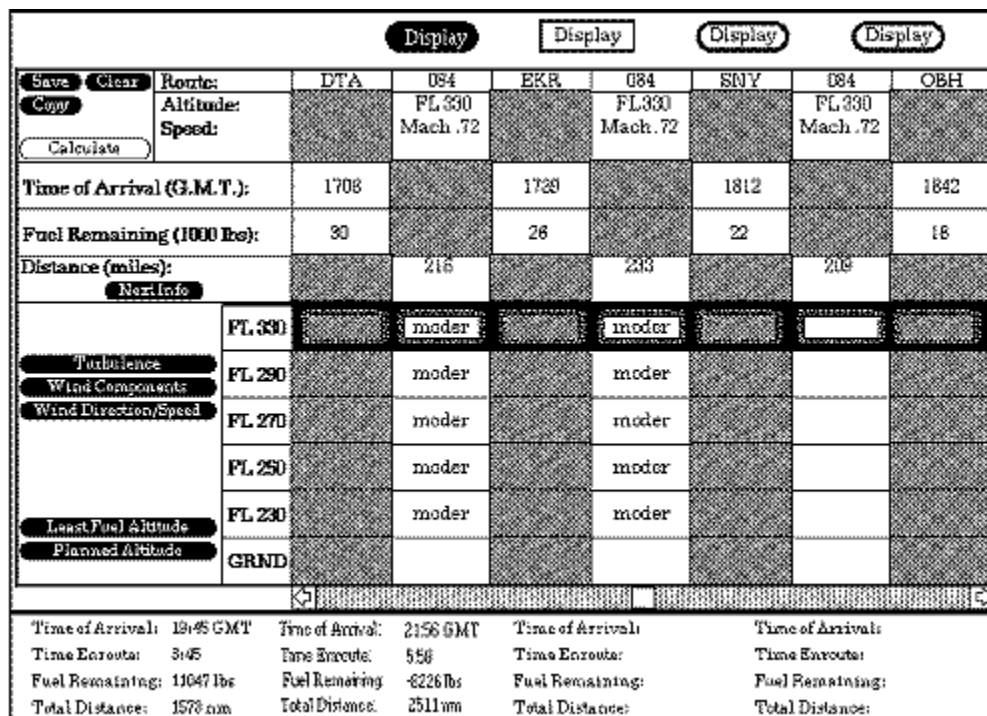


Figure 2 Right Monitor Displays and Controls

The next level of computer support incorporated the sketching form of interaction, but also included a method for placing constraints on a desired solution and allowing the computer to propose a solution which satisfied those constraints. For instance, the pilot could place limits on the maximum severity of turbulence and precipitation encountered, and could specify the desired destination. The computer would then perform a search of the data and solution spaces and propose a route that satisfied the pilot's constraints while minimizing fuel consumption. This proposed route would include both the geographic route and the vertical profile, along with its associated flight parameters. This form of flight planning causes the pilot to plan at a more abstract level than the sketching form of interaction, because the pilot is able to think about the characteristics of a desired solution while the computer handles the lower level details of specific routings. Using the sketching tool, the pilot was free to modify the route proposed by the computer and note the impact of such changes on the flight parameters. This second level of planning can be roughly construed to be a form of consultation system because the computer can be asked for its advice on a problem; it is referred to as the 'route constraints and sketching' system.

The highest level of support corresponds to an expert system that automatically solves a problem as soon as it is detected; upon loading the scenario information, the computer would propose a solution which minimized fuel consumption and satisfied the constraints of encountering no turbulence and no precipitation, as well as arriving at the planned destination. As in the previous level of support, the computer would propose both the geographic route and altitude profile, along with the corresponding flight parameters. If desired, the pilot could also request a solution from the computer based on different constraints, and he could sketch his own solutions.

### 7.3 STUDY METHOD

Thirty male commercial airline pilots were randomly assigned to one of three treatment conditions, wherein each condition consisted of one of the three forms of computer support described above. There were ten subjects in each condition. Each pilot was trained for approximately one hour on his system prior to solving four enroute flight planning cases. Each case consisted of a planned flight that was disrupted because of a change in weather conditions. The task for the pilot was to decide what to do in each situation. All of the pilots solved the four cases in the same order. It took approximately an hour and a half to solve the four cases.

### 7.4 STUDY RESULTS

Each of the four cases provided some interesting insights into the influences of computer tools on human behaviors. The overriding results of each of the four cases are discussed below.

#### *Case 1 General Results*

In the first case, most of the subjects in the 'route constraints and sketching' and the 'automatic route constraints, route constraints, and sketching' conditions chose to fly the computer-suggested route (as expected). However, the 'sketching only' subjects tended to choose routes that were more robust; that is, these subjects put more distance between the aircraft and the storm. These subjects commented that they would like to have more distance

from the storm than afforded by a more direct route (such as the one suggested by the computer in the other two treatment conditions). Furthermore, the 'sketching only' subjects were more apt to explore multiple routes and multiple types of routes, than were the subjects in the other two groups. These results suggest that the sketching form of interaction caused the subjects to consider the data more carefully than did the route constraints tool. One reason for this result is that the sketching tool gave the subjects the opportunity to consider the relationships of various route options and the weather at several points and to consider the robustness of those options given the uncertainties associated with weather. The constraints tool, on the other hand, did not encourage such behavior, and, indeed, the subjects using that tool may have been under the impression that the computer was considering the robustness of routes, when in fact it was not. If the sketching tool encouraged more careful examination of the data than did the constraints tool, and this behavior persisted, one could imagine situations wherein the constraints tool could lead to bad decisions.

### *Case 2 General Results*

While Case 1 provided evidence for the benefits of tools that make the operator the sole decision maker, Case 2 provided evidence to the contrary. In Case 2, the 'sketching only' subjects had significant difficulty, as a group, in searching the relatively large data and solution spaces. Many of the routes explored by these subjects passed through strong turbulence. Indeed, four of these ten subjects chose deviations that exacted a high fuel consumption cost, either because they could not find a more efficient route around/through the weather or because they did not examine wind data which would have indicated that their chosen route encountered strong head winds. By contrast, the subjects in the 'route constraints and sketching' and 'automatic route constraints, route constraints, and sketching' groups successfully used the computer to rapidly find a fuel efficient deviation that avoided all of the weather. Furthermore, nearly all of the subjects who chose an inefficient deviation later stated that they preferred the more efficient deviation suggested by the computer to the other groups.

### *Case 3 General Results*

As noted in the discussion of Case 1, the 'sketching only' subjects chose rather different solutions than did the 'route constraints and sketching' and the 'automatic route constraints, etc.' subjects. Furthermore, it was hypothesized that the 'sketching only' subjects were more involved in the problem solving process than were the subjects in the other two groups. The third case was designed to address the issues related to what happens when the automatic tools suggest questionable solutions: Does the operator recognize that the solution may not be appropriate? Assuming the operator does recognize that the solution is inappropriate, can he readily come up with a better solution?

In Case 3, the computer suggested two different routes in the 'route constraints and sketching' and 'automatic route constraints, etc.' conditions, depending upon the constraints placed on it. One deviation passed between two large thunderstorm cells of a volatile storm, which is a risky practice, at best; this route was suggested on the basis of no turbulence and no precipitation. The other route avoided the bulk of the weather, at the cost of slightly higher fuel consumption and a small amount of turbulence; this route was suggested on the basis of light chop, or greater, turbulence and light, or heavier, precipitation. The trend in this case was for the 'route

constraints and sketching' and the 'automatic route constraints, route constraints, and sketching' subjects to choose the first route more frequently than the 'sketching only' subjects. If these subjects had not examined both routes, then it would suggest that these subjects were simply over-reliant on the computer. However, several of the subjects in the 'route constraints and sketching' and 'automatic route constraints, etc.' groups examined both routes before choosing the more risky route; thus, these subjects chose a risky route despite evidence that it may have been a poor choice and that a better option existed. These subjects nearly unanimously changed their minds when later questioned about their decisions.

With few exceptions, the 'sketching only' subjects planned very conservative deviations that completely avoided the weather. However, the 'sketching only' subjects had considerable difficulty in finding acceptable deviations. In fact, one subject chose a deviation that was predicted to cut into his required landing fuel reserves prior to arrival at the destination. Thus, even though the 'sketching only' subjects may have considered the data very carefully, the problem was sufficiently complex that they would have benefitted from some computer assistance.

#### *Case 4 General Results*

Case 4 provided some interesting results with regard to individual differences and with regard to the influence of computer recommendations. The 'sketching only' and 'route constraints and sketching' subjects were nearly evenly divided between a fuel efficient deviation and a robust deviation. When asked about his decision, one of the 'sketching only' subjects made the comment that the decision depended on the person's role in flying the aircraft at the time: if the captain were flying that leg, he would go one way so that he could look at the storm, but if the first officer were flying that leg, he'd go the other way around so that he could see the storm. Obviously this is an extreme example, but it underscores the role of individual differences in decision making.

Unlike the subjects in the other two groups, the 'automatic route constraints, route constraints, and sketching' subjects, were more likely to choose the computer-suggested, economical route, even when they had explored both routes. Combined with the results of Case 3, this result suggests that the computer exerts a strong influence on decision making when it recommends a solution at the onset of a problem.

## **7.5 STUDY CONCLUSIONS**

The goal of the research was not to determine which particular version of an enroute flight planning tool resulted in the best human performance. Rather, one goal was to see how human behaviors were influenced by the tools available. Subjects who had multiple tools available to them (the 'route constraints and sketching' subjects and the 'automatic route constraints, route constraints, and sketching' subjects) were able to use them to develop alternative plans. In fact, there were many instances in which the solution recommended by the computer did not meet the needs of the pilots, so the pilots developed their own plans through sketching. Thus, not only is there a need for tools that allow the operator to go beyond a computer's solution, but there is a need to support individual differences, as well.

The subjects who had only the sketching tool available to them closely examined the available data. As a result, these subjects often planned robust deviations that would not need to be altered if there were further changes in the weather. Where these subjects ran into difficulties, however, was in situations in which there were a lot of potential solutions and there was a large amount of data. In such situations, these subjects had trouble finding appropriate solutions. Indeed, some of these subjects made poor decisions because of these difficulties. The subjects who had some form of computer assistance were able to more efficiently search these spaces, but with some costs.

The tool that automatically suggested a solution to the problem as soon as it was detected did not encourage the subjects to closely examine the data. While this fact did not cause problems in some cases, it clearly did lead to bad decisions in others. Furthermore, the automatic tool's influence on decision making went beyond simple over-reliance to the point where it shifted attention from data which were important to making a good decision.

## **7.6 IMPLICATIONS FOR MAINTENANCE JOB AIDS**

The conclusions outlined above can be readily applied to developing maintenance job aids. For instance, one of the conclusions is that there is a need for tools that allow an operator to go beyond a computer's solution. As discussed above, particularly with regard to Case 3, and as discussed by Roth, Bennett, and Woods (1987) and Suchman (1987), operators frequently have knowledge or information which is not available to the computer, but which is critical to making a good decision. By giving the authority and responsibility for decision making to the operator, and by providing a tool which supports the operators activities (rather than the other way around), the operator is free to explore solutions that may not have been designed into a machine expert.

Another conclusion reached by the above study was that the form of tool that required a person to make a series of decisions (the sketching tool) encouraged the operator to think hard about the problem and to consider the available data at a deeper level, than did the form of tool that encouraged the operator to make a single 'yes' or 'no' decision (the automatic route constraints tool). In this regard, the conclusion supports the notion that designers need to "keep the person in the loop".

However, another conclusion of the above study was that "keeping the person in the loop" did not provide adequate support in some situations. Indeed, in some of the cases (such as Cases 2 and 3) some of the operators were simply unable to find adequate solutions on their own. These operators could have used some help from a computer in exploring solution possibilities. In such situations this is rarely a reflection of human 'limitations', rather it is an indication of the difficulty of the problem. In maintenance, for instance, diagnosing multiple, interacting faults is a difficult problem. One symptom may be characteristic of several faults, or one fault may mask the presence of another. A tool which helps to focus the diagnostician's attention and eliminate false leads would be very beneficial.

Finally, it is important to realize that each person has a different style of decision making; two people who complete the same training course on a given method for dealing with a problem

may use slightly different approaches. Such differences are likely to increase with experience as each person learns methods that consistently work for him/her. Indeed, experts often use several different approaches to solving truly difficult problems because each approach has unique limitations as well as unique benefits. For instance, knowledge of thermodynamics may help localize a fault to a heat exchanger, but knowledge of circuits may lead one to test the power supply of the pump feeding the heat exchanger, as well. Thus, tools need to be flexible to support such individual differences, rather than use a single, lockstep approach, as in the case of 'expert' systems. (Note that although some expert systems do incorporate the observable components of such methods, they do not allow the operator direct access to those methods. Because the knowledge and capabilities of such systems are necessarily incomplete, the systems are 'brittle' in the face of difficult problems, as discussed above)

## 8.0 SUMMARY

Several past approaches to maintenance job aiding were discussed with respect to their impact on human performance. Such approaches have typically used a 'machine expert' to guide technicians through the maintenance process. However, the 'machine expert' paradigm, has met with limited success in operational environments because of problems with unanticipated variability in the environment (or 'brittleness'), extra-machine knowledge, and inflexibility. An alternative philosophy to developing systems was presented, cooperative systems, in which both the human and the computer are actively involved in the problem solving process. This philosophy advocates a change in perspective toward computers as tools to assist people in their work, rather than as prostheses to overcome human 'limitations'. The cooperative problem solving paradigm capitalizes on the strengths of humans and computers in order to improve the performance of both. A study which compared different versions of a job aiding system designed with using this philosophy was presented, along with implications for developing maintenance job aids. Finally, a plan for developing a maintenance job aid was presented.

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## **PROFICIENCY TRAINING SYSTEMS FOR AIRWAY FACILITIES TECHNICIANS**

*Julie A. Jones  
and*

## 1.0 ABSTRACT

Airway Facilities maintenance technicians are being challenged to maintain proficiency on old equipment while learning new equipment. The new equipment is both more complex and more reliable. Greater reliability leads to infrequent opportunities to troubleshoot. Infrequent practice means degradation of the knowledge needed to troubleshoot complex equipment. An intelligent simulator can help technicians to maintain proficiency by providing practice with the help of an expert advisor. This paper describes a "proof-of-concept" prototype advanced technology system for proficiency training of Air Traffic Control Beacon Interrogator (ATCBI-4) troubleshooting.

## 2.0 INTRODUCTION

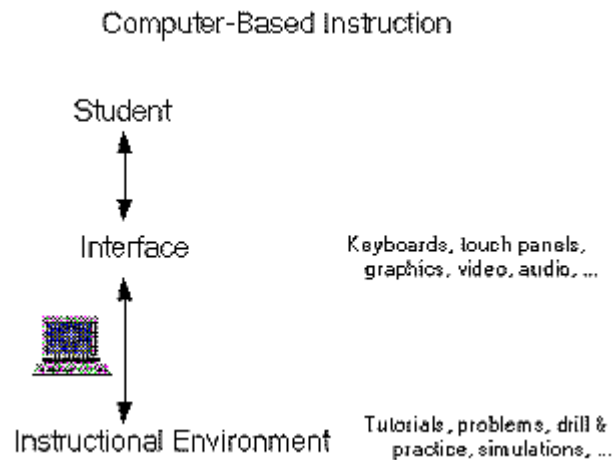
Technicians receive initial training through resident courses which involve a combination of instructional methods (e.g., lecture, lab). After completing initial training for a particular piece of equipment, technicians ideally have the opportunity to practice and apply the newly acquired skills and knowledge on the job. However, sometimes technicians receive initial training several months (or years) before they are assigned responsibility for that specific piece of equipment. In such cases, by the time a technician is asked to apply classroom knowledge, much has been forgotten. Even when training is offered at the ideal time, technicians are responsible for several pieces of equipment; therefore, they are constantly being challenged to maintain proficiency on older systems while learning new systems.

Technicians spend most of their time performing preventative maintenance (PM) checks. Hence, they get frequent practice of these skills. Maintaining proficiency of troubleshooting skills, however, is more difficult. Problems do not occur on the real equipment with any regularity and practicing on the real equipment (by inserting problems) is not feasible. An advanced technology training system may help technicians maintain proficiency of troubleshooting skills by providing safe, on-site, individualized, training.

## 3.0 DISCUSSION OF ADVANCED TECHNOLOGY

In its broadest sense, advanced technology refers to all recent innovations in hardware and software technology. Only a small subset of such technology is applicable to technical troubleshooting training. In particular, this research focussed on advanced technology extensions of traditional computer-based instruction. **Figure 1** shows the generic model for traditional computer based instruction (CBI). As the figure illustrates, a student interacts with an instructional environment on a computer through some type of interface (e.g., a monitor and

keyboard).



**Figure 1 Generic CBI Architecture**

In early **CBI** systems, the information presented by the computer was limited to monochrome text and simple line graphics. Today, there is a large amount of new (affordable) hardware and software technology that permits the capture, creation, display, storage and retrieval of high resolution color graphics, animations, text, and video. Such technology allows technicians to interact with high fidelity images of equipment and permits the storage of extensive amounts of information.

Advances in interface technology have lead to the use of graphical user interfaces (GUI) that allow direct manipulation of the objects on the screen. Such direct manipulation devices, in conjunction with an interactive simulation, permit technicians to "learn by doing." Instructional systems may also take advantage of hypertext (Horn, 1989) and hypermedia (Nielson, 1990) software that has been developed. In a hypertext or hypermedia system, users are not restricted to a single pre-specified learning sequence, but rather may use built-in links to rapidly browse the instructional content and to choose an individualized learning path through the content.

Advances in software technology have also addressed the issues related to making computer-based training more "intelligent". The work of cognitive scientists and artificial intelligence researchers over the past decades have focussed on such software technology, including simulations, expert systems, and Intelligent Tutoring Systems. Simulations model the functionality and behavior of equipment or systems and can be used as part of the instructional environment of a training system. Computer-based simulations have been shown to be effective for diagnostic training (Johnson, 1981, 1987; Maddox, Johnson, & Frey, 1986) Expert systems model the problem solving knowledge of a human expert in some specific area (Hayes-Roth, 1987). Intelligent Tutoring Systems (Polson & Richardson, 1988; Psotka, Massey, & Mutter, 1988) extend the basic **CBI** structure by adding three models: an expert model, a student model, and an instructor model.

**Figure 2** illustrates the conceptual relationship between the generic components of an ITS. The expert model contains the domain specific knowledge that the student is to learn. The student

model is a dynamic hypothesis of what the training system thinks that the student currently knows. This model is based on the observable actions that the student performs in the instructional environment. The instructor model typically compares the model of the student to the model of the expert in order to provide feedback to the student. The instructor model may also monitor the student model to decide when remediation is needed and to select future lessons or problems.

## 4.0 STATUS OF ADVANCED TECHNOLOGY IN AF MAINTENANCE TRAINING

An investigation was conducted to determine if advanced software technology is being applied to Airway Facilities (AF) maintenance training. The investigation was conducted via informal interviews and site visits at the FAA Academy AF Training Development Unit and a regional **CBI** training center. The investigation found that currently available Airway Facilities training does not take advantage of advanced software technology such as simulation, expert systems or Intelligent Tutoring Systems. Rather, the majority of the current computer-delivered training is based on the more limited computer-based instruction (CBI) architecture.

The investigation also found that the currently available AF **CBI** runs on outdated hardware (i.e., monochrome terminals connected to a remote mainframe via 1200 baud modem). However, a new delivery platform has recently been adopted called OATS (Office Automation Technical Support). The OATS platform will permit stand-alone CBI. That is, the courses will be delivered from the local OATS computer without being tied to a remote system through a network. The course material will be stored on CD-ROM and updated CDs will be distributed as needed. For security reasons, however, testing will still be handled over a network.

The AF Training Development Unit has already received positive feedback on the stand-alone course concept. In addition, the AF Developers are planning to augment the basic OATS system with special hardware and software to support multi-media learning including audio, video disk, graphics, and animation capabilities.

Transitioning to the new platform requires translation of existing courses so that they run on the new machines. The AF Training Development Unit has reviewed all existing **CBI** courses for instructional acceptability. Those found to be unacceptable are being discontinued, while the courses which have acceptable content are being upgraded during the conversion to the stand-alone format. The upgrading involves the use of the multi-media capabilities of the OATS platform as well as a break from the simple "page-turner" format. The AF Training Development Unit at the FAA Academy also indicated their plans to make use of expert systems technology for individualized instruction, refresher/proficiency training, and resident courses where appropriate. Given this interest in applying advanced technology to AF training, the research team proceeded with the development of a "proof-of-concept" prototype advanced technology training system.

## 5.0 PROTOTYPE ADVANCED TECHNOLOGY TRAINING



# SYSTEM

A prototype advanced technology training system was developed over a six month period. The development process involved iterations between knowledge acquisition, design, implementation and evaluation. Two important steps were taken prior to actual development: a) selection of the instructional domain and b) selection of the delivery and development hardware and software. This section briefly discusses each of these steps and then describes the prototype system as well as a preliminary evaluation of the prototype.

## 5.1 SELECTION OF THE INSTRUCTIONAL DOMAIN

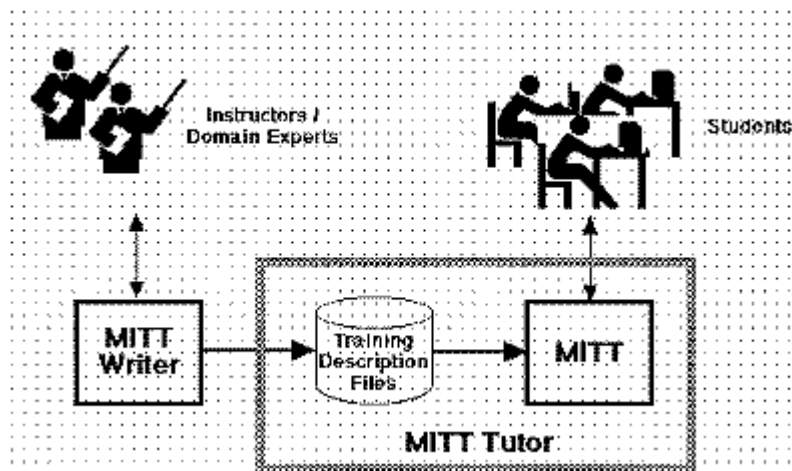
The first step in developing a prototype advanced technology training system was to identify a piece of AF equipment that is appropriate for this type of training and for which additional training is needed. FAA personnel identified the following as candidates for the training system: the Paradyne modem, ATCBI-4, ATCBI-5, and Common Digitizer.

To determine the final selection, discussions were held during site visits to the General National Airspace Sector (GNAS) office in Atlanta, GA and the Air Route Traffic Control Center (ARTCC) in Hampton, GA. Based on these discussions, the Air Traffic Control Beacon Interrogator - Model 4 (ATCBI- 4) was selected as the best choice for prototype development. The Paradyne Modem was rejected due to the lack of available troubleshooting expertise. The Common Digitizer was rejected because the need for training was not as great as for the ATCBI-4. The ATCBI-5 was rejected because the research team was located in close proximity to an ATCBI-4 system and expert technicians.

## 5.2 DELIVERY AND DEVELOPMENT HARDWARE AND SOFTWARE

In order for the prototype training system to be of value to the technicians in the field, it had to be developed for a hardware delivery system that would be available to the technicians. Given that the FAA had selected OATS machines as the new standard, the prototype advanced technology training system was targeted for delivery on an OATS machine in the Microsoft Windows environment. The prototype requires the following minimal configuration: 386/25MHz machine, Microsoft Windows 3.0, 4MB of memory, VGA monitor, a run-time version of Asymetrix Toolbook, and a mouse input device.

The initial prototype development, however, began in the DOS environment in order to make use of rapid prototyping tools: Microcomputer Intelligence for Technical Training (MITT) and MITT Writer. Both MITT and MITT Writer run in the DOS environment and use EGA graphics. **Figure 3** illustrates the relationship between these two tools. MITT Writer (Wiederholt, 1991, 1991, November) is a development environment for producing a description of training without the need to write computer code. MITT (Johnson, Norton, Duncan, & Hunt, 1988; Norton, Wiederholt, & Johnson, 1991) uses the training description files to deliver simulation-oriented troubleshooting training.



**Figure 3 Relationship Between MITT and MITT Writer**

In addition to its rapid prototyping capability, the MITT system is an Intelligent Tutoring System which provides two types of advice: procedural and functional. MITT's functional advice is based on the simulation model which represents the connections between parts. MITT's procedural advice is based on documented troubleshooting procedures and the experience of expert technicians.

Although MITT Writer was designed to aid an instructor or domain expert in developing a MITT tutor, this tool was used by a member of the research team to quickly produce and modify an initial prototype system. The MITT program was then used to run the training system to obtain input and feedback from technicians. Technicians who reviewed the initial prototype system reacted favorably to the MITT approach to troubleshooting training. Thus, the research team decided to capitalize on the MITT technology to develop a similar ITS system that would run in the Windows environment. The final prototype system was developed using Asymetrix Toolbook and Borland C++.

