

**Meeting 6: Maintenance 2000 (1992)**

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

Report of a Meeting

22 - 23 January 1992

Alexandria, Virginia

Prepared by:

James F. Parker, Jr., Ph.D.

Alan D. White, Sc.D.

**BioTechnology, Inc.**

Falls Church, Virginia

under subcontract to

**Galaxy Scientific Corporation**

Mays Landing, New Jersey

**"Maintenance 2000"**

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## FOREWORD

Maintenance operations for every U.S. air carrier will change significantly over the next decade. The forces impacting the maintenance industry today will make such change inevitable. Aircraft under development now for service in the late 1990's include on-board systems to provide diagnostic data and the full range of maintenance information. New aircraft increasingly will use composite structural materials and will incorporate advanced flight control and avionics systems. Aircraft size will increase. Some aircraft may carry as many as 650 passengers. By every measure, maintenance will be even more demanding and will require new capabilities and skills of the aviation maintenance technician.

The air carrier industry will place heavy demands on its maintenance support in the year 2000. Increasing passenger loads per airplane make it mandatory that careful attention be given to every item affecting flight safety. While concern for flight safety and the quality of maintenance will remain unabated, concern for maintenance efficiency will increase. Cost control is becoming more and more important.

The above challenges for future air carrier maintenance are quite demanding. The purpose of this meeting was to discuss the forces impacting air carrier maintenance today, to predict how these forces might affect maintenance a decade from now, and to consider strategies of change that will ensure that maintenance contributes to continuing U.S. leadership in commercial aviation.

This meeting was attended by representatives of all segments within the air carrier industry, including airline operators, manufacturers, maintenance managers, union representatives, regulators, information management and computer scientists, and others. Presentations highlighted issues that air carrier maintenance is facing now and is likely to face in the future. Other presentations described information management technologies that could be employed to considerable benefit in future maintenance programs. I wish to thank all of you who attended the meeting and especially those who gave presentations. The presentations and the group discussions will be of great value to us as we move toward the year 2000.

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

## EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) program on Human Factors in Aviation Maintenance includes support of a series of meetings addressing specific topics of interest in air carrier maintenance. The purpose of this two-day meeting, held in January 1992, was to consider maintenance support for the air carrier industry a decade from now, to identify problems likely to exist at that time, and to begin planning toward solutions for these problems.

The meeting was attended by representatives of all segments within the air carrier industry, including airline operators, manufacturers, maintenance managers, union representatives, regulators, and scientists and engineers working on new technologies of possible applicability. Presentations reviewed problems facing the air carrier maintenance industry at this time and trends likely to affect these problems in coming years. Other presentations reviewed information management technologies which are just becoming available and which might be employed to advantage as the industry works toward solutions in the coming decade. Specifically, the goal of the meeting, as supported by these presentations, was to ensure that over the next ten years the industry could achieve:

- Continuing improvement in the quality and effectiveness of air carrier maintenance.
- Productive and efficient utilization of maintenance personnel.
- Incorporation of new technologies beneficial to the air carrier maintenance industry.
- Adherence to rigorous cost control procedures.

Based on presentations given and ensuing discussions, the following recommendations are presented:

### The Maintenance Workforce

#### Recommendation

1. Demands to be placed on U.S. air carriers in the year 2000 can only be met with a fully staffed and well-qualified workforce. Questions have arisen concerning the adequacy of a supply of maintenance candidates at the end of the decade. If problems are foreseen for that time, planning for solutions must begin now. An in-depth study should be made of factors likely to affect the maintenance workforce in the year 2000. Study coverage should include evaluations of (1) manpower projections indicating a shortfall in the 25 - 34 year old group, (2) likely availability of women and minorities in the workforce and (3) the impact of release into the workforce of maintenance personnel from airlines ceasing operations.

### Personnel Capabilities

#### Recommendations

1. Aviation maintenance technicians increasingly need to work with computer-based systems to obtain necessary work instructions and supporting data. The next generation of aircraft will be capable of providing much of this information through on-board systems which present both diagnostic data and maintenance materials through computer displays. The industry goal of reducing human error to the lowest achievable level requires that this man-computer exchange of information be accurate and expeditious. A considerable number of studies have been made, many reported in *Human Factors*, the journal of the Human Factors Society, which seek to determine the parameters of an optimized computer display

for various classes of information. These studies should be reviewed systematically for their application to work requirements projected for aviation maintenance technicians with the advent of aircraft such as the Boeing 777. To the extent that information to define an optimum computer interface is not available, appropriate research should be conducted. When this computer interface can be defined, consideration should be given to establishment of an industry standard for air carrier maintenance operations.

2. The Federal Aviation Administration is planning to conduct a job task analysis of the aviation maintenance technician (AMT) position. The goal is to define the manner in which job activities are accomplished, the knowledge and skills required, the manipulative capabilities necessary, and the training required after certification. While the principal output of the job task analysis will be a clear exposition of the current AMT position, one part should review projected task demands and, on this basis, offer a picture of the AMT position in the future.

## Cost Factors

### Recommendation

1. Airlines are continually examining ways to reduce costs. No additional recommendation to do so is warranted. However, cost control efforts must continue, with a measure of these efforts directed toward maintenance. Since the aging aircraft issue came into prominence, primary attention within the FAA and the maintenance establishment has been on quality of maintenance. This attention now should be expanded to include "cost control in maintenance," giving it a priority immediately beneath quality. This attention, possibly through a joint FAA/industry team, should address:

- Ways to reduce the airline in-house training effort as new and more complex maintenance equipment is used.
- Procedures for assessing the efficiency as well as the effectiveness of maintenance work teams.
- Ways to facilitate the incorporation of new technologies, such as non-destructive inspection (NDI), through the industry as a means of making maintenance better and at the same time less personnel-intensive.

## INTRODUCTION

The Federal Aviation Administration is sponsoring a series of meetings to address issues of human factors in aviation maintenance and inspection. Each meeting in this series addresses a particular topic of relevance for air carrier maintenance. This report presents proceedings of the sixth of these meetings, held in January 1992, and was directed toward "Maintenance 2000." The objective of the meeting was to preview, to the extent feasible, issues likely to confront air carrier maintenance in the year 2000.

The topic for this meeting was selected in recognition that new and heavier demands will be placed on air carrier maintenance in the coming decade. Commercial aviation will grow; more sophisticated aircraft will be introduced into the carrier fleet; increasingly complex diagnostic and repair systems will come into use. Eleven presentations addressed current problems and trends in air carrier maintenance, new technologies being introduced into the workplace, and issues considered important for the future.

"Conclusions and Recommendations" of the meeting are presented just after the "Welcome Address" and "Meeting Objectives" presentations. These conclusions and recommendations are based on a panel session held at the end of the meeting plus a review of the transcripts of each presentation and ensuing discussions.

An edited version of each presentation, taken for the most part from taped transcripts, is presented as [Appendix A](#).

# HUMAN FACTORS IN THE YEAR 2000

*Jon Jordan, M.D., J.D.  
Federal Air Surgeon  
Federal Aviation Administration*

I would like to welcome you this morning to this Sixth Meeting on Human Factors in Aircraft Maintenance and Inspection. This welcome is extended on behalf of the Office of Aviation Medicine in the Federal Aviation Administration. By the comments we have received at the Office of Aviation Medicine, these meetings have been quite successful. Attendance has been good; interesting presentations have been given, and useful recommendations have been generated. As I review the program for this meeting, I can see that the standards set in previous meetings certainly will be met over the next two days.

The mandate for today's meeting is to peek into the future. We want to project, to the extent that we can, a decade from now. What will aviation be like? What maintenance will be required for the aircraft of the year 2000? What problems will be faced by those responsible for aviation maintenance? What will be the most important human factors problems faced by the industry in the coming decade?

The path that aviation will travel in the next ten years will be decided by many factors. One, of course, is industry. Developments leading to new aircraft, to new construction methods, to new test equipment, and to new maintenance technology all will be of great importance.

In this march to the future, we should not ignore the role to be played by the public. The public's willingness to accept new systems, whether this acceptance is based on subjective preference, economic reasons, or perceptions of safety, will be important.

Finally, we come to the Federal Aviation Administration. The FAA certainly will be a player in determining the progress of American aviation. I would like to talk a bit today about the FAA and our view concerning the proper involvement of the agency in the events of the next ten years. To do so, I will speak from the perspective of the Office of Aviation Medicine since, as you know, my experience has been in this office.

Before we move to the future, I would like to discuss the past briefly and describe the mandate of the FAA. Certainly everyone at this meeting knows that the Federal Aviation Administration, as it is now called, was established through the Federal Aviation Act, passed by Congress and approved by the President on the 23rd of August 1958 ([Figure 1](#)). An event which served as a driving force for passage of this Act was the collision of two airliners over the Grand Canyon in 1956. This collision dramatically called attention to the need for improved safety in commercial aviation. As you can see, "safety" is noted clearly as an objective of the Act. Everyone knows this. However, fewer people know that another purpose of the Act, and a responsibility of the FAA, is "to provide for the . . . promotion of civil aviation." The FAA is directed to use its resources to best foster the development and safety of civil aviation.

## **THE FEDERAL AVIATION ACT** (1958)

- to provide for the safe and efficient use of the airspace;
- to provide for the regulation and promotion of civil aviation in such a manner as to foster its development and safety.

### **Figure 1**

It is important that those of you in the industry, as well as the general public, understand that the FAA does much more for aviation than just pass regulations and then enforce them. The regulations are important, of course, since they serve to ensure that a high level of safety is achieved in both

commercial and private aviation. But the passage of regulations by no means represents the sum of our activities. Much of what we do falls more under our mandate "to promote civil aviation." Perhaps this can be illustrated through our approach to the topic of **human factors**.

The Office of Aviation Medicine defines "human factors" broadly. This term might well be viewed as including all of the human activities within aviation systems. We are not alone here. The early attention given by those working in the field of human factors to control and display problems has been broadened to include a wide range of human activities. Meetings of the Human Factors Society now include presentations on topics such as aging, consumer preferences, use of prosthetics, and many others. Human factors is a broad discipline.