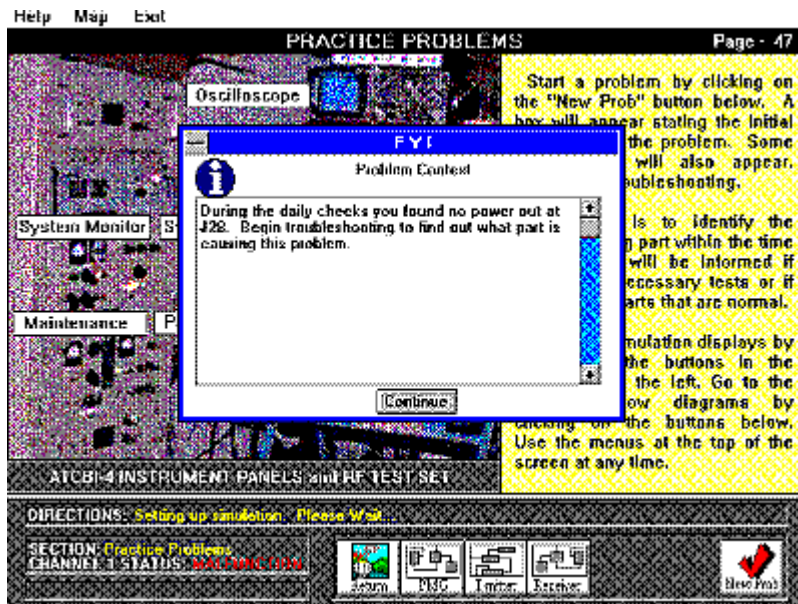
### **5.3 DESCRIPTION OF THE PROTOTYPE**

The prototype investigates the use of advanced technology in proficiency training for AF maintenance technicians in the area of troubleshooting. As discussed above, the instructional domain for the prototype is the ATCBI-4. The ATCBI-4 is a complex electronics system which provides controllers with identification and altitude information about aircraft in the surrounding airspace.

The prototype training system is divided into four major sections: Introduction to Training, Understand the Simulation, Understand the System, and Practice Problems. **Figure 4** shows the main screen of the training system. The four buttons at the bottom of the screen allow the user to access any of the four sections. The Practice Problems section is the primary focus of the proficiency training system, while the first three sections provide background and support information. A description of the Practice Problems section follows.

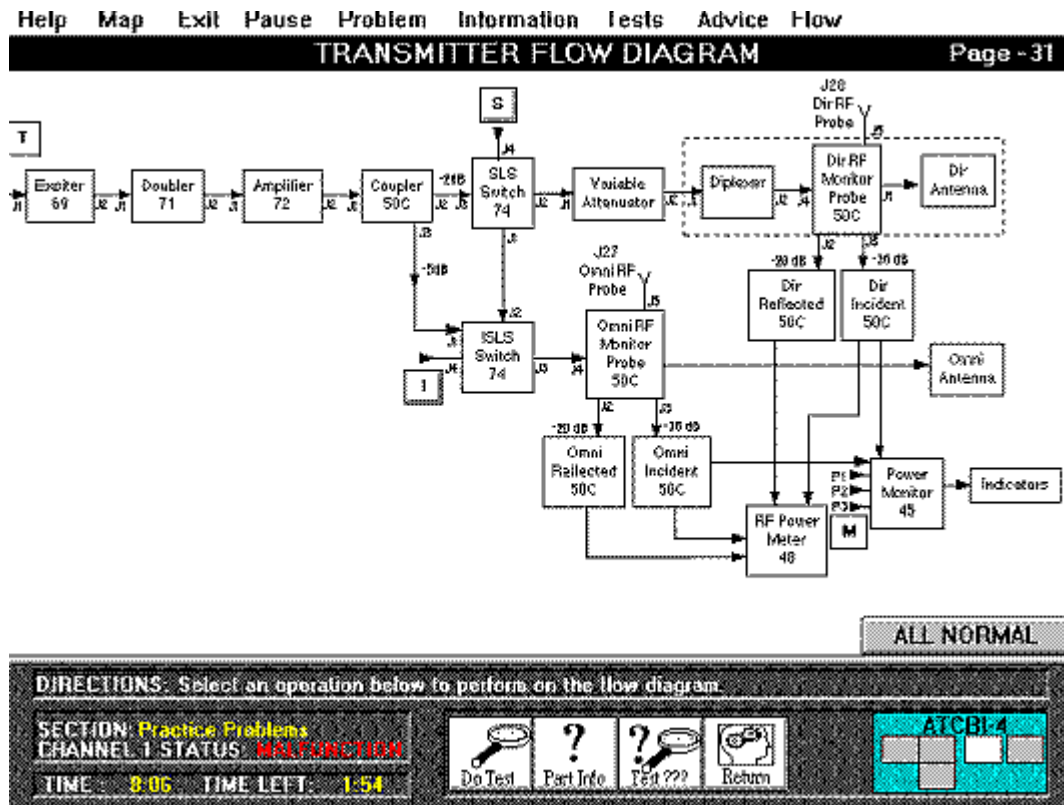
The Practice Problems section allows the technician to practice the mental skills of

troubleshooting with the help of an expert advisor. When the technician starts a practice problem, a scenario is given which states the initial conditions of a problem. **Figure 5** shows an example of a problem scenario. The technician is then free to begin troubleshooting. The technician's goal is to identify the malfunctioning component as quickly as possible without making unnecessary or illogical tests.



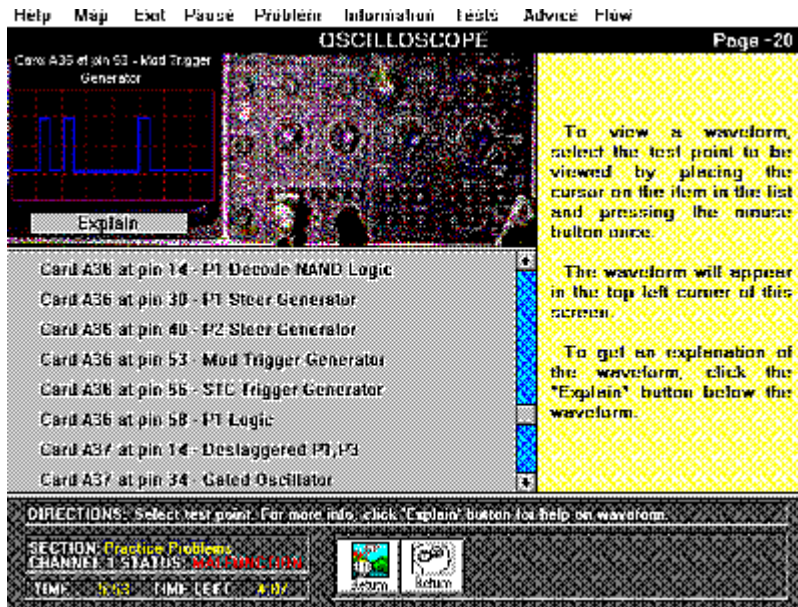
**Figure 5 Example Scenario**

In general, the technician can go to the simulation displays or functional flow diagrams (**Figure 6**) and begin choosing tests to perform. There are two levels of information that can be accessed. Tests performed on the functional flow diagrams (or through the use of the Tests menu) always state the summarized test result, i.e., whether the part or output is normal or abnormal. By reducing the complexity of the information, the technician can focus on learning more generalized troubleshooting skills.



**Figure 6 Example Flow Diagram**

Technicians who want a higher fidelity simulation may use the simulation displays which provide a more realistic decision environment. On the simulation displays, the test results are given as actual data values which must be interpreted as being normal or abnormal. For example, the oscilloscope simulation display is shown in **Figure 7**. The technician selects a test point and the waveform is displayed. The technician must then decide if this is normal output for the selected test point. If needed, the technician may request an explanation of the waveform which describes the waveform and states whether it is normal or abnormal.



**Figure 7 Example Oscilloscope Test**

If the technician does not know what test to perform, he can request either functional or procedural advice. The functional advisor will suggest that the technician perform a test on the part that has the potential for eliminating the most parts from consideration as the malfunctioning part. Functional advice is based on the functional flow connections between parts contained in the simulation of the equipment and logical troubleshooting principles. For example, if a part has bad output, then any part "downstream" of that part cannot be causing the malfunction and can be eliminated from the set of feasible parts. Similarly, if a part has normal output, then any part "upstream" from that part cannot be the malfunctioning part and therefore can be eliminated from the set of feasible parts.

The procedural advisor, on the other hand, will suggest a test based on the experience of an expert technician. A recently retired AF technician was consulted to develop the procedural advice for each practice problem. The expert suggested realistic tests for quickly isolating the malfunctioning part. However, it must be emphasized that there is no single "correct" procedure in terms of which part to test in what order. Therefore, the technician is not forced to follow the exact steps suggested by the expert.

There are times when the technician is penalized, however. The system tracks the students actions and provides unsolicited instructional advice when the technician does one of the following: a) tests a part which is "upstream" from a part that was tested and shown to be normal, b) tests a part which is "downstream" from a part that was tested and shown to be abnormal, and c) identifies a normal part as the malfunctioning part. These three actions count as troubleshooting errors that are tallied and reported at the end of a practice problem session.

## **5.4 DISCUSSION OF THE PRELIMINARY EVALUATION**

An informal preliminary evaluation was conducted with the prototype software. Three



technicians were observed while interacting with the prototype training system during approximately one hour sessions. None of the technicians had used the prototype prior to this session.

Each session began with the first screen of the training system already displayed. The developers informed the technician that the purpose of the session was to interact with the training system to determine what they like and dislike about the system. Each technician was also informed that there would be an evaluation sheet provided at the end of the session to solicit such feedback.

In general, the three technicians were able to use the system with little input from the observers. No major errors were encountered, however, minor changes to the interface were made in response to user comments. The technicians all gave positive verbal comments about the system and each was able to successfully complete a practice troubleshooting problem. Two of the three technicians indicated that they would use this system for proficiency training. (The technician who indicated that he would not use this system is a supervisor and is no longer responsible for troubleshooting the ATCBI-4 equipment.)

## 6.0 FUTURE PLANS

In the next phase of this research, the prototype system will be extended into a complete proficiency training system for troubleshooting the ATCBI-4. There are four major tasks involved in this effort. First, input will be obtained from the AF Development Unit and AF technicians to guide development of the complete training system. Based on this input, changes will be made to the instructional environment, student model, instructor model, and the expert model. Third, knowledge engineering work will continue in order to extend the set of simulated practice problems. Finally, the knowledge base of domain specific data will be restructured to improve the access time and facilitate the development of similar systems.

Upon completion and review of the final ATCBI-4 training system, work will begin on an authoring system for the development of additional AF Maintenance ITSs. The research team will work with personnel at the FAA Academy to develop a functional specification that meets the needs and desires of training development personnel. A demonstration development system will be developed to provide a concrete basis for the discussion.

In addition, work will begin on the development of a plan and preliminary specification for an advanced technology AF Information System. The AF Information System will integrate three components into one system: training, job-aiding, and information storage and retrieval. The completed training system will serve as the initial basis for the training component of the AF Information System. The research plan will detail how the knowledge base of the training system will be extended to support real-time job aiding. In addition, the plan will describe the development tasks for including additional documentation in the system.

## 7.0 ACKNOWLEDGEMENTS

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## TRAINING FOR VISUAL INSPECTION: CONTROLLED STUDIES AND FIELD IMPLICATIONS

*Colin G. Drury  
and  
Anand K. Gramopadhye  
State University of New York at Buffalo  
Department of Industrial Engineering*

### 1.0 ABSTRACT

The three factors most affecting visual inspection performance were derived from a generic task analysis of inspection. For each of these three, possible training interventions were found from the literature on industrial inspection. Direct tests of these interventions were made through five experiments on a computer-based simulator for aircraft visual inspection. One experiment is presented, showing how the size of the area seen by an inspector in a single visual fixation can be trained to improve search performance. Implications of the results of this controlled study for the training of aircraft inspectors are given.

### 2.0 INTRODUCTION

Training continues to be a major way in which airlines and other operators seek to improve human reliability in aircraft maintenance and inspection. While training systems for complex diagnostic tasks are currently being developed (Johnson, 1990), a parallel effort by the FAA's Office of Aviation Medicine is aimed at improving visual inspection training. This paper uses the generic task description of visual inspection (Drury, et al., 1990) to structure a search for ways in which visual inspection training can be enhanced. **Table 1** shows this generic task description of aircraft inspection, where it can be seen that some of the tasks (1. Initiate, 2. Access, 5. Respond) are mainly procedural. The interventions to improve these are less likely to be training interventions than physical changes to job cards, access equipment, recording forms, etc. Even where training is used, there is considerable literature in existence on learning lists of procedures. Of the other tasks, one (6. Repair) is beyond the scope of visual inspection training

as it is carried out by mechanics rather than inspectors, while the final task (7. Buy-back Inspect) recapitulates all other steps. This leaves the key tasks requiring training interventions as 3. Search and 4. Decision Making. Both have already been established as potentially the most error-prone in inspection (Drury, 1989). Within the area of Decision Making are two types of decision tasks, one involving reasoning and the other involving perception.

**Table 1 Generic Task Description of Incoming Inspection, with Examples from Visual and NDT Inspection**

TASK DESCRIPTION	VISUAL EXAMPLE	NDT EXAMPLE
1. Initiate	Get workcard. Read and understand area to be covered.	Get workcard and eddy current equipment. Calibrate.
2. Access	Locate area on aircraft. Get into correct position.	Locate area on aircraft. Position self and equipment.
3. Search	Move eyes across area systematically. Stop if any indication.	Move probe over each rivet head. Stop if any indication.
4. Decision Making	Examine indication against remembered standards, e.g., for dishing or corrosion.	Re-probe while closely watching eddy current trace.
5. Respond	Mark defect. Write up repair sheet or if no defect, return to search.	Mark defect. Write up repair sheet or if no defect, return to search.
6. Repair	Drill out and replace rivet.	Drill out rivet. NDT on rivet hold. Drive out for oversize rivet.
7. Buy-back Inspect	Visually inspect marked area.	Visually inspect marked area.

Training is aimed at reducing both search errors (all misses) and decision errors (misses and false alarms). From a review of the various training interventions available, it becomes apparent that some interventions are better suited to some component tasks. The following section presents part of this review as a research rationale which will lead to specific experimental tests of training interventions. This review covers three areas which are critical to inspection performance: search, decision-making and perception.

## 3.0 WHAT IS KNOWN ABOUT SEARCH, DECISION AND PERCEPTION TRAINING

### 3.1 VISUAL SEARCH

When an inspector searches an area for defects, small sub-areas are fixated in turn. The eye remains stationary for about 0.3 seconds during each fixation, at which time an area around the fixation point is processed for visual signs of defects. The area which can be processed in one fixation is known as the Visual Lobe, and is an important determinant of search performance.

Larger visual lobes lead to more defects being detected within any given time frame. The visual lobe is measured by repeatedly flashing search areas onto a screen, and asking the inspector whether a target (defect) was present. By placing targets at different points around the center of the fixation, the size of the visual lobe can be mapped out by determining the boundary between those seen and those not seen. However, visual lobe size is not the only aspect of search determining performance. The inspector must have a strategy of how to move the visual lobe across the search area without missing any points, but with efficiency.

Visual lobe training has been studied by Leachtenaver (1978) for photo-interpreters, who found that practice on a search task increased visual lobe size. However, practice on a visual lobe measurement task may also increase lobe size and transfer this increase to search performance.

Search strategy training is an under-represented area in the literature. From the literature it is seen that systematic search is always more efficient than random search, so that a useful assumption is that the searcher is always trying to be systematic. One training objective should be to ensure systematic search, i.e., search in which all areas are fixated, and none are refixated during a single scan. The major difference between systematic and random search is whether or not an area is refixated. The only logical reason for an inspector to refixate an area before a total scan is completed is that the searcher does not remember whether or not that area has been fixated already. Hence, it is seen that it is necessary to provide a memory-aid to the subject to indicate the points of previous fixations to avoid refixations. This could be done by training the inspectors to use feedback from eye movements, either be continuously (on-line) or in a discrete manner at the end of a search task.

Feedback from eye movements can be provided regarding both the number of fixations and the interfixation distance. Literature suggests that these parameters are correlated with an inspector's efficiency in locating possible defects. Providing this sort of feedback would be expected to result in the inspector developing a more efficient search strategy.

## **3.2 DECISION MAKING - REASONING**

Wickens (1984) states that training for decision making can be provided in the following ways:

- Make the decision maker aware of the nature of limitations and biases. Training operators to consider alternative hypotheses might reduce the likelihood of cognitive tunnel vision.
- Provide comprehensive and immediate feedback so that the operators are forced to attend to the degree of success or failure of their rules.
- Capitalize on the natural efforts of humans to seek causal relationships in integrating cues when correlations between variables are known beforehand. Hence, providing information to the operator so as to emphasize the co-relational structure would help in entertaining particular hypotheses.

## **3.3 DECISION MAKING - PERCEPTION**

In perception of fault indications, there are typically many characteristics which must be taken into account. For example, a dent's size, depth, and position in the airframe all affect its

criticality. Similarly, corrosion's criticality depends upon its location, severity, and area. The inspector gradually learns what combinations of characteristics make a fault critical, partly from written rules, but also partly from experience. This experience is known in the training literature as the development of a "schema" for that fault.

The schema is a general body of knowledge about the characteristics of a fault that does not contain a strict listing of its defining features (e.g., features which must all be present for a particular instance to be termed a category). According to Posner and Keele (1968) the development of a schema consists of two components:

- a general representation of the prototypical fault, i.e. the basic form from which all the forms are derived;
- abstract representation of the variability around this prototype.

Research in schema formation suggests that the nature of mental representation which people use to classify stimuli into categories is not a strict list of the characteristics of the prototype but also contains information concerning the variability around the template. This is suggested by Posner and Keele (1968) who found that exposure to a variety of instances of a schema induced better performance than repeated exposure to a single instance. Other data shows that assignment is not made by relating each new instance to a central prototype but rather relating it to the previous fault to which it is most similar and then assigning each new instance to the same category as that previous fault.

From the above discussion, it is thus seen that to help in the development of the schema the training provided should be of variable instances of the fault rather than a single instance of a prototypical member, or rules defining the features which would classify the members by criticality. The amount of variability provided in the training should be similar to that existing in the real setting.

## 4.0 WHAT IS KNOWN ABOUT TRAINING INTERVENTIONS

From the above discussion, training for visual search would be expected to result in reduced search errors (faults missed entirely) and reduced search time. Similarly, training for decision making and perception would be expected to result in a reduction both in misses and false alarms. Although training can be used to improve visual inspection performance, specific training schemes are not associated with factors that determine improvement in visual inspection performance. Hence, *ad hoc* training schemes are developed that guarantee improvements for a particular task without consideration whether such a training scheme could be extended to a similar task or a different task, or whether the training is optimizing the use of instructor and trainee time. Hence, the first step in the development of a rational training scheme is to identify the factors that affect visual inspection performance. The next step is to determine which of the functions of the inspection task are trainable. This, in turn, will establish the sensitivity of the inspection parameters to training.

For any training scheme to be effective it should minimize both search errors and decision errors. Thus, referring to the generic task analysis of visual inspection, it is observed that intervention

strategies developed at various stages of the inspection process can be hypothesized to change the inspection parameters, resulting in improved performance. In order to improve visual inspection performance, it is necessary to develop training schemes which predict improvements in each of the factors: search, decision making and perception. In the following section various training interventions are briefly described. These will need to be matched to the three factors above in order to derive valid, generalizable interventions.

## 4.1 VISUAL LOBE TRAINING

The visual lobe is a very important determinant of search performance, with a larger visual lobe require fewer fixations than those with a smaller visual lobe. A large visual lobe or peripheral acuity may account for superior search performance. We still need to know how a large visual lobe can affect search performance and how people can be trained so as to increase the size of the visual lobe. If the above questions are answered, this would then result in a strategy for improving the visual lobe size. The more general question which arises is: how does lobe size training generalize across tasks (e.g., targets and backgrounds). Will the visual lobe training on a given target type result in an improved search performance for a different target type? Thus, it is essential to identify whether such a cross-over effect exists. If it does, then it is sufficient to train the person on one target type. If not, then it is essential to identify various target subsets, say *T1*, *T2*, within which cross-over does occur so that inspectors can be provided visual lobe training on a single target belonging to each target subset.

## 4.2 FEEDBACK TRAINING

A person needs rapid and accurate feedback in order to correctly classify a defect, or to know the effectiveness of a search strategy. Every training program should begin with frequent feedback and gradually delay this feedback until a level of proficiency has been reached. Additional feedback beyond the end of the training program will help to keep the inspector calibrated. Logically, the following feedback could be provided:

- Feedback regarding the correctness of classifying defective items into categories
- Feedback of search strategy from monitoring eye movements
- Feedback of fixation times from the eye movement search.

The first is known to be essential to learning in perceptual tasks. It provides the novice information regarding the critical difference between a defective item and a perfect item, thus helping to develop a mental template which has the internal characteristics of the defective item. We are, however, still unsure as to what has improved. For example, has learning resulted in a new internal conceptual model of the task (i.e., is the inspector using only certain dimensions of the fault to classify it)?

It has been shown that an important difference between the best and the poorest search performance is the length of the sweeps between eye fixations during a search task. Thus, there exists a difference between how a novice and an expert move their eyes across the visual field. Gould (1973), in a visual inspection study of circuit chips, found that most of the eye fixations occur within a definite boundary, which is the area most likely to contain the targets. It is

demonstrated that eye movements in a visual search scenario occur based on knowledge of the location of faults and on the probability of them occurring. The question that needs answering is: does feedback information regarding the eye movements help improve the scanning strategy? If so, then providing such feedback information would aid the inspectors by allowing them to identify areas not covered or areas where they spend excessive time, and helping them develop a strategy to cover the entire area more effectively.

### **4.3 FEEDFORWARD TRAINING**

The novice inspector has little knowledge of the type of faults, probability of faults and occurrence of faults, so that visual search would be expected to be inefficient. Providing feedforward information should result in an improved search strategy because the uncertainty is reduced; by the inspector knowing both where to look and what to look for. The inspector can use the information to achieve a more systematic search strategy, guided by the knowledge of the fault characteristics. Kleiner (1983) suggests that experienced inspectors make use of feedforward information that complements their sensitivity to the fault. If the fault is one that is not easily detected, then the inspector relies heavily on the information provided. Inspection tasks that will most likely benefit from the addition of feedforward information include those in which it is critical for the fault to be detected, those in which the fault is particularly difficult to detect, and those in which the product may contain rare, detrimental and easily overlooked, faults.

### **4.4 ATTRIBUTE TRAINING**

If a fault has, say, four different attributes contributing to its criticality, then the inspector must be trained on each of these attributes, to allow the inspector to set a response criterion for each attribute. The training should be generalizable in the sense that the inspector should be able to classify the items as defective if the items are faulty on one or more of the attributes. The inspector could be trained on which attributes to match against the standard first, based on the probability of the item being faulty on the attributes, and the ease with which the matching occurs. Experience and training of the inspectors determine how defect attributes are arranged in order.

A similar training scheme has been proposed by Salvendy and Seymour (1973) for developing industrial skills. Here, separate parts of the job are taught to criterion, and then successively larger sequences of the job are integrated. Kleiner (1983) used such progressive part training very effectively in inspection.

### **4.5 SCHEMA TRAINING**

It is essential that the subject develop a valid mental template (schema) of the fault. The key to the development of a schema is that it should provide for successful extrapolation to novel situations which are still recognizable instances of the schema. We need to know how schemas are developed, and how aircraft inspectors can be trained to develop schemas. What sort of training (rule based or knowledge based) should be provided to the inspectors for effective

development of such schemas?

The effects of two methods of training need to be evaluated in schema development: "active training" and "passive training". In active training, the inspector is presented with various instances of the fault and no-fault, and has to classify them as defective/non-defective. Feedback is provided regarding the correctness of classification. In contrast, passive training is where the inspector is merely presented with various instances of the faults without requiring an active response. Both have been found to be effective, with active training particularly useful for older inspectors.

## 5.0 TESTING TRAINING INTERVENTIONS FOR VISUAL INSPECTION

As part of a longer-term study of training for visual inspection, a series of tests of intervention strategies was undertaken under controlled conditions. Each test was aimed at determining whether a particular intervention had an impact on improved performance. Because these needed controlled conditions, often with many repetitions of similar faults, actual airframes and inspectors were not logically possible. For example, the hundreds of cracks and dents required for the visual lobe training would never be available to an inspector. Thus, a visual inspection simulator was developed, using a SUN workstation computer to reproduce the essential aspects of the visual inspection task. Four fault types can be generated on a search screen which shows a large array of rivets on the fuselage of an aircraft. The search screen can be moved along the fuselage to search the whole of the pre-defined fuselage section. Also, a single screen can be presented briefly to the subject to allow visual lobe measurements.

The five experiments run on this simulator are as follows:

Experiment 1: Visual Lobe Training. This experiment tests for the possible cross-over effects on the size of visual lobe measured for different fault types.

Experiment 2: Feedback Training. This compares a control group and three feedback groups, having on-line and off-line feedback of both cognitive factors and performance factors.

Experiment 3: Feedforward Training. Again, a control condition is used as a baseline against which to compare rule-based feedforward, knowledge-based feedforward and combined feedforward.