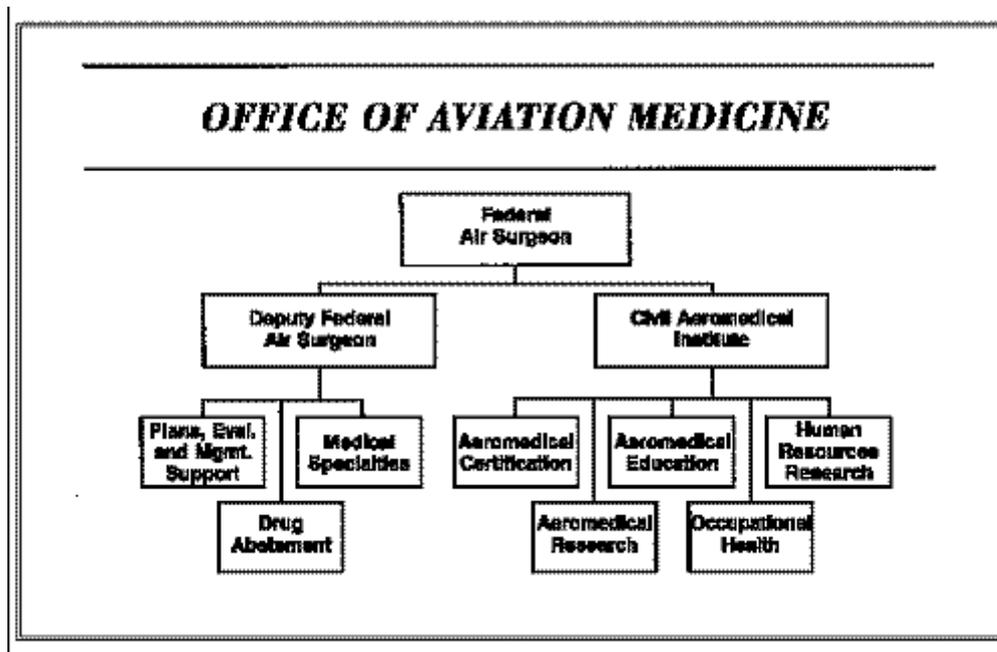
Figure 2 presents my definition of the elements of "human factors." As you can see, human factors encompasses all aspects of the individual and the environment that affect performance and/or well being. The first item, and one that we give considerable attention to in the Office of Aviation Medicine, is the health of a person. We are interested in health status, whether this status represents a permanent condition or is a function of the operation of some environmental stress agent. The next item concerns the performance capabilities of the person. Here we are interested in basic capacities, certainly, but generally more interested in performance capabilities after appropriate training for whatever the task. The next item of concern is the transitory state of the person. This refers to the person's condition of the moment as it might be affected by recent or on-going drug use, by emotional stress, by financial problems, or any other element that might degrade ability to perform. Finally, human factors examines the task demands and the individual's response. We find that the qualities making a person a good Air Traffic Controller may not be the same as those that make a good pilot.

## MAJOR ELEMENTS IN HUMAN FACTORS

- Health
  - Natural state/Environmental influences
- Performance Capabilities
  - Inherent capacity
  - Effects of training
- Transitory Condition
  - Effects of drugs, emotional stress, etc.
- Task Demands
  - Man-machine relationships/Job suitability

### Figure 2

Aviation medicine in the Federal Aviation Administration covers a broad spectrum of medical, behavioral, and human factors science. Figure 3 illustrates the organizational structure of the Office of Aviation Medicine and depicts the major program responsibilities. The left line of organizational elements, those reporting through the Deputy Federal Air Surgeon, are activities conducted at FAA Headquarters in Washington, DC. Activities on the right are those conducted at the Civil Aeromedical Institute in Oklahoma City, an operating element within the Office of Aviation Medicine. Not depicted here is Regional Office structure of the Office of Aviation Medicine's nine regional offices reporting to the Federal Air Surgeon through the Deputy Federal Air Surgeon. Staff at the regional offices administer Office of Aviation Medicine programs at the local level.



**Figure 3**

When one thinks of aviation medicine within the FAA, probably the activity that comes to mind most readily is that of medical certification of pilots. Most certification activities are carried out at the Civil Aeromedical Institute in Oklahoma City. As you can see, however, aeromedical certification, while a very important part of our work, is but one of a number of activities. The Medical Specialties Division at Headquarters includes, in addition to medical certification related to appeals to the Federal Air Surgeon, medical rulemaking, limited research, psychiatry, accident investigation, and occupational health. One part of our research program, directed by Dr. William Shepherd, and managed out of the Medical Specialties Division, addresses the human factors issues in aircraft maintenance. This began as a response to our concerns over the safety of the aging aircraft fleet, but now has broadened into a consideration of a range of human factors issues in aircraft maintenance and inspection. This is the program that supports the meeting we are attending today.

The work that is being done at Headquarters and at the Office of Aviation Medicine's principal research arm, the Civil Aeromedical Institute, contains a mixture of basic and applied research. Much of the research being done, even though it might address the population of pilots primarily, has potential application through the entire aviation workforce. Studies of the process of aging, for example, are concerned at the moment with the validity of the "Age 60" retirement rule for air carrier pilots. However, as the age of our maintenance workers increases, this aging research could be of considerable value as we examine ways to sustain this workforce and maintain high levels of proficiency. In short, we are not concerned just with the problems of pilots. Our studies hopefully will produce information that can be applied profitably to problems of all workers in aviation.

One of the most important activities at the Office of Aviation Medicine is central to our responsibility to ensure safety in aviation. We are responsible for the aeromedical certification of all civilian pilots. There are over 700,000 active civilian pilots in the United States. They, along with those applying for student pilot licenses, must be medically fit and must be granted certification by the FAA. Designated Aviation Medical Examiners, about 5,600 private physicians, perform almost 500,000 required medical examinations each year. The central screening facility at the Civil Aeromedical Institute is responsible for collecting, processing, adjudicating, investigating, and analyzing the medical data originated during this certification process.

The paperwork generated to support medical certification is tremendous. To minimize delays, efforts are underway to modernize this process and to automate the collection of data, the transmission of information, and the total processing operation. While we are concerned with making the process as

rapid as we can, we also are concerned with the number of errors committed by our medical examiners. A new system is being designed which will electronically transfer certification information and should streamline the flow of data between key components of the system. Computer terminals will be used in the Aviation Medical Examiners' offices to record, edit, and transmit examination data directly to CAMI for processing.

As I am describing our problems with data management in the certification process, I am sure that I am striking a chord with many of you. I know that the management of maintenance data has been an on-going problem for years and that some innovative work is being done now as you look toward more automated solutions that will allow you to have the right information at the right place at the right time. Our certification procedures may well benefit in days to come from the work you are doing on automation today.

Another research effort, which I've already mentioned, is studying the relation of accidents to age with a view to assessing the "Age 60 Rule" under which persons at this age are prohibited from serving as airline pilots. The FAA regulation is based on the concept that older pilots are more likely than younger pilots to suffer medical incapacitation and performance degradation that would adversely affect aviation safety. The reason for applying an inflexible age rule is that there are no known ways to reliably predict the onset of performance problems. An on-going study at CAMI is investigating aging and pilot performance and, to a certain extent, medical problems. This study is following two lines. First, an examination is being made of existing data bases. Three historical data bases are being consolidated into one research data base. Analyses of these data will address the relationship between age, experience, and accidents; will improve upon prior methodologies used in this research; and will address the differences between recreational and professional pilots. The second line of examination is an attempt to identify a test battery that might be used to assess performance capabilities.

The findings of our studies on the aging process certainly will apply to more groups than simply pilots. Will there be modest but significant declines in the performance of senior inspectors and mechanics as they approach age 60? While I do not propose that we establish an "Age 60 Rule" or medical certification for maintenance personnel, information concerning the performance effects of aging can be used beneficially as we determine the best manner in which to use all segments of the aviation workforce.

Other work being done through the Office of Aviation Medicine hits on an issue of obvious importance to all work groups. This is the matter of substance abuse, whether abuse of alcohol or other drugs. An alcohol study being conducted now at the Civil Aeromedical Institute is examining the influence of four alcohol-related conditions on pilot performance. The conditions include three minimal blood alcohol concentrations. These are .04 percent, .027 percent, and .013 percent. All very low levels. The fourth condition is looking at the phenomenon known as "hangover." If the data indicate that performance is compromised at low blood alcohol levels and/or during hangover periods, more stringent guidelines may be needed for pilots, air traffic controllers, and systems maintenance personnel. If degradation in performance is not found, a more reliable data base to support current rules concerning alcohol use will have been established. In any event, information from this research will be used to develop educational programs for pilots, air traffic controllers, and other safety personnel.

The FAA also is on the front line in the war against the use of illicit drugs. We now have an industry-wide anti-drug program in effect in aviation. [Figure 4](#) shows the results obtained through this program in calendar year 1990. Of well over 200,000 tests administered, 966, or 4/10th of one percent, were positive. About half of these positives were detected in pre-employment tests. Applicants testing positive were not hired for safety-sensitive positions. By the beginning of 1991, approximately 340,000 aviation employees were subject to the drug testing program. These include pilots, mechanics, flight attendants, airport security screening personnel, flight engineers, and aircraft dispatchers. This obviously has become a major program and it will grow larger. Through Congressional action, the Omnibus Transportation Employee Testing Act of 1991 has placed new responsibilities on the FAA. In addition to codifying authority for current drug testing regulations,

this new legislation requires that the FAA prescribe regulations for alcohol testing in the air carrier industry by October 28, 1992. We are working on meeting this Congressional mandate.

The Office of Aviation Medicine program of most interest to you in the audience today is our **Aircraft Maintenance Human Factors Program**. As you well know, various human factors issues in aircraft maintenance and inspection are under study. These include training, the work environment, use of job performance aids, and organizational factors. One of the primary products of this program will be a *Handbook of Human Factors* to provide guidance for maintenance personnel and others concerned with this process.