Experiment 4: Attribute Training. Training for decision making using attributes training, i.e. providing the trainee with several levels of severity and complexity, is compared to a control condition where narrative descriptions are provided of the fault attributes.

Experiment 5: Schema Training. Schema development is encouraged by exposing trainees to a wide variety of schema instances (corrosion levels and patterns) in both active and passive schemes.

As these controlled studies were designed to test the feasibility of the training interventions, economical but valid designs were used. In this way, areas which should have an impact on



future training schemes for aircraft inspectors could be rapidly assessed. When the results of these experiments are analyzed, the specific implications for airline inspection training can be developed. At this stage, all experiments have been conducted and analyzed, but because of space limitations only the first is described here.

## 6.0 TYPICAL INTERVENTION TEST: VISUAL LOBE PRACTICE

The objectives of this experiment were to determine the relationship between visual lobe size and search performance, relate changes in lobe size to search performance, and evaluate the effectiveness of lobe training. In particular, the experiment measured whether crossover effects exist in visual lobe training. It used two types of rivet fault (cracks and loose rivets) and two types of area fault (corrosion and dents) to determine whether visual lobe training on one fault would generalize to other faults of the same or different classes.

### 6.1 METHOD

Twenty-four subjects were used for this study, randomly assigned to four different groups, Rivet Training, Area Training, Neutral Training, No Training. All subjects were tested for 20/20 vision and color blindness.

Rivet Training Group: Subjects assigned to this group initially performed the visual search task on all the four fault types (randomly ordered) followed by visual lobe training on rivet fault: rivet crack. The visual lobe training consisted of performing the visual lobe task five times. The training session was followed by the search task on the four fault types.

Area Training Group: Subjects assigned to this group also initially performed the visual search tasks on all four targets (ordered randomly). They followed this by visual lobe training on one area fault and dent. The visual lobe training consisted of performing the lobe task five times. The training session was followed by the search task on all four fault types.

Neutral Training Group: Subjects assigned to the group performed the visual search task in a similar manner to subjects in the previous groups. However, this was followed by visual lobe training on a neutral target, a computer-generated character. This training session was followed by a similar visual search task.

Control (No Training) Group: Subjects assigned to this group performed similar visual search tasks. However, they did not undergo any visual lobe training. Subjects in this group performed a computer task for a duration equal to the time required for the completion of the visual lobe training session in the other groups. This was followed by the visual search task.

### 6.2 TASKS

**Visual Search Task.** The visual search task was the computer-simulated airframe visual inspection task. Subjects had to search for a single fault type in a given area. Visual search

performance of the subjects was evaluated on four faults which were classified into two types:

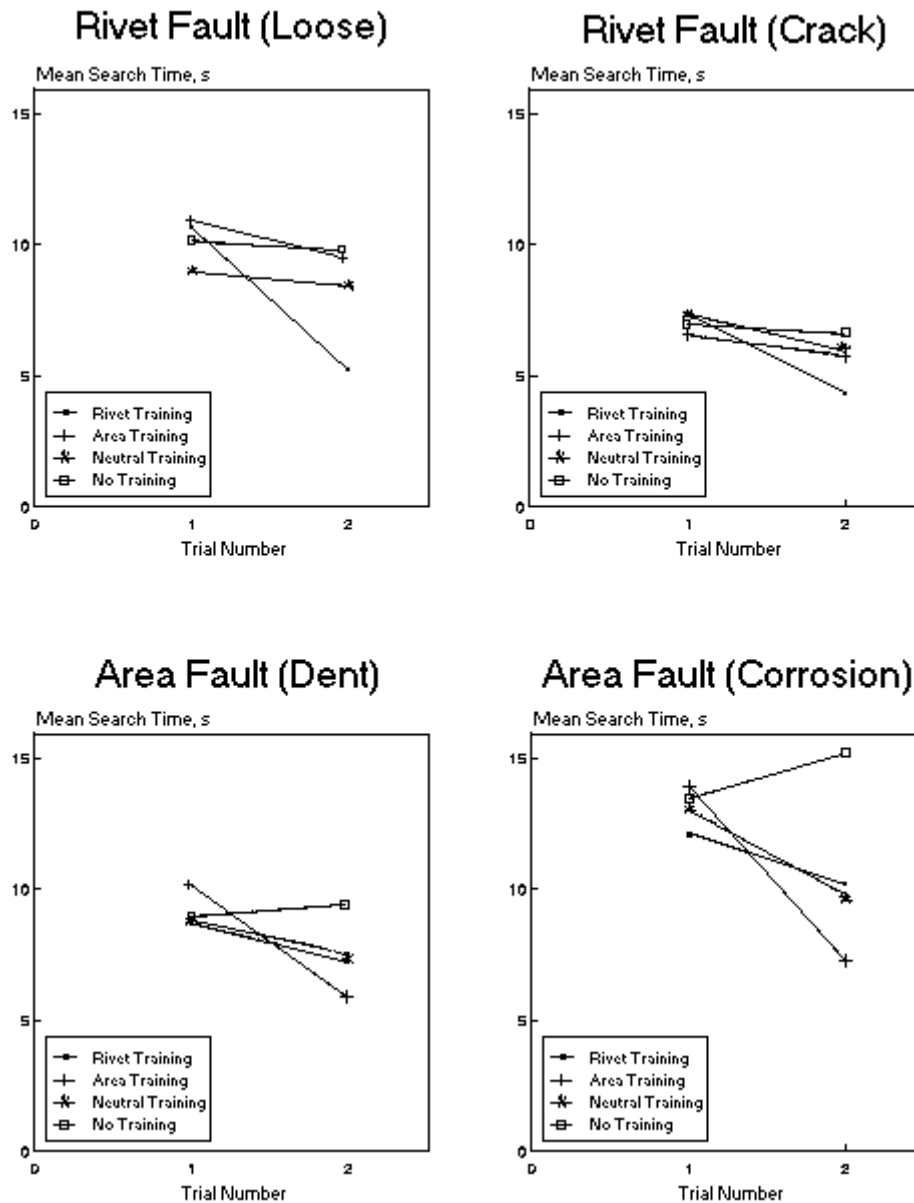
1. Area Faults - 1) corrosion, and 2) dent
2. Rivet Faults - 1) rivet crack, and 2) loose rivets (indicated by streaks of dirt on the rivet edge).

The task was unpaced. During each of the four visual search tasks, the subjects had to search for one of the predefined faults. Subjects were instructed to work as rapidly as possible consistent with accuracy. Subjects verified their response by clicking on the fault with the mouse button. Once a fault was located in a given area, subjects inspected the next area.

**Visual Lobe Task.** The purpose of the lobe task was to determine the size of the visual lobe; i.e., how far into the periphery a subject could see in a single fixation. The basic procedure consisted of determining at what distance from the central fixation point the target was completely seen by the subject in a single fixation of the fault screen. The exposure duration was kept sufficiently short (0.33 s) to allow the subject a single fixation only. Subjects had to identify a single fault (a rivet fault in the case of the rivet training group, an area fault in the case of the area training group and a neutral fault (across) in the case of the neutral training group). The fault would appear on the horizontal center line of the target screen, at six equally spaced predetermined locations on the horizontal center line, three positions on either side of the central fixation point. No prior information concerning the position of the target was provided to the subjects. The subjects identified the position of the target, either to the left or to the right of the origin and accordingly pressed the key "Q" and "P" to register their response. Subjects were requested to avoid guessing and register responses only if they were sure as to the position of the targets. The fault screen alternated with a fixation screen, consisting of crosswires at the central fixation point exposed for a period of 2 seconds. The purpose of the fixation screen was to help the subjects fixate in the center of the screen after each viewing of the target screen.

## 6.3 RESULTS

To determine whether the visual lobe increased in size during the training, an ANOVA was conducted for the lobe size for the three groups (1, 2 and 3) receiving lobe training. Over the five training trial significant effects of group ( $F(2,15) = 11.05, P < 0.0011$ ), training trial ( $F(4,60) = 13.46, P < 0.0000$ ) and their interaction ( $F(8,60) = 1.75, P < 0.1046$ ) were found. To test whether the visual lobe training transferred to the visual search task, Analyses of Variance (ANOVAs) were performed on the mean search times for each fault type. These analyses showed no main effects of groups, but highly significant group X trial interaction. **Figure 1** shows these group X trial interactions, where it can be seen that the two faults trained in the visual lobe training had the largest improvement. For the faults not trained by visual lobe training, the improvement was greater where there was more similarity to the visual lobe fault. Neutral training had a smaller amount of transfer, while no training, i.e., spending equivalent time on other computer tasks, had no beneficial effect.



**Figure 1 Search Performance Before and After Visual Lobe Training**

Similar results can also be seen when the changes in visual lobe size during training are related to the changes in search time after training. **Table 2** relates the dependence of search time for each fault type to the increases in lobe size, using the coefficient of determination ( $r^2$ ) as the measure of dependence. There was a direct transfer from the fault used in visual lobe training to that fault in visual search, with a smaller transfer to the other fault in the same group (rivet or area). The neutral fault visual lobe training transferred only to one area fault.

**Table 2 Dependence ( $r^2$ ) of Percent Changes in Search Time on Percent Changes in Visual Lobe Size for Each Group**

Percent Increase in Visual Lobe Size For:	Percent Decrease in Search Time For:			
	Loose Rivet	Rivet Crack	Corrosion	Dent
Rivet Training Group	0.75	0.36	0.01	0.21
Area Training Group	0.09	0.00	0.68	0.85
Neutral Training Group	0.16	0.05	0.74	0.00

## 6.6 DISCUSSION AND CONCLUSIONS

Providing training, even just repeated practice, in rapidly detecting a fault in peripheral vision, does indeed increase the size of the area in which that fault can be detected in a single glimpse, i.e., the visual lobe. This increased visual lobe is not merely a result of increased familiarity with the experimental visual lobe task, as it transfers to a more realistic inspection task, visual search. Thus, even such a basic measure of inspection performance as the visual lobe can be trained to improve. For each fault type there was a 20-30% increase in lobe size over just five practice trials. This transferred to the search task with percentage changes in overall visual search time of:

Rivet Training Group 1	30%
Area Training Group 2	32%
Neutral Training Group 3	18%
No Training Group 4	-4%

There is a close correspondence between the training on actual faults (rivet and area training groups) and improvement in search times, and even some improvement for training on a neutral fault, i.e., one which did not appear in any search tasks. No training, as expected, produced no effect.

From previous visual search studies it is known that visual search follows a speed/accuracy tradeoff curve, so that what has been measured here as search times, can also be interpreted as search accuracy in a given, fixed time. Thus, this experiment has demonstrated the value of training in increasing the inspector's ability to receive and interpret peripheral visual information. The benefits of a simple, simulator- based study in rapidly determining the feasibility of new training techniques has also been demonstrated. A study based on actual faults on a real aircraft structure would have been impossible as single glimpses cannot be repeated without the inspector learning the true identity of each fault. A study using hardware to simulate the faults would be extremely cumbersome, with hundreds of fuselage samples identical apart from fault location being required.

## 7.0 IMPLICATIONS FOR TRAINING PRACTICE

Each of the experiments run on the simulator has produced positive results, so that more is now known about the basic training interventions for aircraft visual inspection. Successive experiments have shown how the essential factors in visual inspection (visual lobe, search strategy, decision making and perception) can be improved with the appropriate intervention. The next step is to relate these to specific steps which can be taken to improve specific inspector training schemas.

As was noted at the outset, visual inspection is not easy to train. How can the trainer move the trainee's eyes and direct the trainee what to see? In the specific area of visual lobe size improvement, how can the area taken in during one fixation be enlarged? Experiment 1 has shown that if the visual lobe is enlarged, better search performance does result. Thus, lobe size improvements are worth pursuing. It has also been shown that practice in detecting targets away from the direct line of sight in very short time intervals trains people to be alert to their peripheral vision, hence increasing lobe size. The transfer results show that the closer the trained fault is to the actual target characteristics, the greater will be the training benefit.

To take advantage of these results, visual lobe training can be given on a computer system, or even using color slides of actual defects, each defect being exposed very briefly for the inspector. With such practice, the increases in lobe size can be expected to transfer to actual defects on actual aircraft. The more similar the training materials are to the real defects, the greater will be the training benefit, but even visual lobe training on a neutral target provided some improvement in search performance.

Rapid exposure of defects (off-axis) to the inspector is, thus, a valid method of improving the conspicuity of defects, i.e., visual lobe size. This effect should generalize well across many defect types. What is still not known is how to use visual lobe training efficiently. It has been shown to be effective, but how often to give it during training, and how often to retrain are still research objectives, but the basic effectiveness has now been established which makes it worthwhile to proceed with refining the technique.

Experiments 2-5 have been completed and analyzed, with the task now remaining being to interpret their results into practical training interventions in a similar manner.

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## CONTINUOUS IMPROVEMENT AT NWA ATLANTA

Steve H. Eberhardt  
*Northwest Airlines, Inc.*

### 1.0 BACKGROUND

The Northwest Airlines Atlanta Maintenance Facility is a division of the Minneapolis-based airline's Technical Operations Department. The base of approximately 1,500 employees has the responsibility for Douglas DC-9 reliability through 4 periodic check lines, Pratt & Whitney JT8D engine repair and overhaul, and support shops that provide repaired products supporting both product lines. These product lines became the responsibility of Atlanta following the 1986 merger between Republic Airlines and Northwest Orient Airlines.

During the 1987 production year, data collection quickly revealed that production performance would never meet production capabilities. That data collection proved to be true. Periodic check performance barely met 33% of its on-time production capability with post-maintenance discrepancies averaging above 10 discrepancies per aircraft. Engine production data revealed the same information; approximately 63% of capability with some engines staying in the repair or overhaul process for as many as 100 days or more. Test cell acceptance rate was approximately 65%.

The most important item tracked in that year was on-the-job injuries (OJIs), which averaged 17 per 100 employees per month, and were among the worst for a department within the entire airline.

I personally feel there were two major contributors to this poor performance:

1. The 1986 merger of the two carriers brought two entirely different maintenance programs together with no plan as to which program would continue to be used. This led to a large degree of confusion among maintenance personnel.
2. There was a degree of animosity between Republic and Northwest Orient employees after the 1986 merger that caused morale and attitudes to plunge.

The stage was then set and the base was ready to venture into something that would lead them out of this disastrous position.

In late 1987, the Senior Management Team began to plan and implement a Continuous Improvement Process. Year-end data for 1991 revealed that the plan has been working. 1991 periodic check performance improved to 95% of on-time production capability with an average of fewer than five post maintenance discrepancies and engine production increased to 77% with test cell acceptance rate above 85%.

## **2.0 NWA'S SEVEN STEPS OF CONTINUOUS IMPROVEMENT**

The steps an organization takes toward implementation of a Continuous Improvement process may vary, depending on size of the organization and the items of focus. Our organization utilized seven.

First, we knew we had to re-educate our employees. Not only did we have to conduct recurrent technical and on-the-job training, but also realized an emphasis had to be placed on non-technical skills as well.

Before we could get started with our education plan, we made absolutely sure that all employees understood what a Continuous Improvement Process was, and what it would take by all to make it a success. We explained that Continuous Improvement simply means small, positive, incremental changes, that helps save time and money; i.e., reducing OJIs means having more employees on the job, reducing cycle time of product production means saving money by not having products out of service for extended periods of time, doing a job right the first time means reduced rework and that saves dollars, having aircraft available for operations on time means happier customers due to less delays, and the list goes on.

We began our education step by teaching and reinforcing to our employees the Mission of the Corporation, (To Be The Airline of Preference), and the Technical Operations and Atlanta role in contributing to that corporate mission (To consistently provide safe, clean, technically sound aircraft to support on-time operations). We, then, began to work with our administrative and hourly personnel on "soft skills," (public speaking, improved reading and comprehension techniques, listening skills, presentation techniques, Principle Centered Leadership, data collection and analysis, and many others). This education process continues today.

Secondly, an assessment of our base activities was taken by all employees. One day, in December, all employees were asked to go to one of several base meetings, conducted at our Training Center Auditorium. Questions were not only asked in regards to product line



productivity, but how we, as a management team, could help our employees do a better job. (NOTE: I recommend you not take an assessment unless you truly want to hear what your employees have to say about you and fellow management team members, and you have an honest commitment to turning problems into opportunities for improvement.) When assessments are given, and if you listen, employees will tell you what their needs are, what his/her wants are, what they are thinking, and what they want changed.

Next, steps three and four coincide together. The base senior management team developed a base Strategic Plan with tactics to focus on in order to meet that plan. Business Unit managers then developed Tactical Plans with their partners that would support and contribute to the base achieving their targets. Without a Strategic Plan, to show all employees where an organization plans to be within a certain time frame, "achievements" become only "desired outcomes."

Business Unit Tactical Plans are the actual steps that a particular area or department will take in order to contribute to the base wide Strategic Plan.

Once Strategic and Tactical Plans are developed, everyone begins to work (#5) to achieve those targets. After work has started, evaluation (#6), begins on targets. Data collection (evaluation) is very important, in that early in the process trends can be established and determinations can be made to make changes to get processes back on track.

The final step is adjust and/or refine. To be able to adjust and/or refine you must get intimate with the process. At this point, teams become a part of the process. Teams come in many sizes and from many departments. They can be cross-functional (which is cross-departmental), only functional (which is within the department), or corrective action (which works to solve and address problems of urgency). We must remember, these steps must become institutionalized. They are the beginning of a never ending cycle.

### 3.0 KEYS TO SUCCESSFUL IMPLEMENTATION

There are several keys to successful implementation, and, as the steps, they will also vary, according to the needs of the organization.

First, targets should be selected that are urgent and will show quick results, but that will also stretch your organization. This will get employees acclimated to Continuous Improvement processes and will convince "doubters" that this is not something that should intimidate anyone. EXAMPLE: Safety. This is an item that can be tracked daily, weekly, monthly, etc., and can show quick results. Regardless of whether the information is good or not, you quickly identify problem areas, pockets of concern, or areas that need quick attention.

Secondly, expectations must be specified. It is very important that all employees know and understand the targets that the corporation expects us to meet, all the parameters that will be involved, and what impact non-compliance will have on the overall operation.

Next, and most important as we all know, is effective communication. You can never over communicate, and the means of communication will vary. One key tactic to our communication process was the institutionalization of crew meetings. Crew chiefs, foremen, managers,

directors, and the base vice president have established crew meeting schedules. This was a direct response to a recommendation by our Atlanta Base Planning Team, comprised of one director, one manager, and approximately ten employees from a cross section of our work force. Other communication tools implemented in Atlanta were a monthly newsletter and an every-other-month video (produced in-house), both of which discuss the activities of our base, including production, process improvements, milestones reached, innovation, recognition, etc.

## 4.0 BARRIERS TO PROGRESS

We all know that for every step to improve a procedure, implement a new process, or a new philosophy of business strategy there will be many barriers.

First and foremost of the barriers is that most business units, and individuals, are results oriented. Whenever you focus only on results, you lose focus of what is driving those results. Our organization made a shift to process orientation. To understand the process means to reveal methods by which a particular function is performed, and if a process is improved, the desired results will occur. Process orientation produces the desired results with a better understanding of how we produce products.

Secondly, as we all know, "old school" managers and task performers simply resist change. That's just human nature. We found that technically experienced personnel had been successfully performing tasks a certain way and did not want to change. Ironically, we discovered that administrative personnel and staff personnel were more reluctant to change than task performers. Traditionally, task performers know the product, for which they are responsible, better than the support or engineer groups. This is because a product that is worked daily by an employee becomes a part of that employee.

Another barrier that we faced was that managers felt they were giving up authority by having decisions made at a lower level. The fact is, managers never had that authority to give up. It was already down to the task performer level. Managers also dreaded anticipated resentment, or resistance to change. The truth is, as previously explained, task performers welcomed the change more than others.

Another barrier to overcome was the pockets of administrative and labor groups misunderstanding of what Continuous Improvement meant. We didn't explain it well enough and some became doubters about its success without even giving it a chance to succeed. These pockets felt improvement to a process meant less cycle time to a product which meant less need for all personnel which meant job loss. That is incorrect. We had to convince these people Continuous Improvement means you can now take extra resources and redeploy them to other tasks. It really means more work. You can now bring other work in rather than send work to a vendor or outside entity.

## 5.0 REMOVAL OF BARRIERS

All the steps to implementation and understanding what the barriers one may face will not amount to any positive changes unless leaders remove some barriers. Removal of insecurities is vital to success. We, as leaders, had to, and must continue to, assure our peers and subordinates that we are here to help and work together. When we have failures or setbacks, we have to go to root causes and resolve or correct those causes. Make it understood that it is not the who for setbacks, but the what that caused the setback. Learn from the mistakes of others and help others become successful.

We must also show sincerity towards the Continuous Improvement process. When we began re-education and training classes were held. Administrative and staff personnel (i.e., directors, managers, foremen, engineers, etc.) sat in seminars and training sessions with task performers such as cleaners, janitors, inspectors, stockroom personnel, mechanics, etc. This developed an atmosphere that we were truly in this business together. Remember, as leaders, we are the people others look to for help. Supposedly, we are put in place to lead and for that reason we are kept under a watchful eye to assure we provide that leadership.

Finally, we must maintain sincerity and high ethical and moral values. If you, as a leader, do not have these high ethical values and standards, you certainly can't expect your teammates and subordinates to have them. If you don't have the sincerity to "Walk The Talk" and to do "What's Right," no Continuous Improvement process will survive.

## 6.0 CONCLUSION

I will be the very first to admit, Continuous Improvement is a new philosophy that is met with a great deal of resistance and skepticism. We have to work at changing that philosophy every day. It's tough, but it is very rewarding when you see it work.

Remember, the driving force to Continuous Improvement is, it's not a we-they, it's us together, trying to achieve one common goal: TO STAY IN BUSINESS AND BECOME THE LEADER IN THAT BUSINESS.

## DESIGN OF THE AIRCRAFT INSPECTION/MAINTENANCE VISUAL ENVIRONMENT

*Jacqueline L. Reynolds  
Anand Gramopadhye  
and  
Colin G. Drury  
State University of New York at Buffalo  
Department of Industrial Engineering*

## 1.0 INTRODUCTION

This study was undertaken as a demonstration project in order to demonstrate how human factors

techniques can be applied rapidly within the aircraft maintenance/inspection industry. Since visual inspection is such an important component of aircraft inspection, accounting for almost 90% of all inspection activities, it is imperative that the task be performed in the most suitable work environment (Drury, Prabhu, and Gramopadhye, 1990). Studies in aircraft inspection have shown that poor illumination, glare, and other adverse lighting conditions could be important reasons for "eye strain" or visual fatigue. Visual fatigue results in deterioration in the efficiency of human performance during prolonged work. The objectives of this study were: to identify potential sources of improvement in inspection task lighting, to suggest modifications so that the task can be performed under improved visual conditions, and to provide a guide which can be utilized to assess other visual environments.

## 2.0 LIGHT CHARACTERISTICS/LIGHTING SYSTEM DESIGN

**Light Level.** The required illumination level is task dependent. General lighting requirements for different tasks can be found in Flynn (1979) and IES (1987). Vision can be improved by increasing the lighting level, but only up to a point, as the law of diminishing returns operates. Excessive illumination could result in glare. According to IES (1987), direct, focussed lighting is the recommended general lighting for aircraft hangars. Inspection of aircraft takes place in an environment where specular reflection from airplane structures can cause glare so that low brightness luminaries should be installed. Often additional task lighting will be necessary when internal work, or shadowed parts around the aircraft, result in low illumination levels.

The required illumination levels for aircraft maintenance and inspection tasks are presented in **Table 1**. Generally, most maintenance tasks require between 75 f-c and 100 f-c, although more detailed maintenance tasks may require additional illumination. General line inspections (e.g., easily noticeable dents) may only require 50 f-c; however, most inspection tasks demand much higher levels. Many difficult inspection tasks may require illumination levels up to or exceeding 500 f-c.

**Table 1 Levels of Illumination Required in Aircraft Inspection/Maintenance (IES, 1987)**

TASK	F-C
Pre/post maintenance and inspection	30-75
Maintenance	75-100
Inspection	
Ordinary	50
Difficult	100
Highly difficult	200

**Color Rendering.** Color rendering is the degree to which the perceived colors of an object illuminated by various artificial light sources match the perceived colors of the same object when illuminated by a standard light source (i.e., daylight). The difference in the spectral characteristics of various light sources have a large effect on color rendering, and are described in detail in Hopkinson and Collins (1970) and IES (1984). The color rendering of task lighting is

important, because often a change in color of sheet metal is used as a clue to indicate corrosion, wear, or excessive heating. Commonly used lighting sources with their characteristics can be found in Lumineering Associates (1979) and Ross and Baruzzini, Inc. (1975).

**Glare.** Glare reduces an inspector's ability to discriminate detail and is caused when a light source in the visual field is much brighter than the task material at the workplace. Thus, open hangar doors, roof lights, or even reflections from a white object such as the workcard can cause glare. Glare can also arise from reflections from the surrounding surfaces, and can be reduced by resorting to indirect lighting.

**Reflectance.** Every surface reflects some portion of the light it receives as measured by surface reflectance. High reflectance surfaces increase the effectiveness of luminaries and the directionality of the illumination. Thus, for an aircraft hangar, it is important that the walls and floors are of high reflectance so that they help in reflecting light and distributing it uniformly. This can be achieved by having the floor and the walls composed of reflective materials, or existing structures painted a lighter color. This is more critical under the wings and fuselage where there may not be adequate lighting, due to aircraft shadows. **Table 2** presents recommended surface reflective values, to assist in obtaining an adequate visual environment.

**Table 2 Recommended Reflective Values (Adapted from IES, 1987)**

SURFACE	REFLECTANCE
Ceiling	80 to 90%
Walls	40 to 60%
Equipment	25 to 45%
Floors	not less than 40%

### 3.0 THE VISUAL ENVIRONMENT IN AIRCRAFT IN INSPECTION

**Classification of Light Sources.** The lighting sources employed in aircraft inspection include the following: *ambient lighting* which is comprised of daylight, area, and specialized lighting (built into aircraft), and *task lighting* which includes portable lighting (set up at the inspection site) and personal lighting (e.g., flashlight). The ambient lighting represents the minimum lighting level available on a task, while task lighting represents the maximum lighting level, both from portable and personal lighting devices. Note that to provide adequate lighting for any task it should be possible to reduce glare from ambient lighting and use the task lighting in a focussed manner to illuminate the task without causing unnecessary glare.

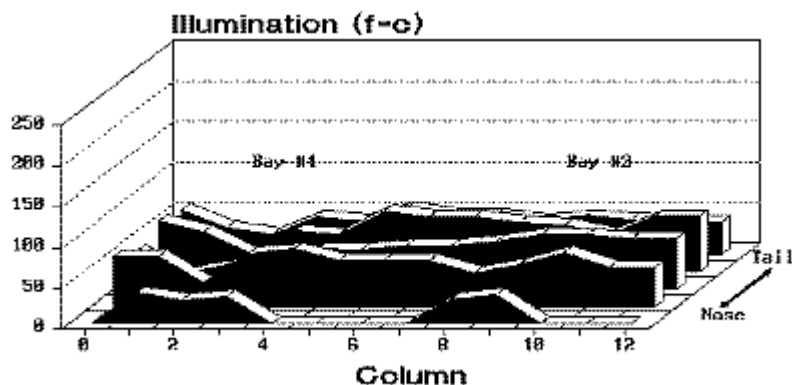
**Site Observations.** **Shepherd et al., (1991)** report the results of Phase I of the program, during which many inspection/maintenance sites were visited. Detailed Task Analyses were performed on numerous inspection activities, resulting in a list of examples of poor human factors design. Each represents an opportunity for intervention to improve the human/system fit and hence, increase job performance with decreased work stress. The conclusions to be drawn from these

observations are that lighting in some cases can range from inadequate to poor for performing inspection tests. Task lighting was not adequate, lighting equipment was not always portable, and the lighting level was well below the IES recommended level of 75- 100 f-c for most visual aircraft inspection tasks (IES, 1987).

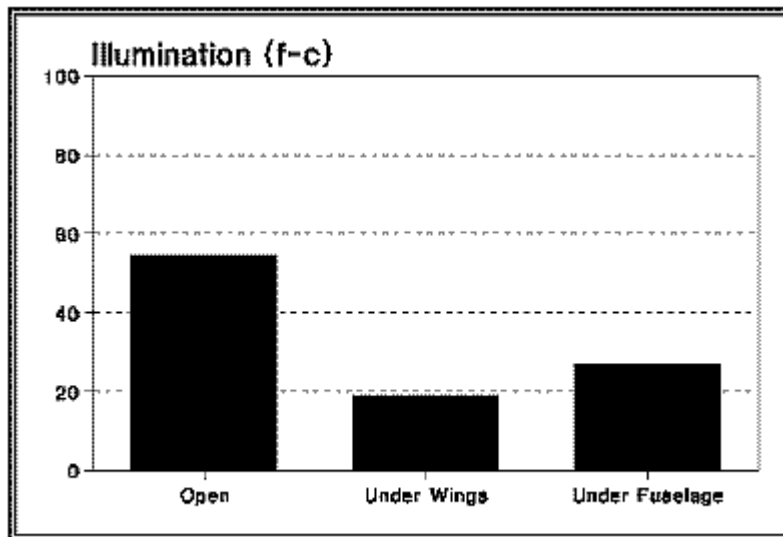
## 4.0 EVALUATION OF EXISTING VISUAL ENVIRONMENT

As a demonstration of how to perform a human factors study of lighting in a facility, an investigation of the visual environment at a representative maintenance hangar was performed. This study included an evaluation of the ambient lighting, task lighting, and perceived lighting characteristics based upon input from inspectors.

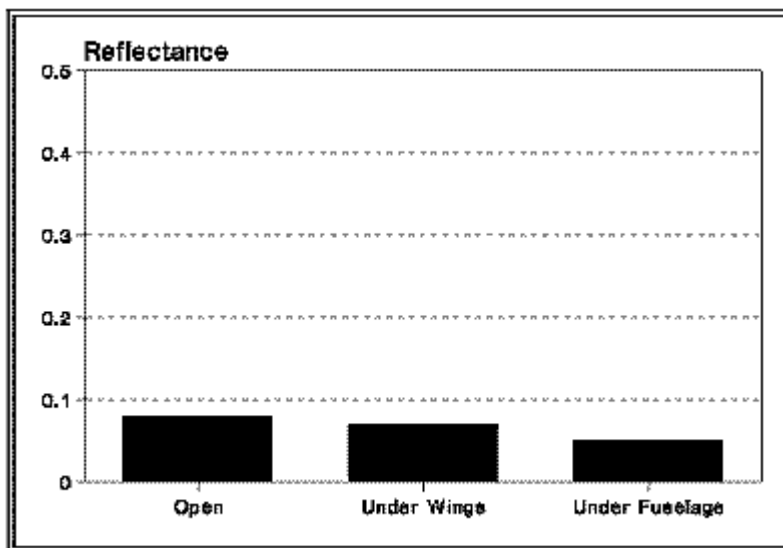
**Evaluation of Ambient Illumination, Luminance, and Reflectance.** The survey measured the illumination and luminance levels produced by the ambient light sources only. Lighting characteristics of the personal and portable lighting were not considered at this stage. The illumination and floor luminance levels were obtained in two different aircraft bays, bay #1 (with an aircraft present) and bay #2 (without an aircraft present). Each bay area was divided into columns and zones. The columns correspond to floor markers in the hangar, and are 22 ft apart. The five zones represent floor locations corresponding to an aircraft area (i.e., nose, front of the fuselage, wings, back of the fuselage, and tail). Several readings were taken in each area, at night with the hangar doors closed. Average illumination and luminance values were calculated, illumination is presented by floor location (**Figure 1**) and by aircraft area (**Figure 2**). Floor reflectance values, the amount of light reflected off the floor compared to the amount of light falling on the floor, (i.e., floor luminance/illumination) were calculated and given in **Figure 3**.



**Figure 1 General Illumination Levels in Aircraft Hangar**



**Figure 2 General Illumination Levels by Aircraft Area**



**Figure 3 Floor Reflectance by Aircraft Area**

The average illumination levels varied dramatically between areas. **Figure 2** indicates that the areas under the fuselage and wings had considerably lower illumination than the open areas (i.e., where no aircraft was present). This is a concern, for many visual inspection tasks occur in these poorly lit areas (i.e., under the wings and fuselage). The floors are presently a natural grey color (cement), thus resulting in low average floor luminance, and reflectance levels well below those recommended across all areas (**Figure 3**). Existing floors could be painted a lighter color (e.g., white), which would improve the overall illumination levels, especially under the wings and fuselage. However, any paint used should be non- glossy to eliminate specular reflections from



the floor surface. For new hangars, or major renovations, lighter colored flooring could be installed to improve reflectance.

**Evaluation of Task Illumination, Luminance, and Reflectance.** A representative sample of aircraft visual inspection tasks was selected from various locations on a Fokker F-100; specifically, air conditioning access (A/C), cargo compartments (cargo), exterior fuselage-nose, nosewell, and wheelwell. A lighting survey was performed (i.e., illumination and luminance) with the results shown in **Table 3**. Each task light environment is indicated and includes the contribution of the ambient levels in conjunction with any additional personal/portable lighting. Values were obtained from various locations in each task area under actual inspection conditions; that is, while the task lighting of choice (i.e., personal/portable) was utilized.

**Table 3 Task Light Environment and Illumination by Task Area**

AREA	TASK CONDITIONS	
	Light Environment	Illumination (f-c)
A/C	3D-Cell Mag Lite	115 SD=138.0
Cargo	Justice Headlamp Specialized, General	182 SD=72.4
Fuselage-Nose	3D-Cell Mag Lite General	97 SD=46.0
Nosewell	3D-Cell Mag Lite Specialized, General	42 SD=22.6
Wheelwell	3D-Cell Mag Lite Specialized, General	102.1 SD=40.0

**Table 3** Task Light Environment and Illumination by Task Area.

Each of these tasks, may require different lighting conditions, based upon the task demands. Thus, task analyses were performed to determine the visual and lighting requirements for each selected task. These surveys and analyses allow the comparison of the existing task lighting conditions with the task requirements.

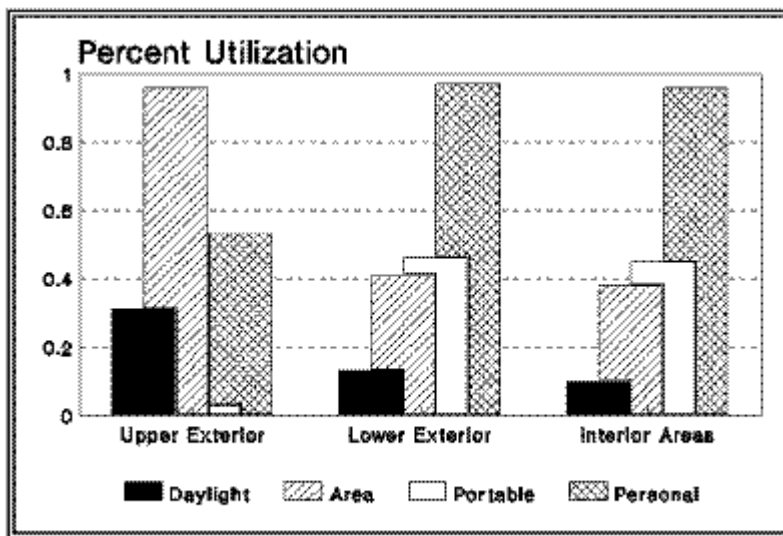
Generally, the *average* task illumination levels were adequate, with the exception of the nosewell. However, large variability existed in these levels, primarily dependent upon whether it was possible to aim the lighting equipment at the point of inspection. In many instances, these areas were difficult to access with the lighting equipment, thus not allowing adequate levels of light to be obtained. Task lighting was necessarily the primary light source in all task areas, for the ambient illumination levels were inadequate. Thus, the accessibility of the area and the portability of the personal/portable lighting determined the light level at a majority of the inspection points.

**Inspector Perceptions.** In addition to the detailed measurements obtained at one facility, a survey was conducted to access inspectors' perceptions of their visual environment at several other facilities. The results are based on feedback from 51 inspectors and maintenance personnel (51% response rate). Verbal feedback was obtained from inspectors, to allow a detailed assessment of the perceived quantity and quality of the ambient and task lighting. Inspectors and maintenance personnel were asked to evaluate the lighting characteristics of the visual

environment (i.e., contrast, glare, flicker, color rendering), as well as the adequacy of the personal lighting equipment (i.e., light level, ease of handling, and focus control) and portable lighting equipment (i.e., light level, ease of handling, and aiming ability).

Verbal feedback was obtained on the visual environment and combined by aircraft area (i.e., upper exterior areas/above wing chord line, lower exterior areas/below wing chord line, and interior areas). Generally, according to the frequency distributions, the perceived light levels and contrast were adequate in the upper exterior areas, but there were many instances of perceived glare. Conversely, the perceived light levels and contrast were frequently inadequate in the lower exterior and interior areas, but there was less perceived glare. Color rendering was perceived to be adequate by most personnel, although this distribution was skewed towards inadequate in the lower exterior and interior areas.

In the upper exterior areas, a majority of personnel indicated a reliance on primarily general lighting (over 90%), with a smaller dependence on daylight and personal lighting (Figure 4), there was minimal reliance on portable lighting. In contrast, in the lower exterior and interior areas, personal lighting was indicated to be the primary light source, with general and portable lighting being somewhat utilized. Daylight contributes minimally to the visual environment in the lower exterior and interior areas. This is presumably the reason why color rendering was perceived to be better in the upper exterior areas, for the other areas rely almost solely on artificial light.



**Figure 4 Lighting Source Utilization by Aircraft Area**

A majority of personnel indicated both personal and portable lighting equipment were necessary to produce adequate light levels. There were varied perceptions with respect to the handling of lighting, although a majority felt personal lighting was adequate and portable lighting was inadequate. Likewise, a majority of personnel felt the focus ability of personal lighting was good, while the aiming ability of portable lighting was inadequate. These perceptions may indicate why personal lighting is relied on more than portable lighting (Figure 4); it is easier to

handle and control. A need exists for better portable lighting to decrease reliance on personal lighting in restricted spaces.

Finally, general comments and concerns related to personal and portable lighting systems and the visual environment were obtained. The major considerations, which can be utilized to assist in standardizing the visual environment evaluation process, fall within the categories of: light characteristics, ease of handling, durability, work shift, hangar maintenance, flexibility, and other attributes.

## 5.0 EVALUATION OF ALTERNATIVE LIGHTING SOURCES

An evaluation of lighting sources was performed to identify systems which possess features which may contribute to the existing visual environment of aircraft inspection/maintenance operations. This evaluation included a survey of available systems, and both laboratory and field evaluation of the selected sources.

**Laboratory Evaluation.** A number of both personal and portable lighting systems were selected to represent the types currently being used in inspection and alternative sources available in catalogs. Several attributes (light output/distribution, weight, etc.) of these selected personal and portable lighting systems were investigated in a controlled environment.

**Field Evaluation.** A sample of the lighting systems evaluated above were further investigated to determine their perceived suitability during actual task performance. Personal and portable lighting sources, which appeared to hold promise in the laboratory evaluation, were evaluated. **Table 4** and **Table 5** present information related to the portable and personal lights. Evaluation was based upon verbal feedback obtained from five on-site inspectors. The authors felt that the selected sample of light sources provided adequate coverage of the various types of lighting sources with respect to size/portability, type of light, and power source. Verbal feedback was obtained from the inspectors after they used the sample of lights to perform different tasks in various locations of the aircraft.

**Table 4 Specifications of Selected Portable Lighting Equipment (Center illumination measured at: \*0.5 m or \*\*2.0m)**

Light Source		Wt. (lbs.)	Aiming	General Durability	Safety Req'ments	Accessories
Ericson Twin-tube Handlamp #900-25	Fluorescent 13 watts 85 f-c*	0.8	No	Adequate	NEC #410- 35(a)(b),36,42(a)( b),44,45 OSHA #1926.405( E)(F)(i)(ii) (iii)(A)(B)(V) UL listed	Hook
Ericson Portable Lamp #1227	Fluorescent 27 watts 164 f-c*	10	No	Adequate	NEC #410- 35(a)(b),36,42(a)( b),44,45 OSHA #1926.405( E)(F)(i)(ii) (iii)(A)(B)(V) UL listed	Hangers, Magnets
Fostoria PUL-500Q- HC	Halogen 500 watts 1200 f-c*	9	Yes	Adequate	UL listed for indoor/outdoor use	Handle Stand

**Table 5 Specifications of Selected Personal Lighting Equipment (\* center illumination measured at 0.5m)**

Light Source		Wt. (lbs.)	Focus	General Durability	Safety Req'ments	Illumination (f-c)*
2D-Cell Mag Lite	Krypton Bulb	1.5	Yes	Adequate	Explosion-proof MIL-STD-810C	340
3D-Cell Mag Lite	Krypton Bulb	2.0	Yes	Adequate	Explosion-proof MIL-STD-810C	1100
4D-Cell Mag Lite	Krypton Bulb	2.4	Yes	Adequate	Explosion-proof MIL-STD-810C	1900
Justrite Headlamp #1904	Incandescent Bulb	1.9	Yes	Adequate	None indicated	1500

The following provides a summary of the results obtained from the laboratory and field evaluations:

\* There are two different kinds of lights: inspection and work lights. Inspection lights (i.e., dynamic sources) must provide easy handling, for inspection normally demands frequent movement in and around the aircraft. In addition, the lights must provide a focused beam of light which can be controlled to reduce glare. Work lights (i.e., static sources) need not be as portable as inspection lights, for they are normally used in one place for a period of time (i.e., generally 30 minutes or more).

\* The Mag Lites provide adequate light, durability, and focus control to reduce glare. They are also easily portable, which suits most inspection tasks. The light outputs and distributions of the Mag Lites increase with the size of the light (i.e., 2D to 4D), for the larger lights have more batteries; however they are also heavier. The focus ability of the Mag Lites provides either an intense focused beam, or less illumination over a larger area.

\* The Justrite headlamp provides adequate light, and focus control to reduce glare, and produces a comparable amount of light as the 4D-Cell Mag Lite, although it is lighter and allows

hands-free portability. However, it meets no additional safety requirements, thus possibly limiting its use in some environments. The actual weight of the lamp is less than the indicated weight, for the batteries are separated from the light source (0.3 lbs.).

\* The Ericson Twin-tube #900-25 is not well suited for many inspection tasks, for the power cord reduces its portability and it does not provide a highly focussed beam. However, this light can serve as a small portable light source. It produces less light over a smaller area than the other portable lights, but gives off minimal heat and can fit into small access areas. It is very durable and meets OSHA and **NEC** safety requirements related to general electrical codes.

\* The Ericson Portable lamp #1227 is a good static light source. It can be hung, using the provided strap or magnet, or placed (e.g., under a wing) in the work area for overall, heat-free light. Furthermore, these lamps meet OSHA and **NEC** safety requirements related to general electrical codes.

\* The Fostoria PUL-500Q-HC provides a large amount of light over a large area. It can be used to illuminate large static work areas. However, it gives off heat, and thus could not be used for interior inspections or in small areas, limiting its use to open, exterior areas. In addition, it is UL listed for indoor/outdoor use, possesses up/down aiming control, is light-weight, and has a handle for easy portability and set-up.

\* The color rendering characteristics of the standard incandescent lamps (i.e., Justrite headlamp #1904), krypton lamps (i.e., Mag Lites), and halogen lamps (i.e., Fostoria) are superior. The fluorescent lights generally provide adequate color rendering characteristics, dependent upon the chemical composition of the liner, and are more energy efficient, as opposed to incandescent lights.

## 6.0 RECOMMENDATIONS

Based upon the above evaluation of the visual environment and the selected sample of lighting sources, initial recommendations are presented. The task demands, the restrictiveness of the space to be inspected, the ambient light conditions, and the lighting requirements are considered (**Table 6**). Recommendations are advanced for the wheelwell area evaluated earlier, and only consider the lighting sources investigated during detailed field evaluation (**Tables 4 and 5**). Caution should be exercised in generalizing these recommendations to other task situations and light sources.

**Table 6 Lighting Recommendations**

Area	Task Demands	Space	Lighting Req'ments			Recommendations
			Illum. (f-c)	Focus /Aim	Handling	
Wheelwell	Inspect main landing gear, landing gear assembly, for corrosion and cracks. Inspect for security of joints, safety pin for shear, hinges of door for wear and play.	R	200	Yes	Dynamic	2D,3D-Cell Mags Justrite Headlamp
				Yes	Static	Ericson Twin-tube Fostoria PUL-500- HC Ericson #1227

For each task area, the task demands will dictate the required illumination, the focus/aiming, and the required handling. A majority of inspection tasks require dynamic sources, to allow for frequent movement in and around the area; whereas maintenance tasks may be adequately illuminated by static sources. Although inspection tasks are the primary focus in this study, recommendations will also be made for static sources, for they can be useful in contributing to the ambient light level in many areas, thus reducing reliance on personal lighting. As discussed previously, the ambient illumination levels in all the considered task areas were inadequate for satisfactory performance, thus there must be some reliance on personal or portable lighting in each area.

Inspection of the wheelwells require dynamic, focussed average illumination levels of 200 f-c. These areas are somewhat restrictive (R), thus requiring the smaller Mag Lites or Justrite headlamp for better handling. The Ericson Twin-tube and portable #1227 could be hung/placed in tight locations in these areas, while the Fostoria PUL-500-HC could be aimed up into these areas for general overall lighting. Based on the task demands and corresponding illumination requirements, it is observed that each of the recommended personal lighting sources furnishes the required illumination.

## 7.0 GUIDE FOR VISUAL ENVIRONMENT EVALUATION

A methodology by which to evaluate and design a visual environment may be advanced based upon the techniques employed in the above demonstration project.

**Evaluate Existing Visual Environment.** This includes the measurement of the ambient and task lighting conditions. In addition, task analyses should be performed in order to determine the task demands and associated operator requirements. In addition, personnel should be consulted to obtain additional information regarding the light characteristics and utilization and adequacy of the currently used lighting sources.

**Evaluate Existing and Alternative Lighting Sources.** Manufacturers' catalogs can be consulted to determine the current status of lighting source technology. These alternative sources, in addition to the sources currently being used, can be evaluated. Evaluations performed to date, including the present one, have used various criteria to judge visual environments (e.g., light

output, glare, luminance, etc.). There needs to be standard criteria defined which allows visual environments in aircraft maintenance/inspection operations to be evaluated in a consistent manner, and ensure that important components of the process are not over-looked. An attempt has been made to identify the most important components which need to be considered in the evaluation of an aircraft inspection/maintenance visual environment. The operator perceptions and other factors discussed earlier should be considered in the selection of adequate lighting sources.

**Selection of Lighting Sources.** Lighting sources can be selected based upon a comparison of the lighting requirements with the various lighting sources. An investigation of the existing visual environment (Step 1) will allow the determination of the lighting requirements based upon the task demands. These results can be directly compared with the capabilities of the various lighting sources (Step 2), to determine which lighting sources provide the most appropriate visual environment for each task analyzed.

**Evaluate and Address General Visual Environment Factors.** Based upon the operator perceptions and lighting design principles, factors needed in the design of an adequate visual environment can be identified. The assessment of these considerations (e.g., hangar maintenance) should result in additional improvements in the overall visual environment.

This methodology allows various light sources to be matched to different tasks, based upon consistent criteria. This methodology provides flexibility, for each practitioner can choose relevant criteria most important in their environment on which to base evaluation. The techniques utilized to assess the visual environment at the representative facility may be incorporated into a formal methodology and utilized to investigate visual environments and guide selection of lighting equipment at other aircraft inspection sites.

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## DESIGN OF WORK CONTROL CARDS

Swapnesh Patel

Prasad Prabhu

and

Colin G. Drury

State University of New York at Buffalo  
Department of Industrial Engineering

### 1.0 ABSTRACT

The workcard is the prime source of on-line directive and feedforward information in aircraft inspection, and serves as a prime factor influencing inspection performance. The present study develops a methodology for design of workcards, based on the application of human factors knowledge to the analysis of aircraft inspection tasks. A taxonomy for design of usable documentation was developed, comprising four basic categories: Information Readability, Information Content, Information Organization, and Physical Handling and Environmental Factors. Within the framework of this taxonomy two extreme representative conditions of aircraft inspection tasks, the A-check and the C-check, were analyzed for the use and usability issues of the workcards. Issues were identified within the taxonomy using data from user responses. This data was then used to develop and propose alternate design solutions offering improved usability. Not only does this study propose specific design solutions, but it also provides us with a highly generic methodology that can be followed for design of quality documentation for other aircraft inspection tasks, and for design of usable information for automated jobcards, and hypermedia-based documentation.

### 2.0 INTRODUCTION

The work control card is the primary document that starts the inspection and serves as a prime influencing factor on inspection performance. If these costs are due to failure to detect a fault, or due to faulty detection, or are weighed against the cost of designing and providing quality documentation, considering the high risks involved, a strong case can be made for developing improved documentation. There is need for a definite methodology coupled with a set of guidelines for design of documentation. This study develops such a methodology based on the intersection of human factors knowledge with the analysis of aircraft inspection tasks. The

methodology developed, being highly generic, can also be extended for design of information for portable computer based jobcards, as well as hypermedia based documentation for inspection and maintenance tasks.

## 3.0 GUIDELINES FOR DESIGN OF EFFECTIVE DOCUMENTATION

### 3.1 A TAXONOMY OF ISSUES IN DOCUMENTATION DESIGN

From the extensive Task Analysis of inspection generated in Phase 1 of this program (**Shepherd, et al., 1991**) and from the literature on the human factors of information presentation, evolved a taxonomy for design of usable documentation comprising of four basic categories, namely

1. Information Readability
2. Information Content
3. Information Organization
4. Physical Handling and Environmental Factors

### 3.2 INFORMATION READABILITY

Typographic Layout. "Typography without words", as it is referred to by some, is a means of addressing some conceptual issues that underpin typography, comprising the use of vertical spacing, lateral positioning, paragraphing and heading positioning, etc. All the principles of typography cannot be satisfied when the space available is premium, and use of secondary typographic and spatial cues becomes essential. Typographic cueing refers to use of variations in the appearance of the text in order to provide a visual distinction, e.g., boldfacing, italics, underlining, color coding, capital cueing etc. Also, advances in computer technology and word processing provide us with new tools such as right justification of typographic material, which improves reading speed considerably as compared to an irregular margin (Fabrizio, Kaplan, and Teal, 1967).