## **FAA DRUG ABATEMENT PROGRAM**

### **1990**

- 230,621 tests administered
- 966 positives
  - 46 percent in pre-employment tests

### **1991**

- 340,000 employees subject to testing

### **Findings**

- Drug use is low (0.4 percent)
- Most used: marijuana and cocaine

### **Figure 4**

The programs I have just described are but part of the activities of the Office of Aviation Medicine. We have other important activities in occupational health, aeromedical education, human resources research, aeromedical research and accident investigation. All of these program areas touch on human factors issues inasmuch as they all are concerned with the human element and with ways to make the performance of aviation personnel safer and more effective. In each of these programs we are generating new information to better understand the performance of aviation personnel and to allow them to do their jobs better. As noted in the beginning, the goals of the FAA are to ensure safety in aviation operations and to promote civil aviation. The information we are developing supports both of these goals.

Where will human factors, as we have defined it, be a decade from now? Hopefully, human factors research will help tell us how to manage aviation operations carrying many more people than is the case today; how to develop a maintenance workforce to deal with the very advanced technologies that will exist in aviation in the year 2000; how to ensure that aircraft capable of carrying 600 or more passengers are being operated and maintained by personnel who are medically and psychologically fit for this tremendous responsibility. To achieve this program, we must understand our problems today and we must begin programs to overcome these problems. This meeting is a noteworthy step toward our goals for the year 2000. I wish you a very productive and successful meeting. Thank you.

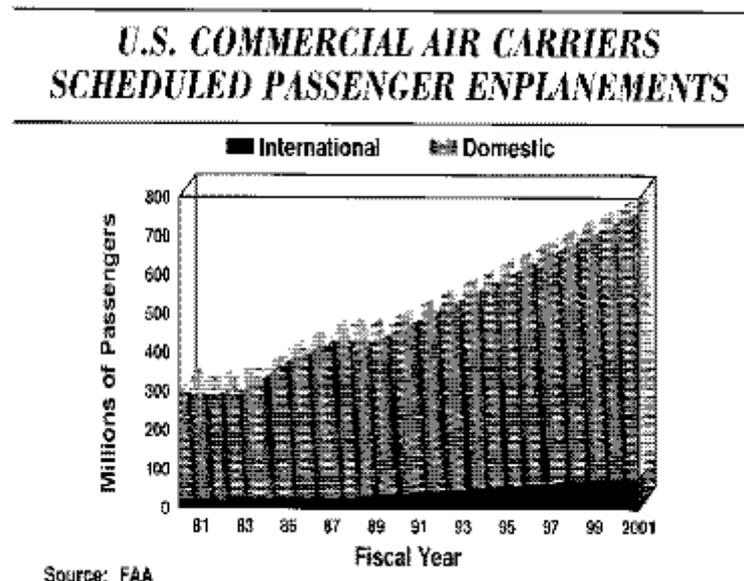
## MEETING OBJECTIVES

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

The objective of our present meeting is to define the issues and problems likely to be faced by air carrier maintenance during the coming decade and beyond. To do this we must look into the future, never an easy task. An examination of trends in maintenance today and the external forces which tend to shape maintenance should, nonetheless, present us some picture of the world of maintenance a decade hence. In doing this, we must look at the directions of U.S. air carrier maintenance and must also consider foreign maintenance. We know that use of foreign repair stations by U.S. carriers is increasing steadily. After these reviews, by connecting our examination of current trends with forecasts for the year 2000, we should be able to anticipate problems that may occur during the next decade. The development of insight into these potential problems increases the likelihood that real solutions can be identified before the problems become severe.

### Industry Growth

The current and projected growth in U.S. commercial aviation is perhaps the most important variable affecting air carrier maintenance. Growth in commercial aviation has been impressive, to say the least. The growth curves presented in [Figure 1](#), covering the two decades from 1981 to 2001, show almost a tripling of the number of people flying. With the number of passengers carried growing at this rate, the industry must make a number of changes in its structure to accommodate this growth. Maintenance certainly is included in these changes.

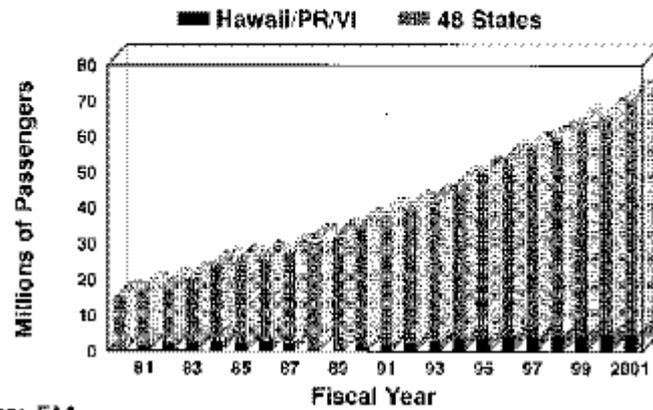


**Figure 1**

Regional and commuter air carriers appear to be growing at an even more rapid rate than the majors. In 1981, less than 20 million passengers were carried, as shown in [Figure 2](#). By the year 2001, this number will have grown to more than 70 million. Here we are looking at an industry increase by a factor of four or five. This should be an item of concern for us. Where will the people come from to operate this system? Where will the airplanes come from? Is the industry capable of handling this

growth? Can proper maintenance of this growing aircraft fleet be assured?

**U.S. REGIONALS/COMMUTERS  
SCHEDULED PASSENGER ENPLANEMENTS**



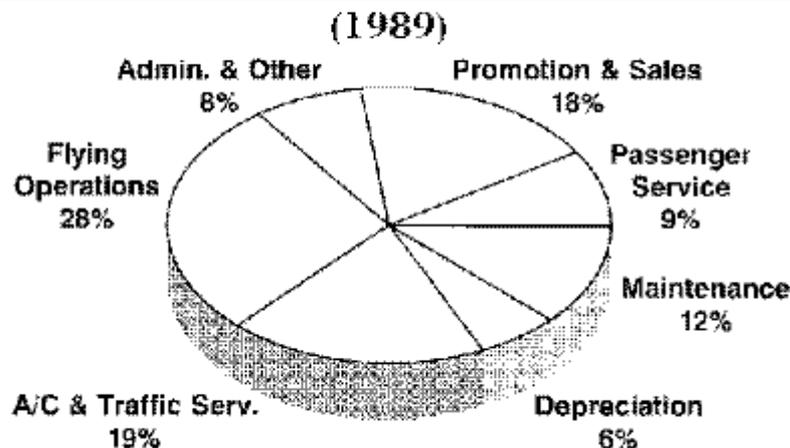
Source: FAA

Figure 2

**Maintenance Expenses**

The growth in air carrier operations over the coming decade will bring a corresponding increase in maintenance expenses. [Figure 3](#) shows that maintenance costs now represent about 12 percent of all air carrier operating expenses. This 12 percent cost item represents over \$8 billion dollars per year and, significantly, is a growing item. The percentage of air carrier operating costs devoted to maintenance is growing at approximately the rate of one-half percent per year at this time. While one-half percent per year does not seem like that much, it is one-half percent of a very large number. While we may not be able to predict the rate of increase with complete precision, we do know that air carrier maintenance expenses are going to increase. Reasons why maintenance will take a larger part of the air carrier operation's budget include costs of maintaining an aging fleet as well as those required for the introduction of a new technology fleet. In any event, the cost of maintenance will be significant.

**U.S. AIR CARRIER EXPENSES**



**Figure 3**

### Trends Affecting Maintenance Practices

A number of trends which can be identified at this time will affect air carrier maintenance in the future. One is aircraft size. Boeing is studying an aircraft capable of carrying 650 or more passengers. This is an impressive airplane and appears, from its design sketch in *Aviation Week & Space Technology*, to resemble a double-deck 747. Consider the possibility that, some years from now, several of these new aircraft should arrive for a heavy maintenance check at the same time. The demand on an operator's maintenance resources would indeed be severe.

Another trend, well underway, which will affect future maintenance is the movement toward advanced avionics. More and more aircraft now incorporate the "glass cockpit" design. In the not too distant future, all aircraft operated by the majors will have glass cockpits, with this technology beginning to spread to the airplanes of the commuters and regionals. Maintenance for glass cockpit systems, as opposed to the older round dials of earlier aircraft, requires new skills and new maintenance philosophies.

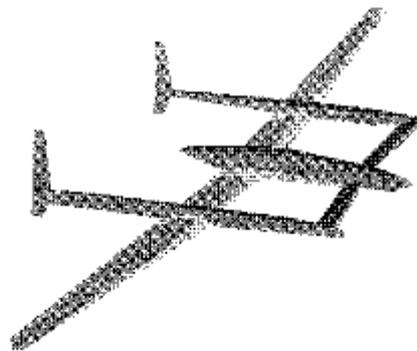
Use of new materials is another factor affecting maintenance. Here I am thinking particularly of the use of composite materials such as carbon fibers, aramid fibers, and fiberglass in the construction of new aircraft. Composite materials are already being used in the structures of the Boeing 757 and 767, as well as the AirBus A-310. This trend toward composite materials can be found in military aircraft as well as in civilian airliners. For instance, in the F/A-18 aircraft, composite materials account for 10 percent of the structural weight and 50 percent of the surface area. Finally, insight into the extent to which composite materials can be used is found in the Voyager aircraft, which completed its non-stop circumnavigation of the Earth several years ago. This airplane, shown in [Figure 4](#), uses approximately 90 percent graphite fiber materials. While we might not see such extensive use of composites in air carrier airplanes in the next few years, this does illustrate the direction in which aircraft construction is moving.

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### ***THE VOYAGER AIRCRAFT***

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**(90% From Graphite Fibers)**

**Figure 4**

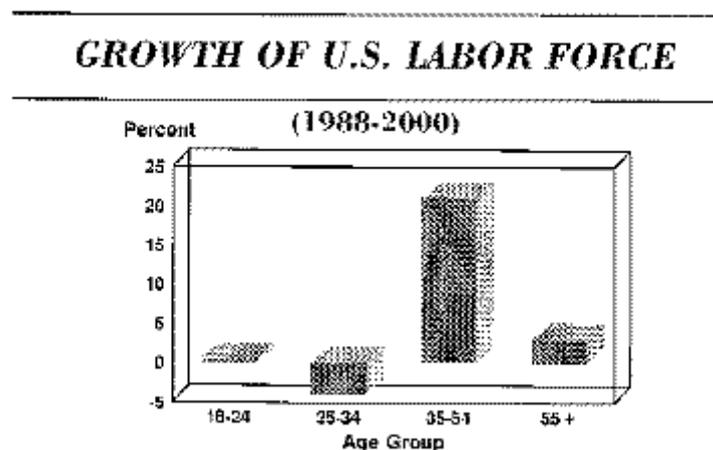
### Workforce Dynamics

Changes are taking place in the national workforce and in the maintenance industry which, when combined, will have considerable influence on air carrier maintenance. The first of these is purely a demographic issue. In the decade ahead, there simply will not be enough people in the age groups typically drawn on for entry-level maintenance technicians. Projections from birth rates of recent years tell us that there will be a significant drop in the numbers of potential mechanics. In addition, there will be considerable competition for that small group of people from other industries, such as electronic companies, which require technicians with comparable skills.

The skill requirements for technicians in the coming decade will increase, which complicates the personnel availability issue. The fact that the industry will be using new materials, high-tech flight deck avionics, increased automation in flight systems, and other changes means that a higher level of qualification will be required of the future technician. Individuals with marginal high school records will find it difficult to enter the maintenance profession.

Another factor affecting maintenance in the future is that there likely will be a merging of specialties. We will see fewer technicians skilled in only one area as, for example, hydraulics. AirBus, for instance, is working toward a workforce in which technicians are capable of working on any part of the airplane. They are blending the requirements for maintenance technicians and avionics technicians into a single specialty. For a number of reasons, including economics, this seems to be a reasonable goal for the industry. The increased level of qualification means, however, that a real increase in training time will be necessary. Under these conditions, entry into air carrier maintenance will be even more difficult for those individuals who apply and do not have the necessary basic training in reading and mathematics.

A better appreciation of the problems to be faced in air carrier maintenance can be achieved through a more detailed look at changes anticipated in the U.S. labor force. [Figure 5](#) shows projected growth for four age groups by the year 2000, using 1988 data as a base. Anticipated growth for two groups, the 16 - 24 year age group and the 25 - 34 year age group, is negative. They show a decline in the number of people available in the year 2000 as candidates for positions in the maintenance industry. These age groups, of course, are where essentially all entry-level personnel are found. Figure 5 also illustrates the extent to which the American workforce is aging. The age group showing the largest growth during this period is that between ages 35 and 54. When one considers workers in their 50's, you are looking at people approaching retirement. These individuals may not be as amenable to the changing work requirements in maintenance as will those in the younger age groups.



**Figure 5**

Figure 6 shows that the predicted growth in the American workforce in the decade of the 90's is about twice as great for women as for men. There will be twice as many women as men entering the workforce in the decade ahead. More and more, women represent a potential group to consider for entry into the maintenance workforce. There are growing numbers of women in this workforce now and they are performing quite capably, with some excellent examples in military aviation maintenance. This is one segment of the American workforce that must be drawn on if we are to deal with expected personnel shortages.

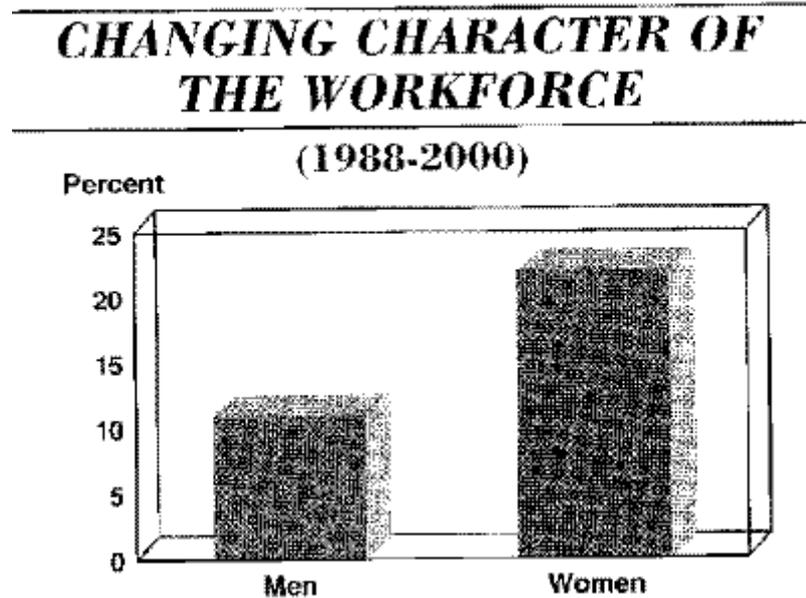


Figure 6

The workforce in the coming decade also will change in its ethnic character. During this period, we expect to see negative growth in the caucasian workforce, as shown in Figure 7. There will be fewer white males seeking positions in air carrier maintenance. There will be growth in the Black and Hispanic workforces so we can anticipate these groups to be participants as maintenance technicians of the future.

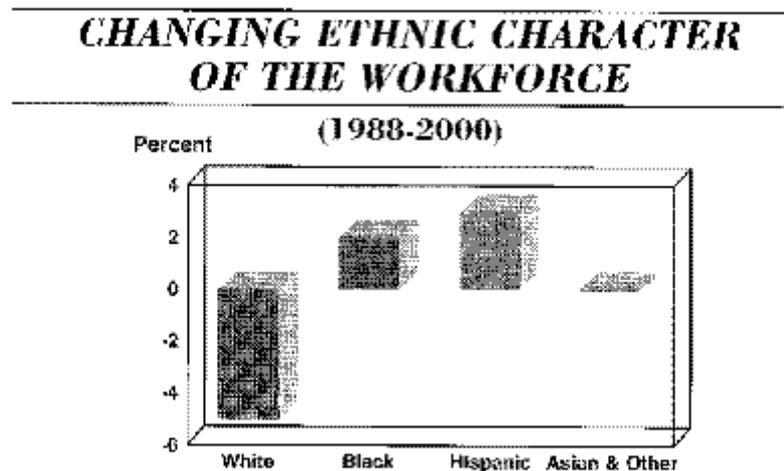


Figure 7

## Conclusions

As we look toward the year 2000, several conclusions can be drawn concerning air carrier maintenance and the forces that will shape this industry. Some of the more important are:

- Air carrier maintenance will experience significant growth. Current projections call for at least a 60 percent growth in commercial aviation between the years 1990 and 2000. Air carrier maintenance will need to grow at least as rapidly.
- Automation and new materials may change the nature of maintenance. The age of the glass cockpit is upon us. The use of composite materials in aircraft structures is increasing each year.
- Personnel shortages are likely. Projections call for an actual decrease in the number of potential aviation maintenance technician candidates below 35 years of age.
- Training must keep pace with new work requirements. The new technologies to be incorporated in aircraft of the coming decade will require a high level of understanding and proficiency in electronics, computer sciences, materials technology, and other skills not so important in maintaining the previous generation of aircraft.

The assembled group at our meeting today represents the best expertise available in air carrier maintenance. Your deliberations will be of great value as we all work toward the development of solutions for the issues I have just described. Thank you.

## CONCLUSIONS AND RECOMMENDATIONS

The present state of the U.S. air carrier industry can only be viewed with ambivalence. There is much to praise; at the same time, there are genuine causes for concern. Had Charles Dickens written his famous opening line from *A Tale of Two Cities*, "It was the best of times, it was the worst of times" some one hundred and thirty-three years later, he might well have been speaking of commercial aviation in the United States.

The recent performance record of U.S. commercial aviation carries some impressive statistics. In 1991, over 450 million passengers were carried in almost seven million departures. All of this was accomplished with an outstanding safety record. For this same year, there were only six accidents with fatalities. A total of 39 deaths occurred in these accidents, an unfortunate but nonetheless minuscule number when compared with that for highway transportation.

The contribution of U.S. airlines in meeting national transportation needs, combined with a commendable safety record, certainly is praiseworthy. Yet, expressions of concern can be heard. Safety continues to be a topic for two reasons. First, an airline accident draws attention. Even though more people may be killed in highway accidents on the same day, the aviation accident receives the press coverage and gains national interest. Second, older aircraft continue to fly as airlines delay earlier retirement plans for these aircraft.

Another topic of concern centers on maintenance personnel. The availability of an adequate supply of maintenance candidates over the next decade, the extent to which these candidates will be qualified for entry positions, and the training systems necessary to develop and maintain appropriate skills are continuing questions. As new aircraft, new airframe materials, and new avionics systems appear, these questions grow in importance.

A final, and quite serious, concern is over the financial condition of the air carrier industry. Last year, three major airlines stopped operating. Others continue to operate under the oversight of bankruptcy courts. As one can imagine, control of operating expenses is a matter of great importance for airline management. Maintenance costs must be considered here inasmuch as these costs have risen from \$5.5 billion in 1986 to almost \$9 billion in 1991. Maintenance represents a major cost item.

Issues of airline safety, personnel utilization, and operating costs all are directly affected by maintenance. Over the coming decade, maintenance can make a positive or negative contribution to airline viability depending on the extent to which issues impacting maintenance are understood and managed. The objective of this meeting is to define the issues and problems likely to be faced by air carrier maintenance in the coming decade. The goal of this meeting was to review all topics that would ensure over the next 10 years:

- Continuing improvement in the quality and effectiveness of air carrier maintenance.
- Productive and efficient utilization of maintenance personnel.
- Incorporation of new technologies beneficial to the air carrier maintenance industry.
- Adherence to rigorous cost control procedures.

Those attending this meeting represent all segments within the air carrier industry, including airline operators, manufacturers, maintenance managers, union representatives, regulators, information management and computer scientists, and others. Formal presentations given during the two days covered a variety of topics related to trends in maintenance today and new technologies likely to impact maintenance performance during the coming decade. Recommendations concerning the management of major issues likely to be faced by maintenance in the future were offered during formal presentations, during ensuing discussions, and during a final closing session. The following recommendations represent a grouping and synthesis of broad topics considered important by attendees, with specific recommendations included within each topic.