The Sentence, the Word and the Letter. Every printed language has some conventions, which the readers are familiar with, and disruption of reading results when these conventions are violated (Haber & Haber, 1981). This suggests that readers routinely use print arrangement as a source of visual information. In addition to the context, the shape alone of the entire word may prove to be useful in specifying its meaning. Carroll, Davies and Richman (1971), demonstrated this using very high frequency words from text (e.g., "the", "and", "it"). However, when the text is presented in all capitals, little or no word shape information is present, indicating a waste of an information resource. Since words are basically composed of letters, each of which has a distinct identity and name, a part of the visual information in reading must include the visual features of the individual letters of the alphabet, yet most fonts have additional redundant features like serifs which are irrelevant in visual processing (e.g., Times typeface).

### 3.3 INFORMATION CONTENT

A workcard writer must not blindly convert all the available relevant information into work control information, but rather anticipate the use that this information will be put to, in what context, and the good or bad influences that it will have on user strategies.

User Strategy Biases. The strategies that the end user adopts may be biased due to a number of reasons, and the information provided in the form of work control information may act as being one of them. One of the reasons may be due to poor cognitive monitoring on part of the user, i.e., they think they know the information and are thus biased towards using primitive routines in accomplishing the task. Also if the information provided is inappropriate and involves increased cognitive costs on part of the user, then the user selects strategies to reduce these cognitive costs by making use of sub-optimal strategies.

Appropriate Information Content. To reduce and eliminate user strategy biases and consequently improve the usability, the information should incorporate the following qualities:

- it should be accurate
- it should be complete, including information regarding: What is to be done, where, how, in what sequence, which specific items to pay attention to.
- up to date with revisions and updates
- easy to use and comprehend
- be written in a consistent and standardized style and syntax
- be clear and unambiguous
- be specific and contextual, e.g., pertaining to the particular aircraft being inspected
- flexible, i.e., to support both the expert as well as the novice user
- use only approved and proper acronyms
- have logical and uncontradictory statements

Graphic Information. Plain text can be uninviting to read and at other times involves high cognitive costs of interpretation. The same objective can be achieved at lower cognitive costs by use of graphic information provided that the graphic information is designed and presented in an appropriate manner. At times verbal information becomes difficult to comprehend, especially while conveying spatial information, hence graphics support provides an economical solution. An ideal content in graphic information should provide for a context for location and identification. Also items not relevant to the task should be eliminated to avoid clutter.

### 3.4 INFORMATION ORGANIZATION

Classification of Information. Information in any work control card can be clearly distinguished into: directive information, references to additional information, warnings, cautions, notes, and procedures and methods for achieving certain goals. They should follow a standard prioritized order within the document itself, e.g. warning should precede cautions and notes. Inaba (1991) suggests that directive information should not include more than two or three related actions per step, keeping in mind the limitations of the human short term memory. All directive information

can be broken into three distinct subgroups: the command verb; the objects and the action qualifier. The command verbs must be selected from a list of verbs which has no synonyms, to reduce the level of ambiguity. The objects need to be broken down into further subgroups to account for action slips. The action qualifier should be distinct from the other two, and may begin with a standard article like "for". An example of the four sub-groups differentiated by typeface is:

**Check:**           - all hydraulic lines  
                  - control cables  
                  - pulleys

for wear, frays, damage, and corrosion

### 3.5 INFORMATION LAYERING

A novice inspector may require elaborate information at every stage; an expert on the other hand might require brief information. The information organization should be such that it caters to the needs of both, the prime goal being to make it more flexible and more context sensitive (Jewette, 1981). Multiple levels can be built into the information organization, for example, having the main ideas at the first level, followed by elaboration of each of the main ideas at the second level, and finally detailed descriptions at the lowest level. A number of methods can be adopted to present multi-layered information in hard copy format: using distinctly separate layers (for example, a checklist and a detailed information sheet); indented paragraphing (Jewette, 1981); use of color, graphical anchors, boxes; use of different print sizes and styles; use of symbolic nomenclatures e.g., "A", "B", "1.1", etc. Also, at the lowest level, other tools such as italics, boldface, underlining, brackets, footnotes, appendices etc. can be used.

In addition to the obvious advantages to the user in terms of flexibility of usage, multi level writing has some distinct advantages to the writer. It is easy to write, as it has a preset framework within which to write. It is less dependent on fancy phraseology. Sequencing and rearranging of information becomes an easier task, with less planning requirements. The amount of redundancy in the information is also considerably lower. It involves the use of explicit statements of intention and is hence less error prone.

Other Organizational Issues. Ideally speaking, both text and graphics should be presented on the same page or facing pages, but for reasons of cost effectiveness and system limitations this may not be feasible at all times. The page size should be treated as a naturally occurring module within a document, in the physical sense. The information should be organized according to a rational task order, which may either be the most rational way of doing that task or may be the order followed by most inspectors, due to practical reasons discovered during workcard usage.

### 3.6 PHYSICAL HANDLING/ENVIRONMENTAL FACTORS

An ideal workcard can satisfy all the aforementioned principles of information design, but if it is not physically compatible with the task at hand, it will be of little use as people will be reluctant to use it.

Non-compatibility with the working environment can encompass a number of factors:

- physical handling difficulty due to unwieldy size
- excessively heavy, cannot be held continuously
- environmental degradation due to wind, rain and snow
- incompatible with the other tools used in the workplace e.g., lighting equipment, hand tools, etc.
- improper lighting conditions, need for a localized reading light

This issue is often neglected, and remains a problem in most "work area" usage of documentation. Handling and usage is a critical factor and will remain so even with automated job-cards using scratch pads or laptop computers. Providing a simple workcard holder can at times solve this problem. Depending on the task, however, a specialized design of a workcard holder may be essential to improve the usability of the documentation.

## 4.0 CASE STUDIES IN WORKCARD DESIGN

Within an aircraft schedule, inspection checks are performed at periodic intervals, ranging from routine flight line checks and overnight checks, through to A-, B- and C-checks, to the heaviest or the D-check. Among these, two extreme representative conditions were considered as demonstration case studies. The A-check is a more frequent but cursory inspection, while the C-check is a less frequent but more detailed inspection. Only the A-check case study is presented here for reasons of space.

### 4.1 A-CHECK CASE STUDY

Task Description. The maintenance supervisor assigns the A-check work control card to the technician. Normally two technicians are assigned to an aircraft, one technician is assigned with an assistant who helps in cleaning and aiding maintenance work. The two technicians proceed to the scheduled aircraft and begin the inspection which is usually carried out in the open, under all environmental conditions and with poor lighting. Any discrepancies or faults are noted on a non-routine worksheet. Normally, the maintenance technician completes the inspection and testing tasks before beginning work on reported discrepancies. The technician has to perform and sign off each of the 201 items mentioned in the workcard, in the scheduled time. A sample page from the current workcard is shown in **Figure 1**.

03FEB92 07.51 A/C 0306 HOU REV DATE: 09-04-90 JCCR NO: 02189	WORK CONTROL CARD	MFG P/N: J07-3200-21-02-001 PROC, A/C, 3200, B727, ATA32,	M&E P/N: 07-521-1-0017 LANDING GEAR
* POS*	JOB DESCRIPTION	* MECH * INSP*	
* 01 * TITLE: LANDING GEAR			
ATTACHMENTS : T07-3240-1-0001, T07-32-1-0005		N/A	N/A
1. CHECK SYSTEMS CONDITION			
A. LANDING GEAR AND WHEEL WELLS			
(1) CHECK FOR GENERAL CONDITION, DAMAGE AND EVIDENCE OF FLUID LEAKS		N/A	
(2) CHECK FOR BROKEN ADJEL CLAMPS ON HYDRAULIC LINES IN THE WHEEL WELLS AND ON THE LANDING GEAR ASSEMBLIES AND CHECK FOR CHAFING HYDRAULIC LINES.			
NOTE : DISCREPANCIES IN THE ABOVE ITEM SHOULD BE CORRECTED PRIOR TO DISPATCH OF THE AIRCRAFT.		N/A	
(3) CHECK BRAKE DEBOOST VALVES, BRAKES AND TIRES FOR BEING WITHIN LIMITS.			
NOTE : SEE ATTACHMENT FOR PEX EFFECTED ACFT DEBOOST VALVE CHECK.		N/A	

**Figure 1 Sample Page from the Current Workcard**

The maintenance technicians who perform the A-checks range in age from 23 to 55 years, with an experience on A-checks varying between 1 year to 25 years. All the 201 signoffs within the A-check can be classified into 18 subtasks, which again can be collected into two general categories of tasks, namely "inspection tasks" and "testing tasks". The inspection tasks are those of visual inspection, to ascertain conformance to predetermined standards. Testing on the other hand involves determination of the proper functioning. Both inspection and testing can be further classified into "internal" and "external" tasks, depending on whether the task is to be performed on the interior or exterior of the aircraft.

**Methods.** Field visits were conducted to the various A-check inspection sites. These visits included direct observations of the task, observational interviews, and personal interviewing of experienced as well as inexperienced inspectors, technicians, and supervisors. In addition, a questionnaire study was conducted to obtain a broad range of user responses regarding workcard usability, from all A-check inspection sites within the airline. The questionnaire asked for information regarding the age and experience of the technician, coupled with a set of 12 scaled questions using a rating scale from 0 to 8; a set of five written feedback questions, and a final question asking for the sequence in which the user performed the 18 subtasks of the A-check.

**Results.** The taxonomy for documentation design was used to identify the issues relating to the current workcard design for the A-check as presented in **Table 1**. This study demonstrates how such a taxonomy can be used to analyze any existing documentation and to identify the key issues that need improvement.

**Table 1 A-Check Workcard: Issues Identified Within the Taxonomy**

1. INFORMATION READABILITY	
A. Typographic Layout	<ul style="list-style-type: none"> <li>- no consistent typographic layout as such</li> <li>- layout discontinuous, breaks within pages</li> <li>- no usage of secondary typographic cues, eg boldface, etc.</li> <li>- no use of right justification of typographic material</li> </ul>
B. Sentence, word, and, {2.2.2}	<ul style="list-style-type: none"> <li>- non-conformability with a few of the printing conventions listed in Table 1.</li> <li>- use of all capitals format, resulting in a low reading speed</li> <li>- no room for selecting an appropriate typeface</li> <li>- use of a 5x7 dot matrix typeface</li> </ul>
2. INFORMATION CONTENT	
A. Appropriate content	<ul style="list-style-type: none"> <li>- some level of inaccuracy in the information</li> <li>- incomplete information for certain tasks</li> <li>- language, difficult to use and comprehend</li> <li>- syntax not standardized</li> <li>- directive information ambiguous</li> <li>- generalization across aircraft types, is a cause of confusion</li> <li>- not flexible to use</li> <li>- use of difficult acronyms</li> <li>- logical errors and contradictory statements</li> <li>- redundancy and repetition</li> <li>- not consistent with user training</li> <li>- does not foster generalizations across tasks, as every task is described differently</li> </ul>
B. Graphic Information	<ul style="list-style-type: none"> <li>- system unsupportive of graphics</li> <li>- spatial information conveyed through text, results in the use of complex and lengthy sentences which are difficult to comprehend</li> </ul>
3. INFORMATION ORGANIZATION	
A. Information Classic {2.4.3}	<ul style="list-style-type: none"> <li>- no categorization or classification of tasks</li> <li>- notes, cautions, methods, directions, etc. not in any prioritized order</li> <li>- no demarcation between directive information, references, notes, methods etc.</li> <li>- directive information isn't broken up into command verb, objects, and action qualifiers</li> <li>- directive information includes more than two or three related actions per step</li> <li>- both, general as well as specific information chunked together</li> <li>- external as well as internal tasks not properly demarcated, mixed</li> </ul>
B. Information Layering	<ul style="list-style-type: none"> <li>- no layering of information</li> <li>- not conducive to expert as well as novice usage</li> <li>- difficulty in writing such unstructured information</li> </ul>
C. Other organizational {2.4.3}	<ul style="list-style-type: none"> <li>- no use of naturally occurring page modules for fitting in information</li> <li>- improper sequencing of tasks</li> </ul>
4. PHYSICAL HANDLING & ENVIR.	
	<ul style="list-style-type: none"> <li>- physical handling difficult due to unwieldy size</li> <li>- excessively heavy, cannot be held continuously</li> <li>- usage in extreme environments difficult</li> <li>- not compatible with the other tools used along with, during the task.</li> <li>- inadequate lighting conditions</li> <li>- no holder or place for holding the workcard while usage</li> <li>- all these factors force them to carry out the external inspection without the workcard, relying only on memory</li> </ul>

A total of 60 questionnaire responses were received from fourteen sites. Most respondents had been in the industry for less than 15 years, had less than 14 years experience of maintenance, with less than 10 of it on A-checks. What emerges from the responses, is a moderate level of satisfaction with the current workcard, but a number of users who need different information. There was a substantial agreement that the current ordering of information was incorrect and that the sign-off procedure was not performed after every step. **Table 2** summarizes the conclusions from the A-check rating scale questions. In addition, the questionnaire solicited open ended responses to questions. Over 200 such responses were obtained, showing that the technicians both had strong views and that they were willing to report them when given a formal opportunity. An analysis of the task sequence preferences obtained from the questionnaire



responses was undertaken. Based on these responses, an optimal task sequence was developed, which again is in agreement with the four basic task divisions of the A-check pointed out.

**Table 2 A-Check Questionnaire: Interpretations of Scaled Question Responses**

Q.No.	Interpretation
1.	- 66% of the users find the present workcard as a useful source of information
2.	- 60% of the users refer to the workcard while doing the A-check, either usually or always
3.	- most people feel that the readability of the current workcard is either fair or good
4.	- there is no unanimous opinion amongst the users, as to whether they prefer a concise or detailed workcard
5.	- almost half the users prefer a smaller size workcard, while the other half feel that the current size is about right
6.	- most users feel that the information provided on the workcard is only sometimes sufficient to carry out the A- check task
7.	- almost 50% of the users feel that the current workcard is moderately easy to understand
8.	- most users face problems either sometimes or always in physically using the workcard while working
9.	- 65% of the users do not carry out the A-check activities in the same way as listed out in the workcard
10.	- 80% of the users say that they have felt the need for more information that was not provided on the workcard, either sometimes or always
11.	- there is no unanimous opinion amongst the users, as to whether they use the A-check ACCT list provided at the beginning of the current workcard
12.	- 50% of the users signoff the completed tasks on the workcard at the end of the entire inspection

Work control card for A-check: Proposed design. Based on the issues identified in **Table 1** and the taxonomy, a design for the work control card for A-check's, has been proposed. This design comprises two parts: the design of the information and the paperwork itself and the design of a workcard holder.

The proposed workcard for the A-check has a two level hierarchical layering of information, as discussed. The top level is in the form of a checklist (**Figure 2a**), with brief task descriptions for each of the 201 signoffs, a place for the signoff itself and comments. This is the only part that is issued fresh to the inspector before an A-check. At the lower level is the detailed information in the form of a bound copy (**Figure 2b**), which remains the same until a new revision or update comes up. The directive information is broken up into the command verb, the objects, and the action qualifier as illustrated.

S.#	Description	P#	Signoff	Comment
<b>A</b>	<b>Landing gear and wheel wells</b>	---	-----	-----
1.	General condition, damage, fluid leaks	5		
2.	Wheel wells, landing gear assemblies, hydraulic lines	5		
3.	Brake deboost valve limits	5		
4.	Brake limits	6		
5.	Tires, for wear, damage, fluid leaks	6		
6.	Nose wheel cap attached bolts	6		
7.	Nuts for bottoming of last tread	7		
8.	Shock struts for, normal extension, general condition, leaks	7		
<b>B</b>	<b>Tire pressure check</b>	---	-----	-----
1.	Tire pressure	7		
<b>C</b>	<b>Main gear doors</b>	---	-----	-----
1.	Doors, operating cable, cranks & arms, general condition	8		
<b>D</b>	<b>Main gear wheel well down lock viewing windows</b>	---	-----	-----
1.	Indicator stripes for clarity and legibility	8		
<b>E</b>	<b>Right and left main landing gear wing doors</b>	---	-----	-----
1.	Presence and legibility of wheel chock location placard	8		

**Figure 2a Proposed Design for A-Check Workcard: Checklist**

*2A&B LANDING GEAR (Nose & Main)*

Check systems condition

**A. Landing gear and wheel wells**

(1) *Check:* general condition damage and evidence of fluid leaks.

(2) *Check:* - wheel wells  
                   - landing gear assemblies  
                   - chafing of hydraulic lines  
                                   for broken adel clamps on hydraulic lines on the

**Note:** Discrepancies on the above item must be corrected prior to the dispatch of the aircraft.

(3) *Check:* - Brake deboost valves  
                                   for being within limits

**Note:** See attachment for PEX effected ACFT deboost valve check

**Continental**

*Work*  
*Control*  
*Card:*  
**Landing**  
**Gear**  
*SC7C/AAC*

*03Feb92 07:51*  
*Rev date 090490*

*JCCR No. 02189*  
*MFG P/N: J07*  
*3200-21-020-001*  
*Proc. A/C 3200,*  
*B727, ATA32,*  
*M&E P/N:*  
*07-0521-*  
*1-0017*

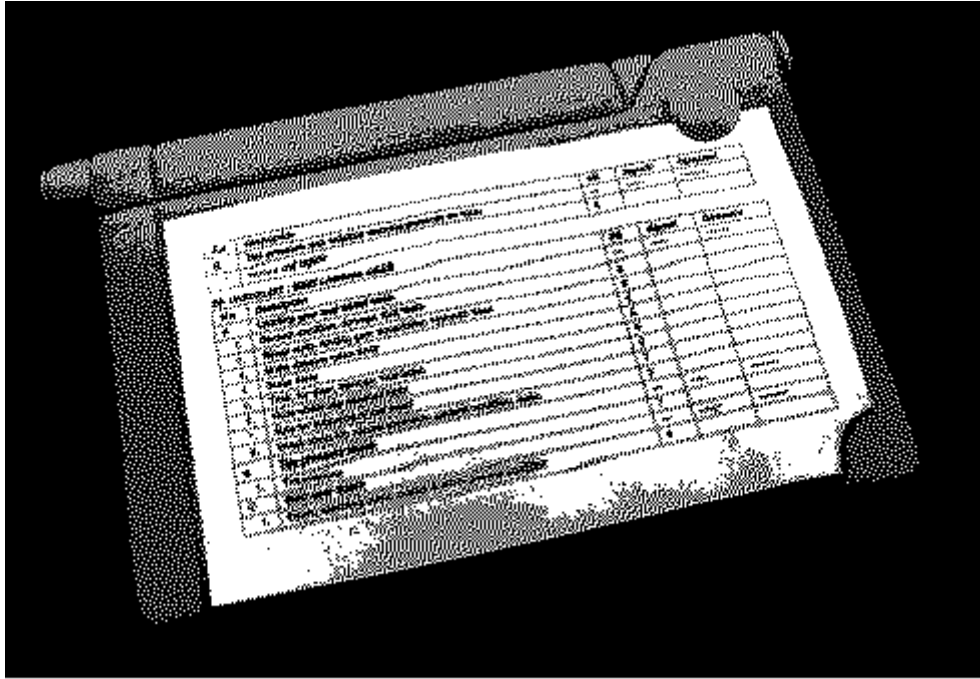
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**Page 5**

**Figure 2b Proposed Design for A-Check Workcard: Detailed Information**

A design was proposed for the workcard holder using the issues brought out in **Table 1** under the heading of "Physical Handling/Environmental Factors." The top layer holds the checklist portion (19 pages) which can be clipped on every time before going out for an inspection, and the inner

compartment holds the detailed information sheets, which remain in there until a new revision comes up. The top layer opens on a hinge which houses a small reading light to enable reading in poor lighting conditions. The holder also has paper retainer clips which aid usage in windy conditions. The prototype is shown in **Figure 3**.



**Figure 3 Prototype of a Workcard Holder**

## **5.0 RECOMMENDATIONS AND CONCLUSIONS**

The A-check case study, and the C-check case study not reported here, both showed that substantial redesign of the existing workcards is required. This is true whether they are to be replaced by new hardcopy workcards, or by a portable computer system. The taxonomy of documentation design presented here provides the framework required for investigating documentation in field conditions, using direct observation and user feedback in a structured manner to develop improved designs.

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## **CREW COORDINATION CONCEPTS FOR MAINTENANCE TEAMS**

*John Stelly, Jr.*  
*Continental Airlines, Inc.*  
*and*  
*James Taylor, Ph.D.*  
*University of Southern California*

### **1.0 INTRODUCTION**

Several months ago while conducting a workshop in Los Angeles, a facilitator was approached by a woman who was about to attend the class. She stated she couldn't wait to attend the workshop and had been looking forward to it for weeks! It seems her supervisor had attended Crew Coordination Concepts (CCC) a month earlier and it had made a profound change in his attitude and in their department; so much so, she had changed her plans to resign from the company and was now looking forward to continuing her career at Continental!

Experiences such as these illustrate the significant impact Crew Coordination Concepts has had on individuals at Continental. Today, I would like to present an overview of the course as it is currently conducted. Secondly, Dr. James Taylor, Ph.D. will discuss results of his research. And finally, I will conclude with some feedback we have received and comments on future plans.

A recent survey conducted at Continental found that 70% of a maintenance managers time is spent interacting with **people**, not using technology. This is generally spent in crew meetings, assigning tasks, answering questions and interacting with other departments.

We have recognized that Maintenance has as much responsibility for safety as cockpit crews - this is a **safety** program. As we have seen, most human factors efforts have been in other areas e.g., environment, publications, etc. This program focuses specifically on **human behaviors, relationships and interpersonal skills**.

NASA research in 1979 identified management of resources as a critical area. This has formed the basis for CRM or CCC at Continental. We believe Maintenance has the same problems in human behavior, listening, and speaking.

This program was initiated at Continental Airlines by Ray Valeika, Senior Vice President, Technical Operations. He had attended a Pilot's CRM workshop. He concluded the same issues are faced in Maintenance. We began CCC Workshops in June 1991. We have trained 1200 of 1800 management employees thus far.

## 2.0 KEY OBJECTIVES

The key objectives we discuss in the course are:

**Assertive Behavior** - This is often **confused with aggressive** behavior. This program, throughout Continental Airlines, is defining the word ASSERTIVE.

**Leadership Style** - We all are different and it's important to understand these differences in order to make the Technical Operations work "Teams" more effective.

**Norms** - "That's the way we do it here." NORMS are often a powerful influence, and often in conflict with safe operations. They exist in every organization!

**Developing Interpersonal Skills** - Listening, Supporting, Confronting and Feedback. **THESE SKILLS ARE NOT WELL DEVELOPED IN MOST INDIVIDUALS**. Elaborating on these skills can make supervisors and work teams more effective.

**Problem Solving** - How to use all available resources and recognize the possible weaknesses in our own skills in decision making.

**Stress** - Understanding it and then how to control it. Much is written on this subject but little is understood; the purpose is to build awareness and ways to manage our own stress.

## 3.0 SEMINAR STRUCTURE

The Seminar Structure is as follows:

- The program was originally designed for Supervisory Personnel (Assistant Supervisors, Supervisors, Managers etc.).
- It now includes all other management personnel and Inspectors.

- It is mandatory for all levels in the organization.
- We utilize two facilitators; one Human Factors facilitator to present concepts, one Continental Airlines Technical Operations facilitator to relate concepts to workplace.
- This is a full two-day workshop.
- We normally have 20-25 participants, mixed by Department and level within the organization.
- It constructed as a highly interactive Program. It is not a lecture. It relies on case studies, videos, table work, and individual/team exercises.

As stated earlier, the program is divided into two days. The concepts are presented in the following fashion.

## 4.0 DAY 1

**Introduction** - UA Portland Flight 173 Video. This is a classic industry accident which sets the tone for the workshop.

**Perception vs Reality Case Study** - CAL GUAM 043/046 This Maintenance case study helps participants relate course concepts to their own work place. It helps to make it real. This module consists of discovering how an individual may be focusing on the wrong problem. What assumptions do we make? The concept of testing assumptions is introduced.

**Behavioral Styles** - Introduction of the concept of three basic behavioral styles. This is not new technology, but most individuals are not aware of the impact of their own style.

**Leadership Style (SDI)** - This module aids an individual in ascertaining who they are. This is not an "in depth" instrument, but Continental Airlines history suggests that it provides insight.

**Assertiveness** - Now it's time to define this preferred Behavioral Style. This has tremendous impact because the groups develop the definition of the concept!

**Stress** - This is a very stressful occupation. The focus is on awareness and how to control stress.

## 5.0 DAY 2

**SUB ARCTIC SURVIVAL** - An exercise in decision making and team work. Most individuals assume they possess acceptable decision making skills. This module helps build awareness and possibly a better way to do it!