## The Maintenance Workforce

The viability of the air carrier industry is dependent on an effective maintenance workforce, available in adequate supply and well-trained to meet the demands of maintaining the complex airliners of today and tomorrow. Considerable attention has been given to the availability of candidates for jobs as aviation maintenance technicians (AMTs) in the year 2000. This was a major topic in the Fourth Human Factors Conference entitled "*The Aviation Maintenance Technician*", held in December 1990. Since that time, many pros and cons concerning the seriousness of the maintenance manpower problem in the future have been expressed.

Growth of the air carrier maintenance workforce has been steady. [Table 1](#) shows this growth in the five years from 1986 to 1991. Only the final year (1991) shows a decline in workers and this can be attributed to the demise of three air carriers during that year. Other than 1991, manpower growth has been relatively constant. In fact, during the ten years from 1981 to 1991, the number of AMTs employed in air carrier maintenance operations increased by almost 30 percent.

YEAR	MECHANICS
1986	47,651
1987	51,233
1988	55,001
1989	57,282
1990	60,952
1991	58,819

Source: *Air Transport Association* (1992)

Just how large a maintenance workforce will be needed by the year 2000? The growth of this workforce certainly will approximate that of the air carrier industry itself. Forecasts by the Air Transport Association, based on FAA projections, indicate that airlines will carry almost 650 million passengers in the year 2000. This is approximately a 45 percent increase over the passenger volume of 1991. If the maintenance workforce were to increase at exactly the same rate as the industry grows, an additional 26,500 AMTs would be needed by the end of the decade. Other projections are for an even greater increase. The Future Aviation Professionals of American (FAPA) estimated several years ago that the industry would need almost 46,000 AMTs in the next ten years.

Without doubt, the size of the maintenance establishment to support air carrier operations will grow in the coming years. The issue is whether there will be an adequate supply of qualified applicants to fill the needs of this industry. National demographic forecasts suggest a serious problem may be developing. Reports by the Bureau of Labor Statistics indicate that, while the national labor force will grow between 1988 and 2000, there will be a 3.8 percent decline in the 25 - 34 year old age group. This is the age group from which most entry-level AMTs typically originate.

Balancing the above picture of a possible manpower shortage are a number of other factors. The workforce at the turn of the century will include a higher percentage of blacks and other minorities than is the case now. Women also will be present in larger numbers. Until this time, aviation maintenance has not drawn on these groups to any significant extent. If aviation maintenance begins to employ more members of these groups, as anticipated, the manpower availability problem may be lessened.

Finally, there is another variable whose potential impact is not known. Last year, three major U.S. carriers (Pan American, Eastern, and Midway) went out of business. When these airlines stopped operating, a considerable number of maintenance personnel became unemployed. Will they gradually be absorbed by other airlines; will they be employed in some comparable but different technical industries; or will they simply retire? At the moment, there is no clear picture. However, these previous maintenance employees represent a well-trained group with known credentials on which the industry can draw.

## Recommendation

1. Demands to be placed on U.S. air carriers in the year 2000 can only be met with a fully staffed and well-qualified workforce. Questions have arisen concerning the adequacy of a supply of maintenance candidates at the end of the decade. If problems are foreseen for that time, planning for solutions must begin now. An in-depth study should be made of factors likely to affect the maintenance workforce in the year 2000. Study coverage should include evaluations of (1) manpower projections indicating a shortfall in the 25 - 34 year old group, (2) likely availability of women and minorities in the workforce and (3) the impact of release into the workforce of maintenance personnel from airlines ceasing operations.

## Personnel Capabilities

Maintenance practices are changing and will continue to change as the airline industry grows and as a host of new technologies are incorporated in the aircraft of tomorrow. The Boeing 777 airplane exemplifies the aircraft for which maintenance technicians will be responsible in coming years. The 777 airplane is different and more advanced in many respects than those flying today. It uses a fly-by-wire flight control system and has advanced high-bypass ratio turbo fan engines. The airplane also has folding wing tips to make it easier to move into loading gates and maintenance spaces.

Of particular interest for maintenance personnel are the Electronic Library System (ELS) and the On-Board Maintenance System (OMS). The ELS is part of Boeing's program toward a "paperless airplane." Displays on either side of the instrument panel will be able to call up items such as flight operations manuals, navigation charts, and maintenance documents. The OMS will provide maintenance monitoring data and will allow functional testing. It includes a direct maintenance access terminal for technicians and has direct connections through the airplane so that a portable access terminal can be used.

The Electronic Library System and the On-Board Maintenance system illustrate the direction in which the maintenance industry and the tasks facing maintenance technicians are moving. The capabilities required of an aviation maintenance technician are changing as maintenance becomes ever more complex and demanding. More and more, technicians must be comfortable working with computer-based diagnostic, training and information management systems. The move toward these systems is impacting airline management, technician training, and technician hiring. While the exact manner of this impact is unclear today, planning for the air carrier world of the next decade should begin now. The Chief Project Engineer of the 777 program was quoted recently (*Aviation Week & Space Technology*, 20 April 1992) on issues Boeing faces in developing the Electronic Library System:

*"The airlines need to decide how they are going to use information in the future and how information will be integrated across their entire business, including the 777 and the rest of their fleet and ground systems. It is not a trivial task."*

The technician required to maintain aircraft of the future, such as the 777, must be different than today's technician in terms of capabilities, skills, and orientation. This person must understand new information management and information presentation systems. The primary source of new technicians will be specialized technical training institutions. These institutions, working with the

Federal Aviation Administration, are responsible for delivering a product that is as advanced over the technician of today as the 777 is over other aircraft of today.

## Recommendations

1. Aviation maintenance technicians increasingly need to work with computer-based systems to obtain necessary work instructions and supporting data. The next generation of aircraft will be capable of providing much of this information through on-board systems which present both diagnostic data and maintenance materials through computer displays. The industry goal of reducing human error to the lowest achievable level requires that this man-computer exchange of information be accurate and expeditious. A considerable number of studies have been made, many reported in *Human Factors*, the journal of the Human Factors Society, which seek to determine the parameters of an optimized computer display for various classes of information. These studies should be reviewed systematically for their application to work requirements projected for aviation maintenance technicians with the advent of aircraft such as the Boeing 777. To the extent that information to define an optimum computer interface is not available, appropriate research should be conducted. When this computer interface can be defined, consideration should be given to establishment of an industry standard for air carrier maintenance operations.
2. The Federal Aviation Administration is planning to conduct a job task analysis of the aviation maintenance technician (AMT) position. The goal is to define the manner in which job activities are accomplished, the knowledge and skills required, the manipulative capabilities necessary, and the training required after certification. While the principal output of the job task analysis will be a clear exposition of the current AMT position, one part should review projected task demands and, on this basis, offer a picture of the AMT position in the future.

## Cost Factors

The U.S. air carrier industry is facing severe economic pressures from global competition, alternative transportation industries, and inter-airline competition within the United States. As these economic pressures grow, so do the operating expenses of the industry. From 1986 to 1991, operating expenses increased by about 28 percent while the number of scheduled departures increased by only six percent. Although the cost increase can be explained in large measure by increasing inflation during that period plus the rise in fuel costs during the Gulf War, the fact remains that air carrier operations are becoming increasingly expensive. The cost of maintenance operations, which regularly falls between 11 and 12 percent of total operating expenses, must be as carefully controlled as any other cost item.

Maintenance practices can affect industry costs in a number of ways. Delays due to maintenance can be quite expensive. As reported during the meeting, if a departure from the West Coast to the Orient is delayed for a maintenance fix, total costs for those who are deplaned can run as high as \$47,000. The need to meet departure commitments is obvious.

Other maintenance issues, some rather surprising, also can affect departure reliability. For instance, one report at the meeting discussed the impact of new technologies on the latest aircraft in service today. These aircraft, which themselves have generally satisfactory reliability, incorporate a number of high technology monitoring and sensing systems. Interestingly, these new systems are operating to reduce aircraft dispatch reliability. The report was that "false or overly sensitive alerts and warnings at departure time in these technology-laden cockpits has made these aircraft only half as reliable as those carrying less sophisticated equipment." The information provided by these monitoring systems obviously has not been fine-tuned to meet the real needs of maintenance and operating personnel.

Yet another cost issue can be found in the training of maintenance technicians. One airline reports

incurring large training costs to improve the skills of newly hired technicians to a point where they can work with the complex technical equipment now being used in maintenance. As newer aircraft come on line and as advanced diagnostic systems are used, this problem will only get worse. Ways are needed to reduce the on-the-job training requirements for new hires.

Airlines are facing great pressures today to control costs. Maintenance expenses represent one cost element to consider although no airline would jeopardize quality of maintenance and flight safety. However, ways to reduce maintenance costs must be examined. The most obvious way is in terms of personnel utilization. To illustrate, between 1986 and 1991, there was a 23 percent increase in employment of maintenance technicians by U.S. airlines. Over this same five year period, scheduled departures by the airlines increased by only six percent.

## Recommendation

1. Airlines are continually examining ways to reduce costs. No additional recommendation to do so is warranted. However, cost control efforts must continue, with a measure of these efforts directed toward maintenance. Since the aging aircraft issue came into prominence, primary attention within the FAA and the maintenance establishment has been on quality of maintenance. This attention now should be expanded to include "cost control in maintenance," giving it a priority immediately beneath quality. This attention, possibly through a joint FAA/industry team, should address:

- Ways to reduce the airline in-house training effort as new and more complex maintenance equipment is used.
- Procedures for assessing the efficiency as well as the effectiveness of maintenance work teams.
- Ways to facilitate the incorporation of new technologies, such as non-destructive inspection (NDI), through the industry as a means of making maintenance better and at the same time less personnel-intensive.

## Appendix A: Meeting Presentations

### CHANGING AIR CARRIER MAINTENANCE REQUIREMENTS

*Joseph Vreeman  
Air Transport Association*

Fourteen airlines met some 55 years ago in 1936 in Chicago, where they agreed to establish the Air Transport Association (ATA), created to enhance aviation safety and to promote and develop the business of air transportation. Those goals and objectives are very similar to goals and objectives of the FAA. ATA has a long and proud history of aviation activity over those 55 years. Our archives document engineering activities that go back as far as 1939. Then, people were discussing ways to heat engines so they could start them in the winter. They were proposing and discussing various solutions to in-flight fire hazards. They were trying to set standards for weight and balance. It's rather humorous to read some of these things. One of the first memos I found was on the subject of gross weight of the DC-3. Back in those days, the gross weight of the airplane was established by the pilots and the airlines sitting down and negotiating. We've come quite a way since those days -- although we are still talking about weight and balance.

We also were involved in setting standards and specifications for engines, aircraft and fuel. Other efforts included educating pilots about aircraft strength limits. Also of concern was the growing tendency to use small commercial airplanes for violent aerobatics and stunt maneuvers for which they were not originally designed. During the 1950s, after a series of disturbing mid-air collisions, ATA was among the groups that lobbied Congress to create an independent agency to oversee airline safety. In 1958 the FAA was formed. The next time you're complaining about the FAA, remember ATA helped form them. We are partially responsible for them being here.

The airline business has been one of constant change. Of the original fourteen ATA members, only six still existed under the same name at the time of deregulation. Today, that number has dwindled to just three -- United, American and Northwest. That tremendous change means we have to change as well. Yes, we are changing. We don't want to be a dinosaur. Last year alone Pan Am, Midway and Eastern stopped operating. Today ATA represents 17 U.S. air carriers and two Canadian associate members. Be reminded that only North American airlines can become ATA members. ATA's activities encompass suppliers and manufacturers, both foreign and domestic, foreign airlines and regulators. ATA, however, primarily represents the major U.S. air carriers.

ATA is involved in all phases of the airline operation. My expertise is in the engineering, maintenance and material area. I am responsible to the ATA Engineering, Maintenance and Material Council, made up of the senior or top technical persons in each of the 19 airlines. Most of the airline people here today work for these individuals, either directly or indirectly.

Today's presentation addresses the changing air carrier maintenance requirements. I will tell you what we require so that you can see how you can fit in and support meeting these requirements. I will give you a perspective of airline business requirements so you can see how the business position affects maintenance requirements. Secondly, I will present measures that you can use to judge the value of any project. Last, I will suggest actions that I think need your immediate attention.

Our maintenance requirements are directly affected by our business position. Last year we lost \$1.3 billion as an industry in the United States. In 1990, we lost even more. It was about \$4 billion. We cannot continue to survive in a business, as usual posture. Midway, Eastern, Pan Am, and others have proved that won't work. We need to create a safer and a more productive aviation system. We need to focus on improved service with the aim of becoming competitive and staying in business. No longer can we depend on government regulations, treaties, or the like, to guarantee staying in business. Our industry is rapidly becoming global. Under these conditions, the way you stay in

business is by providing a better service at a lower cost than the competition. The traveling public is our customer. They want better service. They want cheaper tickets. If they don't get that, they will go someplace else, maybe to another airline or maybe to high speed trains.

There are four actions we need to undertake. **First, we need to work to improve safety.** There ought to be a measurable, tangible, quantifiable improvement in safety from any project in which you are engaged.

**Second, we need to improve reliability.** When I went to the Metro station on my way here this morning, I knew the train was going to be there. I knew I was going to get on. I knew I was going to get here in time. I cut it very close, having only ten minutes to spare. Also, I have two very reliable foreign cars in my garage. When I went out this morning to drive to the Metro station, I never worried about the car starting. It always starts. When I walk down a jet bridge and get in an airplane, however, I don't have the same feeling. That is not right. We must instill a feeling of reliability in our customers. It can come from many things. It comes from the science and technology we are using to help airplanes cope with weather. It comes from the way we service and maintain our fleet. We must make real strides toward improving the sense of reliability that we need in order to succeed.

So, improved safety and improved reliability are two things that you can quantify and measure. You can say, "Here's something I'm doing that will have a pay-off that's promoting the industry."

**Next, we need to improve the capacity of our airplanes.** We don't all build airplanes as Boeing does, so we can't make them lighter, cheaper and carry more people farther. But we do have an influence on that. One of the most dramatic influences is not having them in the hanger all the time doing maintenance, but keeping them airworthy, on the line, ready to fly. We need to be able to carry more people with this very expensive hardware that we bought.

**And lastly, we need to lower cost.** You can lower cost in many ways and in innovative ways. You cannot afford to let the maintenance cost, representing about \$9 billion for our industry, go up. That has to go down. There are ways to do that. We have much waste in what we do, and if we just eliminate the waste we will have a substantial reduction in maintenance costs.

The above four actions represent a tremendous challenge. We must make progress on these four actions or we are not going to stay in business.

Let's examine each of these four actions in greater detail. We need some feeling for where we are and how much of an improvement we need to make in each of these dimensions.

**Safety.** Air transportation is the safest form of transportation. However, our rate of improvement has plateaued. Over the last ten years, we have averaged .068 accidents per 100,000 departures. That means about one accident every 1.5 million departures. This really has not changed much over the last ten to twenty years. Boeing evaluated 110 accidents that occurred over the entire world (during the last ten years). In 91 of these accidents, Boeing had enough information to trace the cause of the accident. In 61 percent of these accidents, or 59 of out of the 91, blame was placed on the air crew. From a maintenance perspective, we have only a small part of the total picture. But I think we can make a positive contribution. We can help reduce the likelihood of flight crew error by not putting them in a bad situation in the first place. Many times the flight crew is blamed because they were the last element that failed to prevent the accident. In fact, there may have been a half dozen actions upstream. Any one of these actions done properly or done differently would have prevented the accident by not putting that flight crew in the situation.

Now we're good, but we've plateaued. How good do we need to be? Some projections show a doubling of the number of departures by the year 2000. I believe the traveling public will not tolerate an increase in the number of accidents that we are experiencing today. So a reasonable goal is to cut the accident rate in half by the year 2000.

There is a never-ending search for improved safety. This is the focus of our efforts each year and we need to find some way to break through the plateau that we have established. There are many areas

and different disciplines that need to be involved in making that happen. Suffice it to say, each year we at ATA take the time and trouble to list initiatives, this year 21 different initiatives, that we all agree would positively impact safety. The ATA initiatives list -- our safety agenda -- has been given to each of you.

**Reliability.** Passengers need to feel as comfortable on our airplanes as they do when boarding a train or driving their car. New technology for weather is coming into the airplanes. There are self-monitoring systems. However, we really need to focus on the practical outcome of all of this science. Let me quote from a talk given by Dave Kruse, Senior Vice President for Maintenance and Engineering, American Airlines. He spoke to the FAA's Flight Operations Policy Board meeting last October in Dallas. He stated:

*Our concern is the performance of the new technologies on the latest aircraft such as the 747-400, MD11, A320, and to some extent the Fokker 100. While the mean time between failures of these systems is generally satisfactory, they are self-defeating. They are eroding our aircraft dispatch reliability. False or overly sensitive alerts and warnings at departure time in these technology-laden cockpits have made these aircraft only half as reliable as those carrying less sophisticated equipment. At the risk of oversimplification, it seems that those designing today's alerting systems are not knowledgeable enough about what the pilot and/or mechanic need to know at departure time.*

*I'm going to suggest a rule of thumb: 'If it is not significant enough to require action before further flight, then don't let the light come on.'*

*During more than half of the delays being experienced today on our newest aircraft, our customers are waiting for mechanics to complete reset procedures to turn off lights or warnings that should not have occurred in the first place.*

What do our customers want? They want increased dependability. Today's hub and spoke operations make dependability of paramount importance. Delays cause us to miss connections, not just be late. The Department of Transportation's (DOT) published arrivals that are within 15 minutes of schedule looks pretty good for the industry. You see their statistics in the newspaper. But, guess what? The DOT rules omit mechanical delays. They are not counted. Our customers, the passengers, are not as generous. They don't care who caused the delay. All they want is to depart on time.

How dependable do we need to be by the year 2000? I would suggest that we need to be twice as dependable as we are today. If we achieve this, I think passengers will continue to regard us as a safe mode of transportation and will feel that we are becoming more reliable and more dependable. Maybe they will continue to take the shuttle to New York instead of AMTRAK, or whatever.

**Capacity.** This action is harder to quantify. There are so many things outside of maintenance that affect the number of people we can carry -- air traffic control, the design of the airplane, etc. However, time-out-of-service is interesting to look at. In 1987 our ATA fleet was averaging 2734 hours per airplane per year in revenue service. Three years later, in 1990, we were six percent worse than that. We were down to 2572 hours per airplane. We all know about airplanes getting older and needing more maintenance. But we cannot afford to continue that trend.

In terms of flights, in 1987 we were at 1870 flights per year average. In 1990, we were 12 percent down. We were only 1640 flights per year average. We need to look hard at the time needed for maintenance. We need to reverse this trend. We need to keep the airplanes on the line and ready to go.

**Cost.** Maintenance costs need to go down. We need to be spending less of our resources maintaining airplanes. We need to eliminate waste. Maintenance costs have increased from about \$1.4 billion in 1970 to about \$9 billion in 1990. This is a tremendous increase during twenty years, up 635 percent. A lot has happened in those twenty years -- deregulation, large number of airplanes, etc. Try to normalize that statistic. Look at available seat miles and look at available ton miles. The available ton miles has been increased by only 260 percent. Maintenance costs went up by a factor

of six, and the amount of capacity that we had only increased by a factor of 2.5. Taking into account inflation, it doesn't look all that bad. Today we are paying 7.7¢ for available ton mile. In 1970, if we adjust for inflation, we were paying more. Then we were paying 10.5¢ for available ton mile. That trend needs to continue. To be successful, we need to provide a better product. We need to provide it at a lower cost. We need to stop the losses our industry has had over the last two years and make a reasonable return on our investment.

You have a lot to face -- more complex airplanes, more challenging jobs, more meaningful work and more meaningful training. You are dealing with a new generation of people, maybe not as well educated as in the past. We need to drive responsible decisions and interventions down to the lowest level within your organizations. We need to keep our capacity up, our costs down, and provide an even more reliable and safe product than we have today.