**NORMS** - EAL 855 Case Study leads to frank discussion about what goes on in the workplace. Effective/ineffective NORMS and what can we as Supervisors do. This module helps promote good listening, supporting, feedback skills, and also how to deal with conflict.

We close the day with activities addressing listening skills, supporting others, conflict and how

to deal with it, and proper feedback.

It is important to understand in a little more detail the concepts we present in the workshop. Each one of these concepts form the "core" of our program.

## 6.0 PERCEPTION VS. REALITY

As discussed earlier, Perception vs. Reality is presented in the context of a case study. This case study is an event which occurred in Guam last year where two DC-10's were involved in a ground handling accident. This incident caused serious damage to both aircraft.

The issue is made that unless your perception of a situation is actually reality, you **are considering the wrong problem.**

As supervisors we "**Must test the assumption**". This is an important communication process relying on the freedom to speak-out.

## 7.0 TESTING ASSUMPTIONS

Major or minor incidents can not happen if your organization commits to assertive behavior. Methods of testing assumptions are:

- **Advocacy** - Speaking up. It is my responsibility to tell all involved what my plan is, and permission is given for all "Team" members to contribute.
- **Inquiry** - It is your responsibility to tell me what's wrong with the plan or what you don't understand about the plan.
- **Active Listening** - Nothing works unless we hear and understand it.

## 8.0 BEHAVIORAL STYLES

This module sometimes has the most impact on participants. We employ an instrument, referred to as the "SDI" (Strength Deployment Inventory) and several exercises. These combined provide insight to the individual as to his/her own behavioral style and how it relates to the concept of Assertiveness.

At this point the participants have completed the question and answer portion of the SDI.

- The group then puts their arrows on the chart during a break.
- We discuss arrow meaning, i.e.:
  - **Start of arrow** - OK Day
  - **Arrow Point** - Stressful day
  - **Length of arrow** - Degree of change in style
  - **Low Scores** - In a particular dimension, individual experiences great anxiety when required to move to another behavior.



Following the SDI we come back to this issue of assertiveness. It is **a learned skill** and must be practiced in order to be effective. It is a concept based on RIGHTS such as:

- The right to express feelings and ideas.
- The right to be listened to and taken seriously.
- The right to ask for what you want.
- The right to have one's own needs met.
- The right to be treated with respect.
- The right to say "NO".
- The right to ask for information.
- The right to make mistakes.
- The right to be assertive.

**With constructive intent** it is important to use the appropriate behavior at the appropriate time.

After discussing assertiveness, we return to stress. Stress is the element which helped us define a "Bad day" in the SDI administration. Now we try to deal with stress and offer some insight into its effects. We also acknowledge this is a complicated subject and we only scratch the surface. The objectives we attempt to accomplish are: recognize stress, the dynamics of stress, effects on health and performance, and intervention points (or what can we do about it).

At the beginning of Day 2, we start with a fun exercise. This is similar to others you may be familiar with such as "Lost on the Moon". This one however, has its roots in aviation since it deals with an aircraft crash.

- Sub Arctic Survival Situation involving an aircraft crash into a lake in northern Canada in October
- **Exercise will show a group will do better than an individual** in decision making 96% of the time.
- Facilitators will comment on how groups arrived at decisions and the positive/negatives of interpersonal skills.
- The discussion will center around the question: "Would being more assertive by all group members have changed the outcome of your decisions?".

## 9.0 NORMS

Norms are discussed in the context of a case study, EAL 855 - Miami, 1983.

- "Norms" are unwritten rules and behaviors which are reinforced by the group. "This is the way it's always done here!" "Everybody always does it this way."
- Groups are put to work identifying "Norms" which are evident in the case study.
- Groups identify NORMS which apply to our operation.

Examples of NORMS discussed are:

- Not using taxi checklist
- Working from memory
- No wing walkers
- No head-set communication

- "But will you take it anyway?"

Finally, we discuss as supervisors, how to change norms.

## 10.0 ACTIVE LISTENING

We relate this back to the Sub-Arctic Survival exercise, facilitators speak to how each group listened to one another. We use a sleep exercise ("**SELECTIVE HEARING**") to illustrate that we hear what we want to hear. A communication model is introduced. This model illustrates the inefficiency of communication. Listening barriers are discussed. These include rank, preoccupation, interrupting, and detouring. We consider eye contact, affirm and ask questions, and provide feedback as listening tips to improve skills!

## 11.0 SUPPORTING/CONFRONTING/FEEDBACK

Role plays are an important part of the module. They make it relevant and "Operationally Oriented". This is the implementation of **ASSERTIVENESS!!!**

This covers general course content as presently structured.

Since the beginning of this program we have collected survey data and operational performance data. Now Dr. Taylor will speak to the results of that study and analysis.

## 12.0 CCC EVALUATION

What I am presenting today is a sample of the survey and performance results from the ten months experience evaluating Continental Airline's "CCC" training in technical operations. This includes selected data from attitude questionnaires (4 types) and from performance measures (14 types).

This Results/Evaluation research involves cooperation among three institutions. A brief description of the division of labor in this evaluation task will put the research in context. The FAA Office of Aviation Medicine has funded the data analysis and will publish the conclusions. The other two institutions are involved as follows.

### **Continental Airline's (CAL) role:**

- Conceived the data.
- Designed and developed the training.
- Chose the basic questionnaire.
- Administered the training and the questionnaires.
- Provided monthly performance measures.

### **Institute of Safety and Systems Management (USC) role:**

- Helped CAL modify the selected questionnaire.

- Designed the analysis plan.
- Validated questionnaire and performance measures, and confirmed statistical methods.
- Acted as objective third party for receiving the questionnaire and analyzing the results.
- Processed raw data and performed statistical analyses.
- Prepared reports and draft conclusion to simulate discussion among the FAA, CAL and other industry representatives.

## 12.1 ATTITUDE QUESTIONNAIRES

The attitude questionnaires developed for this present study are drawn from earlier work by Bob Helmreich (the CRM Attitude Questionnaire), Bill Taggart (the Maintenance, Engineering & Logistics Description) and a Social Analysis Questionnaire by John Geirland. Some questions are multiple-choice, some "write-in;" some are measures of attitudes, some measure perceptions of behaviors, as well as demographic information).

The four versions of the questionnaire used to evaluation the CAL CCC program are as follows:

- a. "Baseline Questionnaire" (n=900 returned from 1800 sent May '91), mailed to all managers in technical operations before training announced.
- b. "Before" training questionnaire (n=600, through March '92), requested of all participants in the first minutes of the workshop.
- c. "After" training questionnaire (n=600, through March '92), requested of all participants at the workshop's conclusion.
- d. "Follow-up" questionnaires, which are mailed out to all past participants two, six, and 12 months following their training. By July, 1992 the numbers of follow-up questionnaire which had been received and coded were: 2-months n=240, 60-months n=200, and 12-months n=75.

## 12.2 PERFORMANCE MEASURES

1. CAL Technical Operations has developed and applied over 100 measures of performance since 1988. Of these, 14 were selected as suitable and appropriate for evaluating the effectiveness of the CCC training in maintenance and inspection.
2. Three criteria for selecting these 14:
  - i. available separately by work unit (not merely by department or function),
  - ii. can be influenced by individual actions,
  - iii. no direct overlap with other measures in the set.
3. The 14 selected fell into three performance categories: Safety, dependability, efficiency.
4. All 14 performance measures were graded by the trainers for their sensitivity to the training.

Today's presentation will illustrates relationships between post-training (including 2,6, and 12 month follow-up) attitudes and behaviors with 4 of the 14 performance measures. I will also

discuss participants' reported reactions to the training, including their open-ended response to write-in questions.

#### What has been accomplished during the first 10 months of the CCC training?

1. It has determined that the 30 item questionnaire could be summarized into four main attitude clusters, two behavioral issues, and several categories of write-in answers.
2. It was determined that the statistical properties of the questionnaires and its data are "good" and we have confidence in the evaluation reported here.
3. It was determined that the statistical properties of most of the performance data are also good -- and this improves when months are added together.

Results reported here today come from the following analyses:

**Examination** of answers to some questions about the training itself and compared them with other companies and occupational groups in the airline industry.

**Comparison** of participant post-training "intentions" to use the training, with their subsequent "reported use" of their learning.

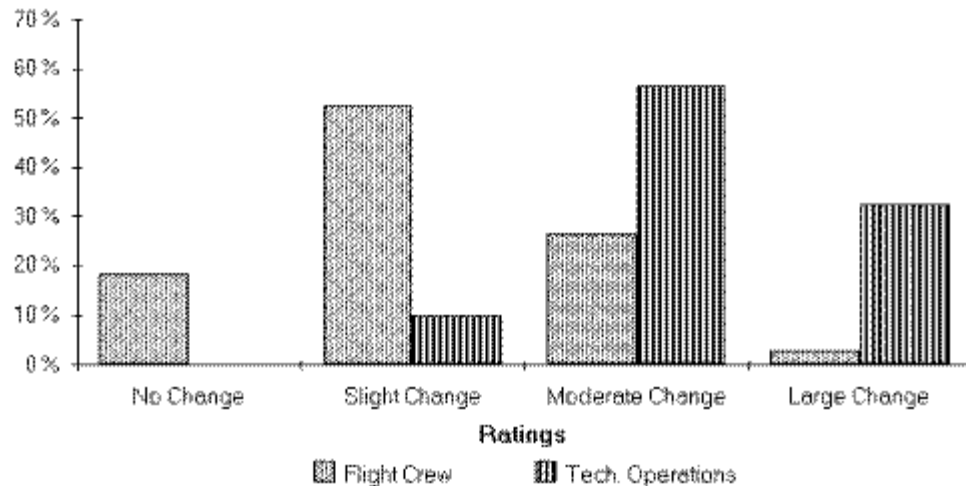
**Matching** of pre-and post-training attitudes to explore the shifts toward "CCC" management beliefs.

**Examination** of the stability of those training-related shifts in attitudes over time (6-months after training).

**Correlation** of the post-training attitudes and behaviors with maintenance unit performance.

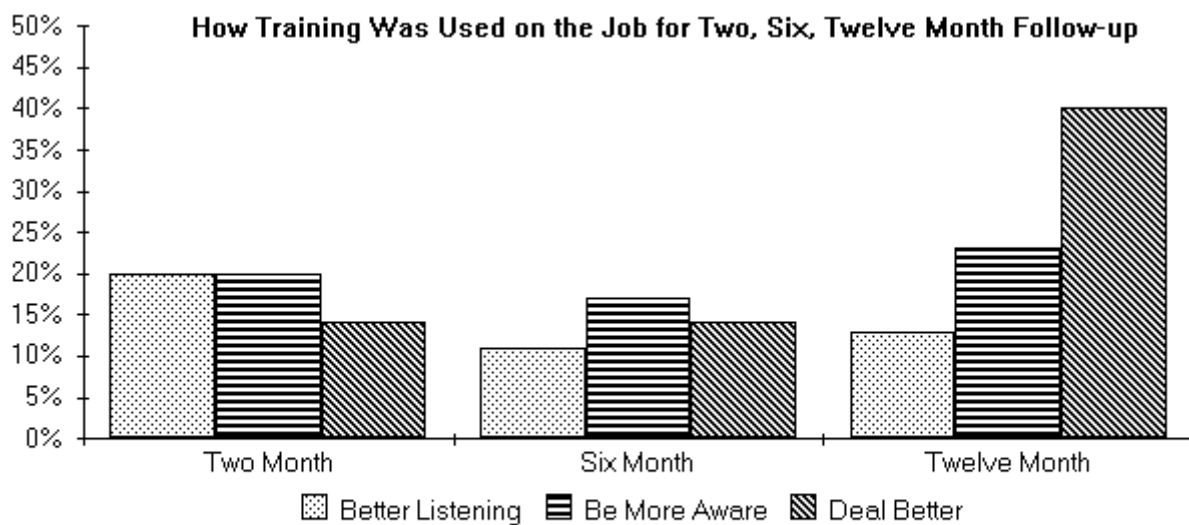
## 12.3 THE RESULTS

**Figure 1:** "Rating Behavioral Change." In completing the questionnaire immediately following training managers answered how much change in the company's way of doing things they would change. The left-hand bar for each category represents a typical pilots' group following CRM training (reported by Helmreich, 1989), and the right-hand bar is the CAL technical operations managers immediately following their CCC training. The graph show that pilots expected that slight-to-moderate change would result from their training. The technical operations managers report that they expected moderate-to-large change; quite an expectation for the managers -- they are saying that the training will really make a difference.



**Figure 1 Percentage Reporting Behavior Change as a Result of CRM Training**

**Figure 2:** "Actual Use of Training." This graph displays the answers to an open-ended question. The three bars for each category are (left to right) "better listening," being more aware of others" (both passive behaviors); and "dealing better with others" (and active behaviors requiring other to react in some way). It shows that two months after training the managers write in that they are using the more passive skills learned in their CCC course, but by 12 months after more of them say that they are actively dealing better with others. This is an exciting findings that are training is sticking with the managers.

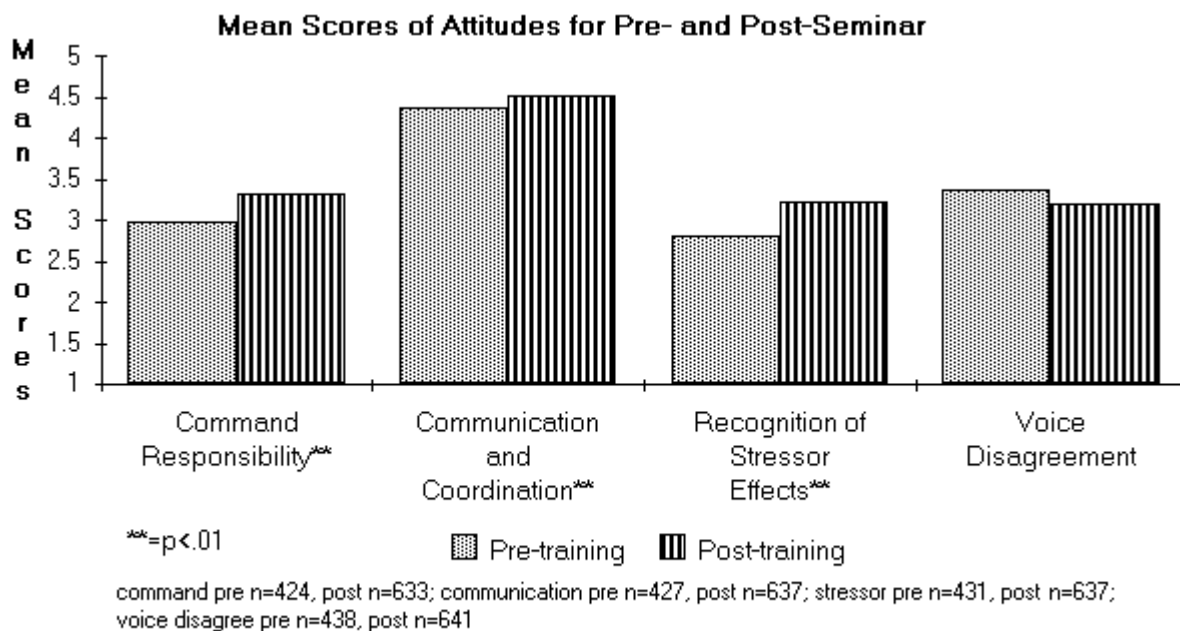


n=215, two months; n=186, six months; n=64, twelve months

**Figure 2 Reported Use of Training**

**Figure 3:** "Pre-/post-training Attitude Changes." Here is the first graph showing the results

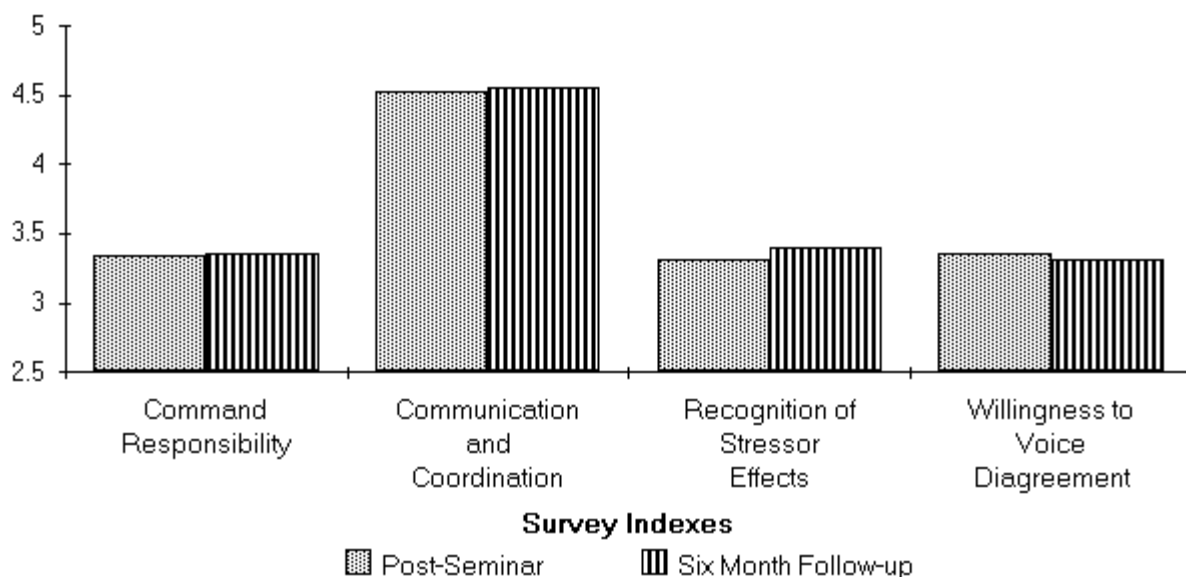
using the four attitude scales derived from the questionnaire. All four of these attitude scales are expected to measure ideas and beliefs taught in the CCC training. From left to right the scales are "Sharing Command Responsibility," "Communication and Coordination are Useful," "Stress Affects the Quality of Decision," and "the Importance of Voicing Disagreement." The post-training attitudes shown in left-most three scaled are significantly higher than before training. The differences shown in the figure may look small but they are real (not likely to be random or chance occurrences) and they are in the direction expected. The right-most scale shows a nonsignificant (statistically it's probably not "real") shift in "willingness to voice disagreement" (our measure of assertiveness). Actually, with further investigation we found that there was a significant and positive change in the value of assertiveness among the maintenance supervisors in our sample, while assistant supervisors, managers and directors showed either no change or a non-significant negative shift.



**Figure 3 Comparisons: Pre- and Post-Training**

There are two other scales from the questionnaire we are interested in that were mentioned above as perceptions of goal attainment behaviors in technical operations. These scales were not expected to change because of the training, but they were included in the questionnaire to help reveal team effects that may be independent of the training curriculum over time. The differences of the goal attainment scales, before and after the training, are not large.

**Figure 4:** This figure shows a test of the stability of the 4 attitude scales 6 months after the training. We can see that the measures are very stable -- the average scores don't change much at all. The goal attainment scales also shows stability of response six months after the training.



**Figure 4 Mean Scores of Indexes for Post-Seminar and Six Month Follow-up for Technical Operations**

**Summary.** What has been presented so far shows, for the first 600 managers, after attending the CCC course...

- They strongly believe that the CCC course is useful and practical.
- They practice more active lessons from the training as times goes by.
- They report changes immediately following the training in their attitudes about sharing command responsibility, the value of communication/coordination, the importance of stress in decision making, and willingness to be assertive.
- And they retain those new levels of attitudes in the months following training, and show stability in their views about goal attainment.

**The final portion of this section on evaluating CCC training will now turn to several of the relationship between the questionnaire scales and four maintenance unit performance measures.** Three of the measures we'll look at here were rated as sensitive to the training. Let's start with that less sensitive one, to explain the way the following tables are set up and to provide a contrast to the more interesting and consistent results in the final three tables.

**Table 1:** "Minimizing Use of Overtime." The left hand side of this table, the four attitude scales and the two goal-attainment scales form the six rows of the table. The four columns represent good performance in reducing overtime costs for four different time periods. August & September 1991 is the concurrent performance immediately following training. Oct/Nov represents two months after training. Dec/Jan is four months after training, and Feb/Mar is six months after.

**Table 1 Questionnaire Scales Related to Overtime Performance**



EFFICIENCY				
n=41	Post-Training Performance Aug/Sep	Post-Training Performance Oct/Nov	Post-Training Performance Dec/Jan	Post-Training Performance Feb/Mar
"Sharing Command Responsibility"	<b>.20+</b>	-.06	-.02	-.02
"Communication and Coordination"	-.11	.00	<b>.18++</b>	-.12
"Recognition of Stressor Effects"	.04	<b>.22+</b>	.00	<b>-.28*</b>
"Willingness to Voice Disagreement"	.04	.00	<b>.19*</b>	-.05
"Goal Attainment with Own Group"	.04	-.09	.14	.05
"Goal Attainment with Other Groups"	-.02	<b>-.19+</b>	.10	<b>-.16++</b>
*p<.05, +p<.10, ++p<.15				

The cell entries are correlation coefficients or statistics showing the degree of relationship between the 6 scales and the overtime measures at four different times. The data that go into the calculations of this statistic are work group averages, so the number can never exceed the total number of groups reporting that performance. Even a large company like CAL only has 60 work units that report overtime used. This table shows that 41 of those were included in this analysis. The missing ones were dropped for a variety of reasons, but mostly because all the managers haven't been through CCC yet.

The trainers expect (other things being equal) that the attitudes will be related positively to performance -- that is that the higher the post training attitudes, the better the performance; and the lower the attitudes, the poorer the post training attitudes.

Theoretically correlations can be either positive or negative and they can be small or large. I've circled the biggest correlations in red (bold). All the others can be ignored as representing no relationship at all -- just random variation. A negative relationship, by the way, is one in which work groups with more positive post training attitudes or behaviors have poorer performance than those units in which the managers report less positive attitudes.

Let's look at the table. Not only is the pattern of larger relationships in the table not uniform, there are several negative relationship as well as some positive ones. This is clearly a situation that the sponsors and trainers of a program like CCC wouldn't want if they expected the training to affect reductions in overtime all by itself. **Remember**, this measure of efficiency in labor costs was rated by the trainers not to be as greatly influenced by the CCC training as other performance measures -- so this is just an example of what everything would be like if we weren't showing training effect. Incidentally the numbers of "large" correlations (7) in this table is the maximum number this size or smaller that we would expect to find by chance (30%).

The final three tables to be presented here show performance measures that the trainers expected

to be related to the training.

**Table 2:** "Reducing Aircraft Ground Damage." This table shows one of the two safety-related performance items in our presentation today. Once again the four attitude scales and the two goal- attainment scales form the six rows of the table. The four columns represent good performance in reducing ground damage for four different time periods. August & September 1991 is the concurrent performance immediately following training. Oct/Nov represents two months after. Dec/Jan is four months after training, and Feb/Mar is six months after. The largest correlations are in bold.

**Table 2 Questionnaire Scales Related to Maintenance Aircraft Ground Damage**

SAFETY				
n=22	Post-Training Performance Aug/Sep	Post-Training Performance Oct/Nov	Post-Training Performance Dec/Jan	Post-Training Performance Feb/Mar
"Sharing Command Responsibility"	.06	<b>-.311</b>	<b>.17</b>	<b>.26++</b>
"Communication and Coordination"	.05	.00	-.04	.00
"Recognition of Stressor Effects"	-.08	.00	<b>.28+</b>	.05
"Willingness to Voice Disagreement"	<b>.43*</b>	<b>.27++</b>	<b>.24++</b>	<b>.69*</b>
"Goal Attainment with Own Group"	.13	<b>.40*</b>	<b>.30+</b>	.06
"Goal Attainment with Other Groups"	<b>.36*</b>	.13	<b>.26++</b>	.08
*p<.05, +p<.10, ++p<.15				

There is only one negative relationship in the table and it is statistically the likely product of random variation (1=4%). The largest relationships on the table are between positive attitudes for assertiveness (willing to voice disagreement") and positive ground damage performance for all four time periods. The average attitude about being assertive (for example, to intervene when aircraft may be damaged) is different in different work groups with this more positive attitude. Their ground-damage performance is better as well. There are several large positive relationships between this safety performance indicator and the goal attainment scales.

**Table 3:** "Reducing Occupational Injury" is another safety-related performance indicator. This table has the same six rows as the previous one, but in this table the four columns contains good performance in reducing work-related injuries for the four time periods (concurrent, 2 mo, 4 mo, 6 mo). Here the major relationships show a pattern that the two goal attainment scales account for most of the difference. In work units where management believes that team goals are shared within their team and between teams occupational injury rates are consistently lower than the other work units in all time periods. Other relationships in the table don't show much uniformity

of pattern.