## AIRCRAFT DESIGN FOR MAINTAINABILITY WITH FUTURE HUMAN MODELS

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

Human models are considered to be graphic or mathematic representations of human structure and performance. In aircraft design, models help to determine the size, arrangement, and operation of things so that they are compatible with human capabilities and limitations. It is much more efficient to predict human performance functioning with equipment before a system is manufactured than to adjust and redesign a system for conformance to human limitations after it is manufactured. This fact is true now and it will become more critical in the future. There will be a continuing need for rapid design and for design efforts involving geographically dispersed partners around the globe.

We are all aware of the current fascination with concurrent engineering. One of the hallmarks of concurrent engineering is to get people together to work collaboratively; in other words, to assure that the design benefits from the contributions of many and different disciplines have an equal opportunity to contribute as the design evolves. Bringing people together to bear on design is a benchmark of concurrent engineering. But herein lies an irony. With changes in the market economy and with changes in the way design is done, many elements of aircraft design are dispersed. They are not brought together. They are dispersed across departments and increasingly around the globe. So we have competing interests. On the one hand, we are attempting to bring people together to design. On the other hand, we are attempting to accomplish design in a widely dispersed arena.

Computer technology may solve some of those problems. Human models also may help to overcome some of these problems because they allow examination and evaluation before the fact. They facilitate analysis of design before design is committed to prototype and certainly before commitment to manufacturing.

In using a human performance model, we first assume two things. We assume that the person knows what is to be done and we assume that the person is somewhat skilled. As an example, consider a mechanic who must service a landing gear strut. We consider that the person knows what is to be done and that he is relatively skilled. Now, we also assume something else. We assume that failures may occur in that person's performance. Such failures are attributed to limitations in how well that person can sense the situation or limitations in his motor responses. These are the underlying assumptions of human performance models.

Next we predict how accurately or reliably this person will execute a procedure given these performance assumptions. The person knows what is to be done. He has the requisite skill level. There will be some performance limitations due to human capacities. We want to predict how accurately or how reliably that person can perform that given task.

## Human Models

There are five major types of human models:

- Anthropomorphic and biomechanical models
- Information processing models
- Control theory models
- Task network models
- Knowledge-based models

You may be most familiar with the first type, the anthropomorphic and biomechanical models. At Douglas Aircraft, we push the use of these models because, for certain questions, they are powerful and efficient in solving problems. We have even produced brochures for distribution within our company to promote the use of these models.

The remaining four types of models are collectively called performance models. The first type of performance model, an information processing model, is concerned with things like attention, memory, response-time and signal detection. A prominent example in human performance modeling is the Human Operator Simulator (HOS). Information processing models place emphasis on mental operations, excluding emotion. They are concerned with mental capabilities and advocate that mental capabilities be represented as rules that govern the flow of information through a person's "sensorium." They emphasize the whole network of sensing and processing through the central nervous system. Information processing models are concerned with human capacities rather than the structure and design of the equipment system.

Control theory models are not in prominent use in aircraft design. They originate from the field of manual control of continuous dynamic systems. The operation of a powerplant or the operation of a steering system on a ship or an automobile are good examples. Control theory models hold that a human is an information processor, or a control and decision element in a closed loop system. A closed loop system is one where the actions of the human are fed back and then serve to modify future actions of that person. Control theory models state that a human would selectively attend to some input. Also, humans have an understanding of how the system works and they estimate the status of that system.

This matter of understanding the system is not as mysterious as it sounds. Think for a minute of how your refrigerator at home may work. In reflecting, you are relying on a mental model, an internal representation of your view of refrigerators. There are two temperature compartments in most refrigerators. Given that there is both a freezer and a fresh food compartment, does that rely on two thermostats? Or, does that rely on one thermostat and an air control mechanism between those two compartments? What happens if there's only one control? If there are two controls, are they mapped to two thermostats, or to an air control? Is the air control somehow tied to the thermostat? Anyway, you and I have these mental models of how the world works. Control theory theorists believe that we can understand people if we understand something about their internal representation of how things work.

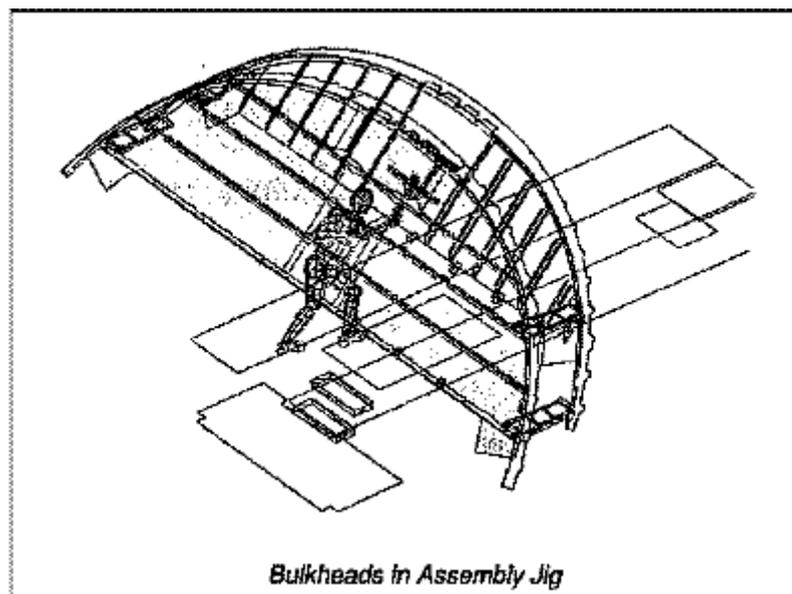
The next performance model type, the task network model, is in increasing use in aircraft design. An example is the model developed and promoted by the Air Force some years ago. It was called Systems Analysis of Integrated Network of Tasks (SAINT). Now it's out in a PC version called MicroSAINT.

Task network models come from operations research. They represent a system by the interconnection of component processes. Each element has a statistical distribution of completion time and a probability of success. As an example, think about a maintenance task procedure that may be found on a job card or in a maintenance manual. Consider each one of these procedural steps to be a node in a network. Each step might be considered to have a probability of success and an estimated time of completion. These estimates or probabilities can be formalized by treating them as distribution parameters. Then a computer program can be used to sample from these distributions to

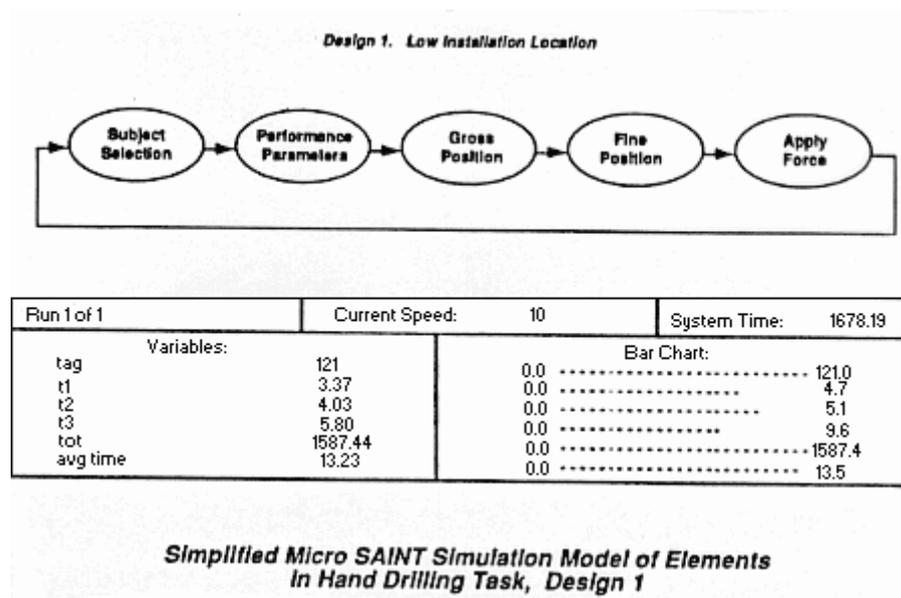
get an estimate of the total task time, or total task likelihood of success.

The final performance model type, knowledge based models, are related to expert systems and artificial intelligence. They are based on explanations on how people decide what is to be done and how they solve problems. Fault diagnosis for repair on aircraft can consume 60 percent of the aircraft repair time. Accordingly, pattern recognition, viewing a pattern of symptoms and trying to make a conclusion about what is at fault with the aircraft, is of significant importance. Knowledge-based models see people as planners and problem solvers who detect anomalies. They compare perceived conditions to their bank of knowledge and operating rules to pose a solution.

Of course, a design problem may be represented with more than one model. Consider the assembly procedure of hand drilling between bulkheads of the C-17 transport, where both access and time to perform the task are concerns. [Figure 1](#) shows a human form model representing the procedure in the case where the location to be drilled is relatively low. Human form representation of drilling in a high location would show an assembler reaching high overhead while standing with legs close together. In either the low or high drilling location, the human form model indicates that adequate clearance exists for assemblers to do the job. To answer the question of how much time will be required for the task, a task network model is constructed to represent the same task. [Figure 2](#) shows a screen from a MicroSAINT representation of the drilling task, again for the case of a low drilling location. A task network model provides a framework for organizing all the elements of the task and examining their sequence and expected elapsed times. (The time data are available from observation, expert judgment, or standard times.)



**Figure 1**



**Figure 2**

The world is not an entirely perfect or happy place for human models. The relationship between human body or human performance data and design for maintainability is not an obvious relationship. This is an important hindrance to further development of models. One reason for this poor relationship is that many models pertain to behavior in relatively isolated circumstances. Consider sample contents of one important collection of research findings in human performance. Here are a few sample contents:

- visual acuity - the effect of exposure time;
- tactile short-term memory;
- probability of correctly reading meters; and,
- characteristics of humans as decision makers.

The above collection of research findings and hundreds of others are isolated models that are available for study. But how can we convert that information into a human performance model that helps us make decisions about the design of aircraft?

Design characteristics are not readily derived from models of isolated behavior. Consider sample contents of MIL-STD-1472C, Section 5.9, the maintainability chapter of the military engineering standard.