**Table 3 Questionnaire Scales Related to Occupational Injury**

SAFETY				
n=41	Post-Training Performance Aug/Sep	Post-Training Performance Oct/Nov	Post-Training Performance Dec/Jan	Post-Training Performance Feb/Mar
"Sharing Command Responsibility"	<b>.19++</b>	-.11	.15	.05
"Communication and Coordination"	<b>.17++</b>	.09	-.06	.09
"Recognition of Stressor Effects"	.04	-.06	<b>-.17++</b>	.07
"Willingness to Voice Disagreement"	-.04	<b>.20++</b>	-.09	.10
"Goal Attainment with Own Group"	<b>.31*</b>	<b>.31*</b>	<b>.22+</b>	<b>.29*</b>
"Goal Attainment with Other Groups"	<b>.19++</b>	<b>.27*</b>	<b>.17++</b>	<b>.45*</b>
*p<.05, +p<.10, ++p<.15				

**Table 4:** "Aircraft Departures Within 5 Minutes of Schedule." This dependability measure involves only the line maintenance stations, so the number of data points in the analysis is less than the last table (26 <41). Here the pattern of large relationships is between sharing command responsibility and on-time performance. There is no surprise here for anyone who's followed a maintenance foreman or manager at a large line station during its busiest hours -- they've got to relinquish moment-to-moment decisions or they will slow things down. These relationships for all four time periods mean that there are differences in management attitudes toward sharing their power and the lower they are the slower they are -- **and** remember, as we saw from the table reporting ground-damage performance, people may have to be willing to speak-up as needed to assure high levels of safety.

**Table 4 Questionnaire Scales Related to Departures Within Five Minutes**

DEPENDABILITY				
n=26	Post-Training Performance Aug/Sep	Post-Training Performance Oct/Nov	Post-Training Performance Dec/Jan	Post-Training Performance Feb/Mar
"Sharing Command Responsibility"	<b>.24++</b>	<b>.39*</b>	<b>.34*</b>	<b>.24++</b>
"Communication and Coordination"	.19	-.13	.19	<b>.29+</b>
"Recognition of Stressor Effects"	.18	<b>.22++</b>	<b>.29+</b>	<b>.37*</b>
"Willingness to Voice Disagreement"	.18	.15	.15	.24+
"Goal Attainment with Own Group"	.12	.07	<b>.40*</b>	<b>.50*</b>
"Goal Attainment with Other Groups"	.08	.03	.14	<b>.36*</b>
*p<.05, +p<.10, ++p<.15				

Also notice here that recognizing the adverse consequences of stress is also related to on-time performance. Recall that line stations (anyone in the industry would agree) are where some of the highest levels of work-related stress are endured.

Finally, by six months after training all six scales are shown to be positively related to dependable performance. This may reflect that by March a large proportion of line station management had gone through the training. Those stations with strong manager support for the CCC program are thus encouraging one another to practice the CCC message.

**Conclusion.** We can -- with confidence and enthusiasm -- report that these (still incomplete) results are beyond expectations -- the training really seems to be making a difference in participant response to it, in changes in attitudes, and performance as well.

## 13.0 REACTIONS

This workshop has been met with almost universal acceptance. The interesting point is to discover how these concepts have been implemented in the daily operation.

For example, last year we discovered that at least for some supervisors at a heavy maintenance base, ETR'S (Estimated Time of Release) for aircraft were no longer stressful. After investigating, we found the director of the base had changed the way ETR'S were established by involving his managers and supervisors in the process. This change coincided with his attendance in a workshop several months prior.

Feedback demonstrates how these concepts are applied. Quotes such as:

"Requested crew input before job start up" and "Listen more, dictate less, always be aware of

safety" appear on follow-up surveys as ways of implementing the skills presented.

I recently discovered this response on a survey that I thought was extremely powerful: "Be more assertive in areas of concern where I used to say 'the boss knows best'. Frostie died because he thought his boss knew best." We feel it is significant that participants are still referring to the concepts two, six, and twelve months after the workshop. What is the bottom line?

During the 12 months the program has been in place, trends have indicated:

- The cost of repair due to maintenance caused ground damage is down 68%.
- The number of maintenance caused ground damage incidents are down 34%.
- Occupational Injury hours paid are down 27%.
- Occupational Injury Medical paid is down 12%.

## 14.0 FUTURE PLANS

- We will conduct year over year analysis of operational statistics to further define impact.
- We will conduct individual station studies to determine why it works well at some stations and not so well at others.
- We are developing a new program for hourly/non-management to begin in January 1993.
- We are developing a supervisory follow-up course to begin also in January 1993.

## 15.0 CONCLUSIONS

- The program is sound.
- We have demonstrated it saves money/increases safety.
- It is a mature program being widely accepted.

We are convinced this program works and there is very little investment. We are happy to have the opportunity to share this information with other operators and organizations. To borrow a phrase from a well known commercial "Some ideas are just too good not to share".

# A HUMAN FACTORS GUIDE FOR AVIATION MAINTENANCE

*James F. Parker, Jr., PhD.  
Biotechnology, Inc.*

## 1.0 INTRODUCTION

The U.S. air carrier industry and the Federal Aviation Administration are dedicated to the highest level of safety in commercial aviation. To achieve this goal, they must rely on effective and

efficient maintenance operations. Proper maintenance support is indispensable to safety, to aircraft availability, and to airline profitability. The safety requirements dictate that maintenance be effectively error-free. Aircraft inspectors and aircraft mechanics must work in an environment and use procedures and equipment all carefully structured to work well and to minimize any potential for error. The design of procedures and equipment must ensure that errors are not built into the system.

The maintenance effort to ensure continuing airworthiness of the air carrier fleet is demanding and costly. The maintenance industry continues to grow in parallel with that of airline operations. **Table 1** shows that, in 1991, about 59,000 mechanics were employed in this industry, with maintenance expenses of approximately \$9 billion. These numbers reflect significant growth over the last decade but do not indicate the changing character of the industry. Maintenance operations are being recast to account for the introduction of new and more complex aircraft and the use of more sophisticated maintenance and inspection procedures.

<b>Table 1</b> Maintenance Parameters for U.S. Scheduled Airlines (1991 Data) ATA (1992); Office of Technology Assessment (OTA) (1988)		
Mechanics employed	=	58,819
Maintenance expenses	=	\$8.8 billion (11.5% of operating expenses)
Major carriers contract approximately 11% of maintenance work		

Aviation maintenance is in fact a large industrial system which includes many elements such as the aircraft, the maintenance facility, supervisory forces, inspection equipment, repair equipment, and the maintenance technician. All of these elements together comprise the "maintenance system." Within this system, the technician functions and should be viewed as one would view any other element. A maintenance technician has a set of operating characteristics. Conceptually this human can be considered in essentially the same manner as other system elements such as, for example, items of electronic equipment. The major difference is that the human is significantly more complex and not nearly as predictable. However, anyone responsible for designing or operating a system, such as a maintenance system, must understand the operating characteristics of each element within the system, and this includes the human.

Human factors is a discipline which seeks to understand the laws of human behavior, the capabilities and limits of humans, and the effects of environmental and other factors on human behavior. A key goal of human factors is to provide guidelines for the optimum use of humans in operating systems. An allied goal is to define the manner in which variables internal and external to a system affect human performance within the system.

The operation of any system can only be optimized if every system element is working properly and if each element is carefully coordinated with every other element. The manager of a system such as a maintenance operation should have all necessary information concerning maintenance

technicians and, in particular, those features of the maintenance environment which serve either to enhance or to degrade technician performance. The manager or supervisor of a maintenance activity can be aided through use of a Human Factors Guide that will provide this information in a form suitable for day-to-day reference use.

A Human Factors Guide will present established principles of job design and work. These principles, if well applied, can make a major contribution toward the control of human error in aircraft maintenance and inspection. Issues of communications, equipment utilization, work scheduling and load, work environment, and management relations all are of importance in determining worker effectiveness. A Human Factors Guide should cover these and other issues of human performance that can be applied in aviation maintenance. In presenting these principles, the Guide should see that the information is especially addressed to aviation maintenance and inspection needs.

The preparation of a Human Factors Guide is timely for a number of reasons. The most important of these reasons include:

1. There is a need. Safety is always a matter of concern. The Guide can contribute to maintenance efficiency and to the control of human error in maintenance. This in turn will support continuing safety. There also is the matter of cost control. Maintenance effectiveness contributes to cost reduction.
2. Human factors is a mature and growing discipline. The knowledge within this discipline should be used to support maintenance operations in the same manner as information from the engineering sciences support specific maintenance procedures.
3. Considerable information concerning human factors in aviation maintenance has been developed both through the research conducted by the FAA Human Factors Team and through the conduct of human factors meetings during which beneficial recommendations have been made by representatives of air carrier maintenance. All of this information should be incorporated into a Human Factors Guide.

The Human Factors Guide, as envisioned now, will be directed primarily toward those concerned with the development and operation of air carrier maintenance organizations. However, the Guide can be structured to meet the needs also of a larger audience of groups interested in and responsible for aviation maintenance. In general, the Guide should provide human factors principles and data of use to:

- Maintenance planners and supervisors
- Maintenance inspectors and technicians
- FAA management and FAA inspectors
- Air carrier operators
- Designers of maintenance equipment
- Aircraft design teams
- Aircraft manufacturers

## **2.0 DEVELOPMENT OF A HUMAN FACTORS GUIDE**



The development of a Human Factors Guide for Aviation Maintenance is underway. The first step in this development was to consider the premise on which the Guide should be constructed. This premise is that the Guide, or any such document, is of little if any value if it is not used. The aviation maintenance community must use the Human Factors Guide if the Guide is to serve any real purpose. For the Guide to be used, it must meet ongoing needs of maintenance personnel and must be prepared in such a manner as to foster use by this group.

In order to collect information to satisfy the above requirements, a survey of a sample of aviation maintenance personnel was conducted. Information solicited by the survey was designed to ensure that the real needs of maintenance personnel would be met and that the Guide could be constructed to be consistent with the ways in which this sample stated they were likely to use such a Guide.

A survey form was constructed and mailed to over 60 individuals affiliated in some manner with the air carrier maintenance industry. Names were selected from the list of attendees at earlier FAA Human Factors Meetings. The list included persons both from the United States and from foreign countries. To date, 38 replies have been received. The role of these persons in aviation maintenance, based on their replies, is shown in **Table 2**.

<b>Table 2</b> Occupation of Survey Respondents	
<b><u>Work Classification</u></b>	<b><u>Number</u></b>
Inspection/Maintenance Manager	22
Educator/Trainer	7
Aircraft Designer	2
Other (Senior Management, Quality Assurance, Consultant, Research, AMT Associate, Crew Systems Analyst)	7

The fact that most replies were received from "Inspection/Maintenance Managers" is to be expected since this job category constituted the bulk of the initial survey mailing.

The survey next inquired concerning the value users would place on a Human Factors Guide for their work. Not surprisingly, almost all of those who replied indicated a Human Factors Guide would be "very valuable" or "valuable." Since these replies were given by persons who had evidenced interest in this topic by attending human factors meetings, these replies were anticipated.

The next survey question concerned anticipated frequency of use for a Human Factors Guide, if the Guide contained appropriate information. This question was asked in order to determine whether the Guide should be prepared as a working document or as a reference manual. **Table 3** presents the replies to this question.

**Table 3** Frequency of Anticipated Use  
for a Human Factors Guide

<b><u>Frequency of Use</u></b>	<b><u>Number of Replies</u></b>
Review initially	1
Daily	3
Weekly	20
Monthly	13
Rarely	1

The replies indicate the preferred use for a Human Factors Guide would be as a working document consulted on a number of occasions during the year.

## **2.1 HUMAN FACTORS COVERAGE**

The coverage provided in a Human Factors Guide is of great importance if the Guide is to be truly useful. Certainly, the topics included in this Guide should be those which members of the maintenance community consider important. In order to collect information concerning desired coverage, an outline of a prototype Guide was prepared. In the survey, each person was presented a list of chapter headings from the prototype outline and asked to judge the importance of the topic on a five-step scale ranging from "very important" (weighting of five) to "not important" (weighting of one). With this system, had each of the respondents judged a given topic to be "very important," that topic would have received a total score of 190. Results for this question are presented in **Table 4**. While there is a dispersion of total scores, it is quite apparent that most topics were judged either as "very important" or "important." The topics in **Table 4** are listed in terms of decreasing order of judged importance.

**Table 4** Importance of Specific Topics  
for Inclusion in a Human Factors Guide

<b>Topic</b>	<b>Weighted Score</b>
Human Error in Maintenance	178
Information Exchange and Communications	178
Maintenance Training and Practices	173
Human Capabilities and Limits	168
Human Performance	166
Work Requirements	163
The Maintenance Workplace	160
Job Performance Aids	157
Man-Machine Interface	156
Workplace Features	152
Automation in Aircraft Maintenance	151

Prior to the development of the survey instrument, a question had arisen about the desirability of including a section within the Human Factors Guide concerning emotional factors. For this reason, a separate question was included that asked "Should the Human Factors Guide contain a section, not usually included in texts of this type, that addresses social and emotional factors that can affect the performance of a worker?" The following responses were received:

**Yes** = 32    **No** = 6

Obviously, the majority of the respondents believe that a section containing the above information should be included in the Guide.

To ensure that no appropriate topics were missed, each respondent was asked to note any additional topics believed important for a Guide of this type. Quite a few replies were received; most appeared to be variants of the topics in the initial list presented in the survey. However, a few were indeed new and are listed below:

1.     Requalification, limitations, and competency verification for aviation maintenance technicians.
2.     Minimum individual qualifications (eyesight, color blindness, and manual dexterity) for specific maintenance functions.
3.     Sexual harassment. (This could become increasingly important as workforce demographics change.)
4.     Working with the handicapped. (The recently passed Americans With Disabilities Act gives impetus to this topic.)

## **2.2 FORMAT**

For a Guide to be useful, it not only must contain appropriate information but also must be

presented in a manner designed to make it easy to use. Several questions on the survey addressed the general issue of format. The first question concerned optimum length. Members of the survey were asked "To be most usable, what size should a Human Factors Guide be?"

**Table 5** presents the responses.

<b>Table 5</b> Desired Length of a Human Factors Guide	
<b>Length</b>	<b>Responses</b>
Less than 100 pages	18
100 - 300 pages	14
Over 300 pages	0
Size is of no concern	6

The above replies clearly point to a shorter rather than a longer Guide. These data are supported by a comment submitted by one respondent:

*A Human Factors Guide should be 50-75 pages for handout to line management personnel. It should be 100-300 pages for managers and supervisors with decision making capabilities for resources and monies.*

The next survey item asked "What format would you find most useful?" This question is considered quite important since the manner in which information is presented can affect the extent to which individuals will seek and use information concerning the topic being presented.

**Table 6** shows the results for this question.

<b>Table 6</b> Preferred Format for a Human Factors Guide	
<b>Format</b>	<b>Number of Selections</b>
Key information and recommendations in bullet form, with illustrations	20
Short statements, with illustrations	8
Running prose, with illustrations	8
Other (Please Specify) (Combine short statements, with illustrations, and key information and recommendations in bullet form, with illustrations; use running prose - segmented by topic statements; use electronic/digital format with key word search.)	2

Results indicate the desired format would be one in which information is presented tersely and concisely, either in bullet form or using short statements. Illustrations should support the materials as needed.

A question next was asked which relates both to the length of the Guide and the manner in which materials are presented. Two alternatives were given with a request for a preference between these two. **Table 7** lists the two alternatives and shows the replies.

<b>Table 7</b> Preference for Physical Structure of a Human Factors Guide	
<b><u>Alternatives</u></b>	<b><u>Number</u></b>
A shorter guide, presenting brief discussions and recommendations, with supporting data elsewhere (possibly in another book or in a computer data base)?	21
A longer guide, with supporting data included as appendices?	17

These results show a slight preference for a shorter Guide, even if one has to look elsewhere for data supporting and elaborating the concise information presented in the Guide. One supporting comment illustrates this: "A shorter Guide. Computerized supporting data would be very nice."

## 2.3 SUMMARY

The results of the survey of maintenance personnel, combined with other discussions with those likely to use a Human Factors Guide, lead to the following conclusions concerning the content and structure of the Guide.

**Audience.** The principal users of a Human Factors Guide will be air carrier maintenance planners and supervisors. However, care must be taken that the structure of the Guide not be oriented entirely toward this group. A Human Factors Guide also can be used to advantage by other groups, including FAA management and FAA inspectors as well as aircraft design teams and designers of maintenance equipment. The document also could be used profitably in training operations.

**Content.** Three topics have been identified as most important for inclusion in a Human Factors Guide. These topics are:

- Human error in maintenance
- Information exchange and communications
- Maintenance training and practices

All topics must be given appropriate coverage in the Guide. Greatest attention, however, will be given to the three topics listed above.

**Size.** The Human Factors Guide should not be a large document and probably should not exceed 200 pages in length. A larger document might well impact use, particularly if the document is to be carried around within the maintenance facility. Current thinking is that supporting materials, which could be quite lengthy, would best be contained in a computerized data base in a CD-ROM system. With proper search strategies, data supporting the Guide could be obtained quite rapidly.

**Style.** Information within the Human Factors Guide, such as basic human factors principles applied to specific maintenance labor, should be presented concisely, possibly using a bullet format, with supporting illustrations. Introductory chapters and materials can be more in a running prose form. The language should be simple and straightforward English. This will make it more likely that the message is conveyed as intended. Use of simple English also will help should the Guide be translated into a foreign language for use in overseas maintenance activities.

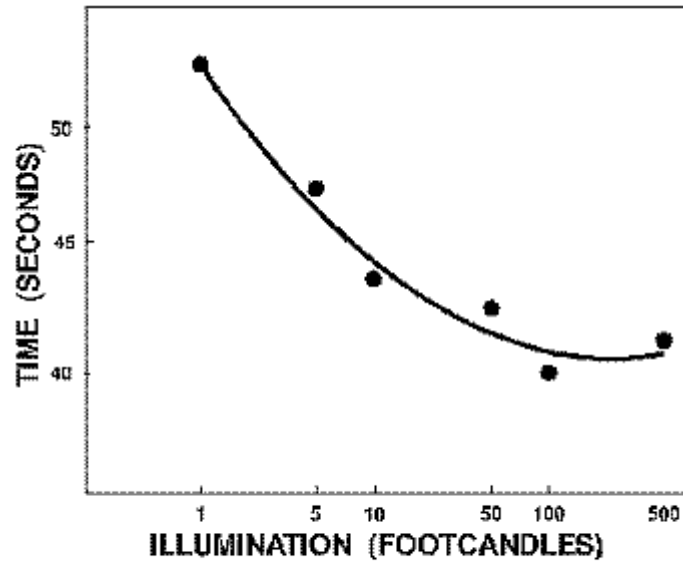
### 3.0 SAMPLE SECTION OF A HUMAN FACTORS GUIDE

This section illustrates the manner in which the above concepts and rules would be applied in the preparation of a section for the Human Factors Guide. The section is presented in highly abbreviated form simply to show the appearance and general content of a part of the Guide. This section does not indicate the depth of coverage planned for individual topics.

## 4.0 SECTION I: AREA AND TASK LIGHTING

### 4.1 IMPORTANCE OF LIGHTING IN INDUSTRIAL OPERATIONS

Lighting conditions in an industrial workplace are important both for worker productivity and for worker comfort. Numerous studies have examined the effect on worker productivity of varying levels of task illumination (see Cushman, 1987). In general, these studies show that performance under low illumination improves to a point as the illumination level is increased. **Figure 1** shows the reduced time required to complete a typical industrial task (reading a micrometer) as the level of illumination on the task is increased. Note that when the illumination reaches about 100 footcandles, no additional improvement is seen. In general, industrial tasks show smaller and smaller improvement in performance as illumination is increased. However, the point where performance finally levels off is task-dependent. Tasks that are visually difficult, as might be true for inspection activities, will require more light to achieve best performance than will easier tasks.



Effect of illumination level on time to complete  
a typical industrial task (micrometer reading).  
Adapted from *Sanders and McCormick, 1987*

**Figure 1** Effect of illumination of time to complete a typical industrial task (micrometer reading).

Research conducted to assess the effectiveness of illumination on performance must deal with two issues which can affect the results. First, motivational factors must be controlled. Subject, or workers, who know they are in a study will tend to perform better independent of the illumination level. Second, the age of subjects is important. Workers who are over 45 years of age will show more improvement with increasing illumination than will younger workers. If a work group contains older workers, illumination should be increased to account for this.

Recommendations for proper illumination levels for various activities have been prepared by the Illuminating Engineering Society and are presented in **Table 8**.



**Table 8** Recommended Illuminance Values  
for Different Types of Activity

<b>Activity</b>	<b>Level (footcandles)</b>
Working spaces with occasional visual tasks	10 - 20
Performance of visual tasks of high contrast or large size	20 - 50
Performance of visual tasks of medium contrast	50 - 100
Performance of visual tasks of low contrast or very small size	100 - 200
Performance of visual tasks of low contrast and very small size over a prolonged period	200 - 500

Sanders and McCormick (1987) point out problems in arriving at recommendations for adequate illumination to ensure proper task performance. Interestingly, they note that recommended levels continually increase through the years. Current recommended levels are about five times greater than levels recommended 30 years ago for the same tasks.

Even though proper levels of illumination are provided, task performance can be degraded if glare sources are present. Glare is of two types. Direct glare is produced when a bright light source is in the visual field. Indirect glare, often called reflected glare, is reflected from the work surface and reduces the apparent contrast of task materials. Either direct or indirect glare can degrade task performance. **Table 9** offers suggestions concerning ways to control the effects of glare sources.

Table 9 Techniques for Controlling Glare	
<u>To Control Direct Glare</u>	<u>To Control Indirect Glare</u>
Position lighting units as far from the operator's line of sight as practical	Avoid placing lights in the indirect-glare
Use several low-intensity lights instead of one bright one	Use lights with diffusing or polarizing lenses
Use lights that produce a batwing light distribution and position workers so that the highest light level comes from the sides, not front and back	Use surfaces that diffuse light, such as flat paint, non-gloss paper, and textured finishes
Use lights with louvers or prismatic lenses	Change the orientation of a workplace, task, viewing angle, or viewing direction until maximum visibility is achieved
Use indirect lighting	
Use light shields, hoods, and visors at the workplace if other methods are impractical	

Adapted from *Rodgers (1987)*

## 4.2 LIGHTING CONDITIONS IN AVIATION MAINTENANCE

A survey of illumination conditions within major air carriers was accomplished as part of an FAA audit (Thackray, 1990). In these facilities, overhead lighting typically is supplied by mercury vapor, metal halide, or high-pressure sodium lights. The principal difference here is in terms of the color rendition of the lights. While color rendition is probably not too important for aircraft exterior maintenance tasks, the level of illumination could be.

**Table 10** shows average illumination levels measured at different maintenance work areas, both for day shifts and night shifts. **Table 10** also presents recommended illumination levels for aircraft repair and inspection tasks. Although slightly below recommended levels, the illumination for work on upper and lateral surfaces of an aircraft appear adequate. For repair and inspection conducted below wings, the fuselage, and within cargo and engine areas, measured illumination levels are not adequate and supplemental light sources are required. In general, supplemental lighting is provided through quartz halogen stand lights, dual 40-watt florescent stand fixtures, single hand-held florescent lamps, and flashlights.

**Table 10** Measured Illumination Levels at  
Major Air Carriers Compared with  
Recommended Levels

<b><u>Measured (Footcandles)</u></b>		
	<u>Day</u>	<u>Night</u>
Hangar area	66	51
Below wings, fuselage and in cargo areas	26	15
Within fuselage	23	18
Visual inspection (2 D-cell flashlight)	100-500	
<b><u>Recommended (Footcandles)</u></b>		
	<u>Min. Level</u>	
Aircraft repair, general	75	
Aircraft visual inspection		
Ordinary area	50	
Difficult	100	
Highly difficult	200	

*Thackray (1990)*

Use of supplemental lighting does not necessarily solve existing lighting problems. The FAA audit of major carriers found that supplemental lighting systems frequently were placed too far from the work being performed and were too few in number. The result was that, even with supplemental lighting, the illumination directly at the work site was less than adequate.

Aircraft inspectors generally use small flashlights as supplementary sources. At times, small lights mounted on headbands may be used. The flashlights provide illumination ranging from 100 to 500 footcandles and are acceptable for visual inspection. However, use of the flashlight means that one hand cannot be used for manipulation of the systems being inspected.

In an attempt to produce more even lighting within maintenance bays, some carriers have painted the walls and even the floors with a bright white reflective paint. While this does tend to reduce shadow effects, other problems can arise. The principal one is glare. Reflected light from bright sources produces glare which can both cause discomfort and reduce visibility of key features of the maintenance task. The glare tends to obscure or veil part of the visual task.

## 4.3 GUIDELINES

The goal of controlling human error in aviation maintenance requires that maintenance be conducted under proper lighting conditions. This is true both for area lighting, that which illuminates the full working area, and task lighting, that directed toward specific work activities.

Improper or insufficient lighting can lead to mistakes in work tasks or can simply increase the time required to do the work. In a program directed toward proper lighting conditions, the following guidelines should be observed:

### **Guidelines**

- Area lighting within a maintenance facility should be a minimum of 75 footcandles. A level of 100-150 footcandles is preferred.
- Care must be exercised to see that the light level available for night maintenance activities in particular does not drop below recommended levels. Any lighting surveys must be conducted both during the day and at night.
- Task lighting for aircraft inspection requires a minimum of 100 footcandles of illumination. For difficult inspections or fine machine work, 200-500 footcandles of illumination is necessary.
- Supplemental lighting must be adequate for the task at hand, best judged by the worker. Task lighting should be placed close to the work being done and, if feasible, should leave both of the worker's hands free for the work. If systems must be manipulated, lights mounted on headbands are preferred to flashlights.
- If the workforce contains a substantial percentage of older workers, i.e. those greater than 45 years of age, recommended lighting levels should be increased, probably in the order of 50 percent.
- Glare sources should be controlled. Supplemental lighting should be placed as far from a worker's line of sight as practical. Reflected glare can be changed by reorienting the work surface or changing the position of lights. Worker complaints are the best means for identifying offending glare sources.

## **4.4 PROCEDURES FOR EVALUATING LIGHT CONDITIONS**

The best procedure for determining if lighting conditions are adequate is through the services of either the industrial hygiene department or the safety department of the air carrier. Individuals in these departments typically are trained in procedures for conducting an environmental audit, possess the necessary measurement equipment, and understand the problems involved in obtaining meaningful measurements. Specialists from these departments also will be able to provide a proper evaluation of the audit results.

If the services of specialists are not available, maintenance managers can assess lighting conditions themselves. Photometric equipment is available which will provide accurate (generally plus or minus five percent) measurement of facility lighting.

Illuminometers/photometers are available commercially for a price in the order of \$1,000. Catalogs of scientific equipment describe these items.

## **5.0 REFERENCES**

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## ATA Human Factors Tiger Team: Status Report

*Anthony Majoros, Ph.D*  
*Douglas Aircraft Company*

This document is not available for viewing, but is available in the printed proceedings.

## Appendix A: Program

### **FAA Office of Aviation Medicine 7th Meeting on Human Factors in Aircraft Maintenance and Inspection SCIENCE, TECHNOLOGY, AND MANAGEMENT**

*Atlanta, Georgia*

**August 4 - 6, 1992**

#### ***Tuesday, 4 August 1992 (Outside Salon 1 & 2)***

Arrival day for many attendees

4:00 - 5:30 p.m.      **REGISTRATION**

No activities planned for Tuesday, 4 August

#### ***Wednesday Morning, 5 August 1992 - Salon 1 & 2***

8:00 a.m.      Registration & Continental Breakfast

9:00 a.m.      **Keynote Address**  
*Charles R. Foster,*  
**Retired NorthWest Mountain Regional**

Director  
Bellevue, WA

9:20 a.m.     **Human Factors in Aircraft Maintenance: Program Overview**  
*William T. Shepherd, Ph.D.*  
**Office of Aviation Medicine**  
Federal Aviation Administration

9:40 a.m.     **National Plan for Aviation Human Factors: Progress Report**  
*Phyllis Kayten, Ph.D.*  
**Deputy Scientific Advisor for Human Factors**  
Federal Aviation Administration

10:00 a.m.     Break

10:20 a.m.     **Job Aiding Research in the U.S. Air Force**  
*Bertram W. Cream and Robert C. Johnson*  
**USAF Armstrong Laboratory**

11:00 a.m.     **Investigation of Human Error in Maintenance and Inspection**  
*Colin G. Drury, Ph.D.,*  
Kara Latorella, and Prasad Prabhu  
**State University of New York at Buffalo**

11:50 a.m.     LUNCH (Congress & Caucas Rooms)

*Wednesday Afternoon, 5 August 1992 - Salon 1 & 2*

1:15 p.m.     **Integrated Information Environments for Training, Aiding & Documentation**  
  
Retrieval  
*William B. Johnson, Ph.D.*  
**Galaxy Scientific Corporation**

1:50 p.m.     **Intelligent Simulations for Maintenance Training**  
*Jeffrey E. Norton*  
**Galaxy Scientific Corp.**

2:30 p.m.     Break

2:50 p.m.     **Job Aiding for Dispatchers and Pilots: Evaluation Results**  
*Charles Layton, Ph.D.*  
**Galaxy Scientific Corp.**

3:25 p.m.     **Training Systems for Airway Facilities Maintenance**  
*Julie Jones*  
**Galaxy Scientific Corp.**

4:00 p.m.     **Training for Visual Inspection**  
*Colin G. Drury, Ph.D. and*  
Anand Gramopadhye, Ph.D.

**State University of New York at Buffalo**

- 4:35 p.m. **SOFTWARE DEMONSTRATIONS**
- 5:00 p.m. **RECEPTION (Cash Bar) Congress Room**
- 7:40 p.m. **BASEBALL: BRAVES vs. REDS**  
(Tickets available at \$9.00 each. See Bill Johnson or Suzanne Morgan,  
Galaxy Scientific Corporation)

**THURSDAY, 6 August 1992 - Salon 1 & 2**

- 7:30 a.m. Registration & Continental Breakfast
- 8:30 a.m. **Continuous Improvement Process at Northwest Airlines**  
*Steve Eberhardt*  
**Northwest Airlines**
- 9:15 a.m. **Ergonomic Research in Aircraft Maintenance**  
*Jackie Reynolds and Swapnesh Patel*  
**State University of New York at Buffalo**
- 10:15 p.m. Break
- 10:40 a.m. **Crew Coordination Concepts for Maintenance Teams**  
*James Taylor, Ph.D.*  
**University of Southern California and**  
*John W. Stelly, Jr.*  
**Continental Airlines**
- 12:00 noon **BUFFET LUNCH (Seating in Cabinet, Caucas, Charter and Committee Rooms)**
- 1:15 p.m. **Human Factors Guide for Aviation Maintenance**  
*James F. Parker, Jr., Ph.D.*  
**BioTechnology, Inc.**
- 1:45 p.m. **ATA Human Factors Tiger Team: Status Report**  
*Anthony Majoros, Ph.D.*  
**Douglas Aircraft Company**
- 2:30 p.m. **Closing Remarks**  
*William T. Shepherd, Ph.D.*  
**Office of Aviation Medicine**  
Federal Aviation Administration
- 3:30 p.m. **ADJOURN**

## **Appendix B: Attendees**

**Seventh Federal Aviation Administration Meeting on Human**



# **Factors Issues in Aircraft Maintenance and Inspection 5 - 6 August 1992**

## **Science, Technology, & Management: A Program Review**

### **MEETING ATTENDEES**

Lori Adkisson, FAA Technical Center, ACD-350, Atlantic City International Airport, Atlantic City, NJ 08405

Jerry Allen, Continental Airlines, 3663 N. Sam Houston Parkway E., Houston, TX 77032 (713) 985-1197

Sigit R. Anggoro, Garuda Indonesia, PT Maintenance & Engineering, PO Box 303, Cengkareng, BUSH 1901 Indonesia FAX: 62-21-5501249

Gene Argyle, Atlantic Southeast Airlines, Inc., Macon Municipal Airport, Macon, Georgia 32197 (912) 784-0318 FAX: (912) 788-9588

Spencer Bennett, Federal Express/ Maint. Tech. Training, 2851 Lambs Place, Suite 13-14, Memphis, TN 38118 (901) 375-6263

Warren L. Bunn, Atlantic Southeast Airlines, Inc., Macon Municipal Airport, Macon, Georgia 32197 (912) 784-0318

Diane Christensen, BioTechnology, Inc., 405 N. Washington St., Suite 203, Falls Church, VA 22046 (703) 534-8200

John Cox, Airline Pilots Association, 4463 39th Street, S., St. Petersburg, FL 33711 (813) 867-2299

Bertram W. Cream, Chief, Logistics Research Division, Human Resources Directorate, Armstrong Labs, WPAFB, OH 45433 (513) 255-3713

John Cuneo, National Helicopter, North Avenue, Garden City, NY 11530 (516) 228-9355

Tom De Lessio, UPS Airlines, 725 Bean Blossom Road, Louisville, KY 40213 (502) 363-8573

Frank Dickson, Change Management Associates Integrated Automation, 6633 Portwest Drive, Houston, TX 77024 (713) 861-2054

Eugene "Dutch" Drescher, IAM & AW, 215 E. 98th St., Bloomington, MN 55420 (612) 726-2814

Colin G. Drury, Ph.D., SUNY Buffalo, 342 Bell Hall, Amherst, NY 14260 (716) 636-2357

Ron Durie, Airbus Service Co., P.O. Box 660037, Miami Springs, FL 33266 (305) 871-3655 FAX: (305) 871-4649

Steve Eberhardt, Director, Support Shops Northwest Airlines, 1000 Inner Loop Road, Atlanta, GA 30337

Tom Eismin, Purdue University Aviation Education Consultants, 761 North 400 West, W. Lafayette, IN 47906 (317) 743-5800

Koichi Emori, Quality Control Engineering & Maintenance, All Nippon Airways Co. Ltd., 1-6-6 Haneda Airport, Ota-ku Tokyo 144 JAPAN FAX: 03-3745-8609

Martin R. Eran-Tasker, Airbus Industrie, **ETOPS** Coordinator, Technical Support (AI/ST42), 1, Rond-point M. Bellonte, 31707 Blagnac Cedex, FRANCE FAX: 61300079

David Finch, Structural Airworthiness Consultant, 12 Rectory Close, Windsor Berkshire SL4 5ER, ENGLAND 011 44 753 866819

Karl Florian, Xerox Corporation, 100 1st Stamford Pl., Stamford, CT 06904 (203) 325-6625

Charles Chong You Fook, Quality Control Superintendent, SIA Engineering Company, Republic of Singapore FAX: (65) 543-0561

Charles Foster, 13817 Southeast 52 Place, Bellevue, WA 98006 (W) (206) 641-6860 (H) (206) 643-3532

Olav I. Geleyns, Lead Engineer, **NDT SPL/CF**, Engineering and Maintenance Division, KLM Royal Dutch Airlines, PO Box 7700, 1117 ZL Schipol Airport, The Netherlands FAX: 31-2064-88155

Atef Ghobrial, Ph.D., Assoc. Professor & Director Aviation Administration Program, Georgia State University, University Plaza, Atlanta, GA 30303-3083

Bruce A. Gindlesperger, Manager, Technical Operations Training, Delta Air Lines, Inc., Ground Training - Department 967, Hartsfield Atlanta International Airport, Atlanta, GA 30320 (404) 715-0753 FAX: (404) 715-0908

John Goglia, Permanent **FAA** Committee, **IAM & AW**, 73 Auburn, St. Saugus, MA 01906 (617) 233-3675

Gary Goodwin, Airworthiness Specialist, Federal Aviation Administration, Mail Stop: ANM-270S, 1601 Lind Avenue, SW, Renton, WA 98055-4056 (206) 227-2285 FAX: (206) 227-1270

Anand Gramopadhye, 342 Bell Hall, SUNY Buffalo, Amherst, NY 14260

Kermit Grayson, ACD-350, FAA Technical Center, Atlantic City International Airport, Atlantic City, NJ 08405 (609) 484-5320

Willard Gregory, GE Aircraft Engines, Mail Drop T-25, One Neumann Way, Cincinnati, OH 45215-6301 (513) 672-7042

David J. Hall, **CAA** Surveyor, Civil Aviation Authority, Sipson House, 595 Sipson Road, West Drayton Middlesex, UB7 0JD ENGLAND FAX: 081-759-5280

Herbert Hamann, Deputy Director Training, Standardization Aeroformation, Avenue Pierre Latecoere, B.P. 36 31701, Blagnac Cedex, FRANCE Tel: 61 93 20 20 FAX: 61 30 05 06

William Hendricks, Director, Accident Investigations, Federal Aviation Administration, 800 Independence Avenue, SW, Room 332A, Washington, DC 20591

William H. Hinson, Jr., Vice President, Technical Services, Atlantic Southeast Airlines, Inc., Macon Municipal Airport, Macon, GA 32197 (912) 784-0318 FAX: (912) 788-9588

Alan Hobbs, Department of Transportation & Communication, Bureau of Air Safety Investigation, P.O. Box 967, Civic Square, ACT 2608, AUSTRALIA FAX: 61-6-247-3117

Dr. Mark Hofmann, Federal Aviation Administration, Mail Code AXD-4, 800 Independence Avenue, NW, Washington, DC 20591 (202) 267-7125

Randy Holder, FAA-Flight Standards, District Office, 5440 Roslyn Street, Denver, CO 80216 (303) 286-5437

Gene Holtsinger, Commercial Engine Business, United Technologies Pratt & Whitney, 400 Main Street, M/S 132-33, East Hartford, CT 06108 (203) 565-1283

Lawrence D. Howell, Jr., Ph.D., PE Associate Director, AAMRL/HE/CSERIAC, Crew System Ergonomics Information Analysis Center, Wright-Patterson AFB, OH 45433-6573 (513) 255-4842 FAX: (513) 255-4823

Frank Iacobucci, Spartan School of Aeronautics, P.O. Box 582833, Tulsa, OK 74158-2833 (918) 831-5212 FAX: (918) 831-5387

Joe Jackson, Software Engineer, Information Division, Galaxy Scientific Corporation, 2310 Parklake Drive, Suite 325, Atlanta, GA 30345 (404) 491-1100 FAX: (404) 491-0739

Rob Jackson, FAA-AEG, Code ANM-270L, 3229 E. Spring Street, Long Beach, CA 90806-2425 (310) 988-5271

Jean-Francois Jannes, Director, Training Course Development Aeroformation, Avenue Pierre Latécoère, P.B. 36 31700, Blagnac FRANCE FAX: 61-93-20-73

Laurie Johns, Columbus State Community College, 5355 Alkire Rd., Columbus, OH 43228 (614) 878-1038

Robert C. Johnson, Chief, Operations Logistics Branch, Logistics Research Division, Human Resources, Directorate Armstrong Labs, WPAFB, OH 45433 (513) 255-3713

William Johnson, Ph.D., Galaxy Scientific Corporation, 2310 Parklake Drive, Suite 325, Atlanta, GA 30345 (404) 491-1100

Julie Jones, Galaxy Scientific Corporation, 2310 Parklake Drive, Suite 325, Atlanta, GA 30345 (404) 491-1100

Harold Joyner, Assistant Vice President, Quality Control, Delta Air Lines, Technical Operations Center, Hartsfield Atlanta International Airport, Atlanta, GA 30320 FAX: 404-714-3310

Barbara Kanki, NASA/Ames Research Center, M.S 262-4, Moffet Field, CA 94035

Phyllis Kayten, Ph.D., Federal Aviation Administration, Mail Code AXR-3, 800 Independence Avenue, SW, Washington, DC 20591 (202) 267-7125

Steve Krause, Delta Air Lines, Dept. 510, Atlanta International Airport, Atlanta, GA 30320 (404) 714-3224

Julie Lanier, Galaxy Scientific Corporation, 2310 Parklake Drive, Suite 325, Atlanta, GA 30345

(404) 491-1100

Kara Latorella, SUNY Buffalo, 342 Bell Hall, Amherst, NY 14260

Chuck Layton, Galaxy Scientific Corporation, 2310 Parklake Drive, Suite 325, Atlanta, GA 30345 (404) 491-1100

Jim Lewis, Manager, Aircraft Maintenance, Delta Air Lines, Atlanta International Airport, Atlanta, GA 30320 (404) 714-3516

Fred Liddell, IAM & AW, Local 1650, P.O. Box 9067, Riverside, MO 64168 (816) 741-5833

Jay Lofgren, Continental Airlines, 8450 Travelair, Bldg. 2, Houston, TX 77061 (713) 640-5084

Anthony E. Majoros, Ph.D., Douglas Aircraft Co., C1 ILC (78-73), 3855 Lakewood Blvd., Long Beach, CA 90846 (310) 593-8387

David Marx, Boeing Commercial Airplane Group, P.O. Box 3707, M/S 2J-52, Seattle, WA 98124-2207 (206) 544-6207

Paul C. Mollenhauer, Lockheed Aeronautical Systems, ATF Transition Team, Bldg. L-12, Zone 0017, Marietta, GA 30063

Suzanne Morgan, Galaxy Scientific Corporation, 2310 Parklake Drive, Suite 325, Atlanta, GA 30345 (404) 491-1100

Garry G. Morissette, Dynamics Research Corp., Systems Division, 60 Concord St., Wilmington, MA 01887 (508) 658-6100

Capt. Thomas W. Murray, Director, Current Programs-Flight Operations, Northwest Airlines, Dept. N7260, 5101 Northwest Drive, St. Paul, MN 55111-3034 (612) 726-2934

Billy Myers, Federal Express/Maint. Tech. Training, 2851 Lambs Place, Suite 13-14, Memphis, TN 38118 (901) 375-6263

Bruce McCoy, Vice President, Aviation Division, Galaxy Scientific Corp., 2500 English Creek Avenue, Suite 1100, Pleasantville, NJ 08232 (609) 645-0900

Daniel McCrobie, Honeywell, Inc., Box 21111, Phoenix, AZ 85036 (602) 436-3604

Brian Nadeau, Boeing Commercial Airplane Group, P.O. Box 3707, Seattle, WA 98124-2207 (206) 477-3262

Robert North, Ph.D., Section Chief, Crew Systems and Maintenance Diagnostics, Honeywell Systems and Research Center, 3660 Technology Drive, Minneapolis, MN 55418 (612) 782-7388

Jeffrey E. Norton, Galaxy Scientific Corporation, 2310 Parklake Dr., Suite 325, Atlanta, GA 30345 (404) 491-1100

Gail O'Brien, Galaxy Scientific Corporation, 2310 Parklake Dr., Suite 325, Atlanta, GA 30345 (404) 491-1100

James F. Parker, Jr., Ph.D., BioTechnology, Inc., 405 N. Washington St., Suite 203, Falls Church, VA 22046 (703) 534-8200

Swapnesh Patel, SUNY Buffalo, 342 Bell Hall, Amherst, NY 14260

Mike Pearce, Galaxy Scientific Corporation, 2310 Parklake Dr., Suite 325, Atlanta, GA 30345  
(404) 491-1100

Prasad Prabhu, SUNY Buffalo, 342 Bell Hall, Amherst, NY 14260

Garrison Rapmund, Ph.D, FAA RE&D, Advisory Committee, 6 Burning Tree Court, Bethesda, MD 20817 (301) 365-1419

Jackie Reynolds, SUNY Buffalo, 342 Bell Hall, Amherst, NY 14260

Ken Rhodes, Manager, Maintenance Training, United Airlines, San Francisco International Airport, San Francisco, CA 94128 (415) 737-6789

Dennis Roach, Sandia National Labs, Dept. 2741, P.O. Box 5800, Albuquerque, NM 87185  
(505) 844-6078

Anne Roberts, British Aerospace, Comet Way, Hatfield Hertfordshire, AL 109TL ENGLAND

J. M. "Max" Roberts, C.Eng., M.R.Ae.S., British Aerospace Corporate Aircraft Division, Comet Way, Hatfield Hertfordshire, AL 109TL ENGLAND UK 0991 - 586774 EXT 44 - 992 - 586774

Michelle Robertson ISSM, Human Factors USC, Los Angeles, CA 90089-0021

Ron Rose, Transport Canada/Air Worthiness Inspection, Centennial Tower, 200 Kent St., Ottawa, Ontario K1A 0N8 CANADA (613) 952-4391

Dave Ryan, Manager, Technical Services National Business Aircraft Assoc., 1200 18th Street, NW, Suite 200, Washington, DC 20036 (202) 783-9000

Hidetaki Sakuma, Director, Engineering Research and Project, Japan Airlines, Tokyo Int'l Airport, Haneda Ota-ku, Tokyo 144 JAPAN FAX: 813 3747 4139

Glenn C. Sanders, TWA/IAM, 5369 N. Richmond, Kansas City, MO 64119 (816) 452-7481

Ernie Sawyer, Maintenance Training, United Airlines, San Francisco International Airport, San Francisco, CA 94128 (415) 737-6709

Don Schurman, SAIC, P.O. Box 50697, Idaho Falls, ID 83405-0697 (208) 528-2105

Robert Scoble, United Airlines/SFOIQ, San Francisco International Airport, San Francisco, CA 94128

Chris Seher, ACD-210, FAA Technical Center, Atlantic City International Airport, Atlantic City, NJ 08405 (609) 484-6787

William T. Shepherd, Ph.D., Office of Aviation Medicine, Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591 (202) 366-6910

Gerry Shutpump, Atlantic Southeast Airlines, Inc., Macon Municipal Airport, Macon, GA 32197 (912) 784-0318 FAX: (912) 788-9588

Fred Sobeck, Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591 (202) 267-7501

Hiroshi Sogame, Manager, Secretariat, Safety Promotion Committee, All Nippon Airways Co., Ltd. 1-6-6, Haneda Airport, Ota-ku, Tokyo 144 JAPAN FAX: 03-3745-8349

Floyd Spencer, Department 0323, Sandia National Laboratories, PO Box 5800, Albuquerque, NM 87185-5800 (505) 844-5647

Bill Sproat, Lockheed Aeronautical Systems Co., 86 South Cobb Dr., Dept. 73-51, M.S. 0484, Marietta, GA 30063 (404) 494-5313

Edith Stein, United Parcel Service Technical Training, 725 Beanblossom Rd., Louisville, KY 40213 (502) 363-8585

John W. Stelly, Jr., Continental Airlines, 3663 Sam Houston Pkwy., Suite 616, Houston, TX 77032 (713) 985-1130

Beverly Stitt, College of Technical Careers, So. Illinois University, Carbondale, IL 62901 (618) 453-8838

Gerry Swartzbaugh, Center for Aviation Systems Reliability, Applied Science Complex II, 1915 Scholl Rd., Ames, IA 50011 (515) 294-1629

Robin Taber, Senior Engineer, Galaxy Scientific Corporation, 600 Louis Drive, Suite 202, Warminster, PA 18974 (215) 672-8005, FAX: (215) 672-8708

Linda Tavlin, President, Tavlin Training, 2301 S. J. Davis Highway, Ste. 823, Arlington, VA 22202 (703) 418-2811

James C. Taylor, Ph.D., University of Southern California, PO Bx 163, 756 Haverford Avenue, Pacific Palisades, CA 90272 (213) 454-2604

Richard Thackray, Ph.D., FAA Consultant, 2324 NW 57th Street, Oklahoma City, OK 73112 (405) 848-8699

Charles Theisen, Jr., Ph.D., Rutgers University, 1966 Brooke Drive, New Hope, PA 18938 (215) 794-8959

William Thomas, ACD-350, FAA Technical Center, Atlantic City International Airport, Atlantic City, NJ 08405 (609) 484-4365

Jim Tonelli, Aviation Administration Program, Georgia State University, University Plaza, Atlanta, GA 30303-3083 (404) 651-3533

Tony Trexler, Mail Code 255, NASA, Langley Hampton, VA 23665-5225 (804) 864-3922

Naohiro Tsurumoto, Association of Air Transport Engineering and Research (ATEC) - Japan, Shin-Tamachi Bldg. 7F, 34-6, Shiba 5-Chome, Minato-ku, Tokyo 108 JAPAN FAX: 03-5476-8578

Richard Ulm, Department Chairman, Aviation Maintenance Technology, Embry-Riddle Aeronautical University, Daytona Beach, FL 32114 (904) 226-6776

Leo Utsman, Galaxy Scientific Corporation, 2310 Parklake Drive, Suite 325, Atlanta, GA 30345 (404) 491-1100

Walter E. VanDuyne, Program General Manager, G.E. Aircraft Engine Group, 111 Merchant Street, R. #360, Cincinnati, OH 45246 (513) 552-2500

Tim VanLoon, Winona Technical College, 1250 Homer Road, PO Box 409, Winona, MN 55987

1-800-372-8164

Leslie K. Vipond, Federal Aviation Administration, AFS-302, 800 Independence Avenue, SW, Washington, DC 20591 (202) 267-3269

Irene Volkova, Galaxy Scientific Corporation, 2310 Parklake Drive, Suite 325, Atlanta, GA 30345 (404) 491-1100

John Wagner, Science Applications International Corp., 2109 Air Park Rd., SE, Albuquerque, NM 87106 (505) 842-7709

Robert Wallace, Saudia Airlines, Jeddah Kingdom of Saudia Arabia

Kunihiro Watari, Director, Inspectorate Singapore Aviation Services Company, 540 Airport Rd., Paya Lebar 1953, REPUBLIC OF SINGAPORE FAX: 65-382-1509

Hayley Waters, Lockheed Aeronautical Systems Co., 86 S. Cobb Drive, Building L-12, Zone 0657, Marietta, GA 30063

Jean Watson, Office of Aviation Medicine, Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591 (202) 366-6985

Steven Weisharr, Research Program Manager, Northwestern University Transportation Center, Birl NW 1801 Maple Avenue, Evanston, IL 60201-3135 (708) 491-4483 FAX: (708) 491-3090

William A. Wheeler, Battelle Seattle Research Institute, 4000 NE 41st, Seattle, WA 98105 (206) 528-3258

Alan D. White, Sc.D., BioTechnology, Inc., 405 N. Washington St., Suite 203, Falls Church, VA 22046 (703) 534-8200

Richard Whittier, Change Management Associates Integrated Automation, 6633 Portwest Drive, Houston, TX 77024 (713) 861-2054

Tom Willey, United Airlines - SFOTI, San Francisco International Airport, San Francisco, CA 94128-3800 (415) 737-6720

Lonnie Williams, SIMU Flite International, 2929 West Airfield Dr., D/FW Airport, TX 75261

Barbara Wright, AFS-300, Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591 (202) 267-3546

Richard Yeatter, USAir Carnot Training Facility, 1407 Beers School Road, Corapolis, PA 15108 (412) 472-7258