- The heads of fasteners should be located on readily accessible surfaces.
- Provide a non-slip surface on the bottom of a unit if the surface will be used as a handhold.
- Field removable items shall be replaceable by using nothing more than common hand tools.
- Equipment items shall be designed so that they cannot be mounted improperly.
- Hinged items shall be provided with a means to hold equipment in the "out" position during maintenance.

What is it about people that makes us say that heads of fasteners should be located on readily accessible surfaces? Why should we provide non-slip surface on the bottom of a unit if the surface will be used as a hand-hold? What is in a human performance model that would lead us to make these conclusions?

The fool-proof design characteristic especially sounds unlike anything that would be derived from human performance literature: "Equipment items shall be designed so they cannot be mounted improperly." The objective of this statement is, of course, to prevent improper installation in the

field or interchange of units that are not functionally interchangeable. However, apart from anecdotes of human errors, there is no set of data in the human performance literature that could be classified as "foolish," in the sense that by reading human performance data one would know how to design equipment to preclude its improper installation.

In reality, these military standard equipment characteristics do not come from human performance literature, or human performance or human form models. Rather, they come from the history of maintaining airplanes. What this translates into is a need to design for human compatibility long before equipment reaches the prototype and long before it reaches the manufacturing stage. We would like to anticipate characteristics like this from our knowledge of human performance and human bodies. Unfortunately, the available data do not lead readily to these kinds of characteristics.

What are the features we would look for in future human performance models? Future human models will:

- Translate more easily into design guidance.
- Represent a greater variety of human behavior (account for motor behavior and problem-solving/attention).
- Represent multiple persons.
- Apply to more aspects of design.
- Be used to "automatically" evaluate design; and,
- Indicate the level of confidence that can be placed into their output.

Future human models also will indicate the interactions among components. For example, tasks that are poorly learned will interfere more with concurrent demands than will tasks that are well learned. Models also will provide optional levels of detail. A system designer may want to look at very small motions or he may want to understand how well people will develop an internal representation of a system. Multiple levels of detail should be selectable by the model user based on the user's requirements.

And finally, it would be wonderful if we could specify mental models for operators or mechanics. Someone who constructs a model of our performance should also understand our view of the world, our mental models. That is really what we want to do when we attempt to model a mechanic's or inspector's performance. What drives or causes the actions on the part of that operator, that mechanic or inspector? Very often it is an internal representation of how the airplane is built.

Let me give you an example of how a mental model can control behavior. An operator had a problem with an aileron control in a transport. There was poor control of these flight surfaces regardless of the control wheel used. Maintenance decided that this was a problem due to a dual mechanical fuse failure. The assumption was made that this aileron control included two mechanical fuses. Once this hypothesis was formed, confirming evidence was sought. They looked repeatedly but never found it. Finally a system expert was called in and fairly quickly determined that the problem was not due to mechanical fuse failures. There were no mechanical fuses in the system. The problem was attributable to sticking tension regulators, a cable and a pulley system. When the tension regulators were cleaned and lubricated, the problem went away. Somebody in maintenance originally had a mental model that the system operated differently. He had assumed there were parts that were not present. He went on to confirm the hypothesis that was the wrong hypothesis. Future models that are sensitive to differences between the way a system actually operates and the way people understand it to operate might help to overcome the human tendency to seize upon a convenient, but incorrect, hypothesis and then attempt to confirm it.

## Use of Human Performance Models

Figure 3 is a representation of how a work station with an embedded future human model might function. On the left is a box labeled "Examine Existing Information." On the right is a section labeled "Generate New Information." A graphics computer is used both to examine existing

information and to generate new information. A personal computer is used to supplement the generation of new information in the workstation. In a workstation like this, users would be able to create structure files and port them to and from an electronic development fixture. Rather than a physical prototype, or a physical mockup, we would work with an electronic development fixture.

## WORKSTATION FUNCTIONS FOR DFM ANALYSIS IN HOW FUTURE MODELS COULD BE USED

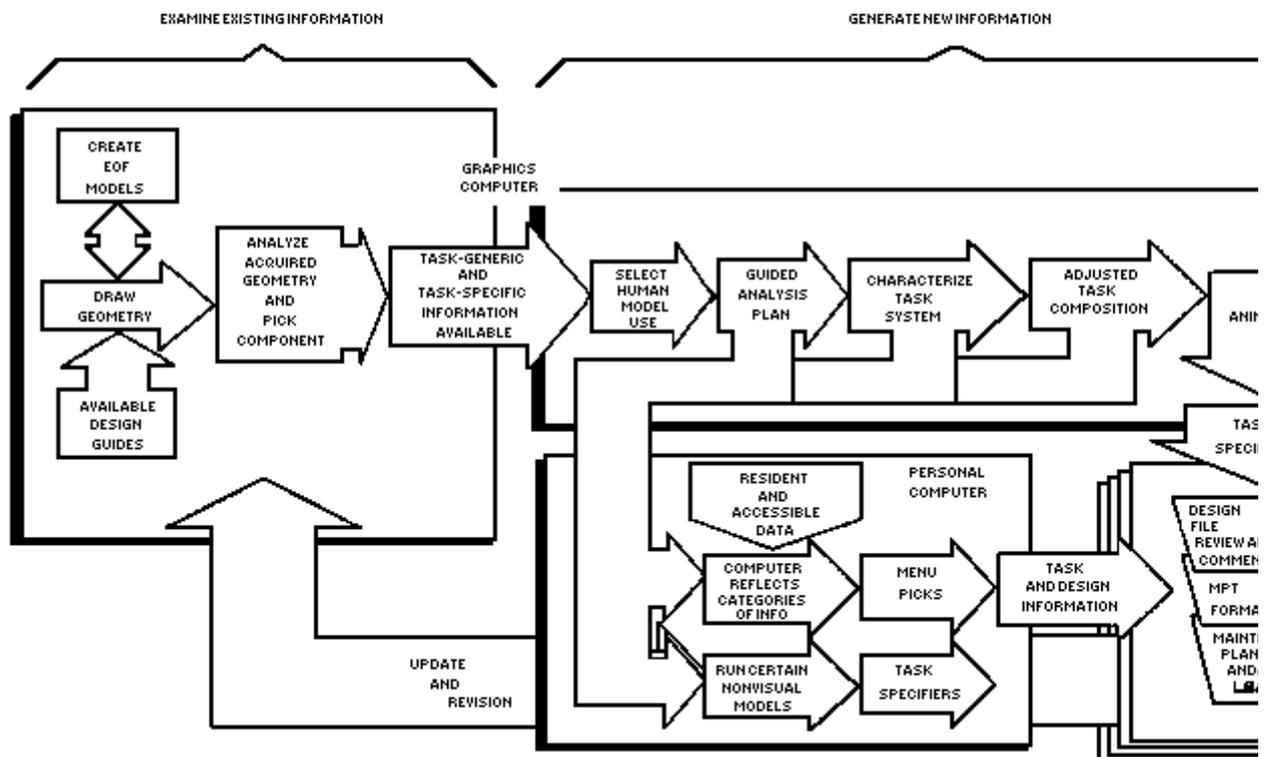


Figure 3

Characteristics of the workstation would include:

- Geometry manipulation;
- Design assistance;
- Component recognition;
- Maintenance task information;
- Evaluation of the design's human compatibility;
- Composition of maintenance task scenarios;
- Performance data bases and models; and,
- Logistics support information.

Designers and analysts would be allowed to perform the traditional fit and interference studies and analyze the association between drawings. Users would be able to find their way around the enormous drawing tree that represents the entire aircraft.

This workstation would provide design assistance. A user would be able to obtain checklists, design and drawing standards, a parts library and review lessons learned. The workstation would afford component recognition, such that line replaceable units (LRU) are recognized by the computer. When the user picks that particular component, information about the expected LRU removal and replacement, reliability, predicted maintenance workload, etc. would be called up quickly. The workstation also would provide maintenance task information, such as the maintenance procedures associated with the LRU that is picked. Ideally, users could study the compatibility of design with human use, obtain information about the tasks associated with the LRU, examine the interaction of the human model, whether a human performance model or a human body model, with a design.

We also could compose models of the maintenance tasks on the workstation. Where suggested by the workstation or by the computer, a possible maintenance scenario task summary would unfold. Also, we could compose and detail specifics of the task so we could have an accurate rendition of how the task would unfold before the aircraft is ever manufactured.

To do all these things, performance data bases in models must be resident or accessible through the personal computer. These models then can be applied to the component and to the task that is selected. And finally, the workstation would provide logistic support information that is of traditional concern for determining crew size, spares, tooling and so forth.

This workstation concept is a vision for the future in which aircraft design for maintainability is accomplished using human performance models. In an ideal world, the model would be ready by the year 2000.

In summary, the use of human models in product development enables engineers to design for ease of maintenance before equipment is manufactured. Future models will extend these design advances, and ultimately will help operators to reduce maintenance costs.

## LOOKING TOWARD 2000: THE EVOLUTION OF HUMAN FACTORS IN MAINTENANCE

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Many textbooks and journal articles over the years have traced the evolution of human factors applications relating to the flight operations environment. Human factors applications in aviation became necessary as technological advances in flying machines began to outpace the abilities of humans to operate and maintain these highly complex systems. As you know, since World War II, human factors applications in the flight operations environment have led to significant improvements in aviation safety. Instead of requiring pilots to adapt to new technology, sometimes unsuccessfully, the industry has begun to change its perspective by requiring new technology to adapt successfully to the pilot. This is called the human-centered approach.

### The Tools for Human Factors Application

During this presentation, I would like to share a perspective on the evolution of human factors application to aviation maintenance. Additionally, I would like to give you a means to envision where the human factors application to maintenance may be headed in the year 2000. In so doing, we will briefly review some basic tools of human factors application; accident investigations, changes in regulatory authority initiatives and airplane design considerations. Also, we will touch on some airline operations applications of human factors.

First, I would like to address the tools of human factors application. In reviewing the evolution of human factors as applied to maintenance, one can identify three basic categories of tools. These are: 1) the use of lessons learned; 2) the use of basic human factors principles; and, 3) the use of

advanced human factors principles.

The first human factors tool used in maintenance as well as in the flight operations environment relates to the use of lessons learned. This is essentially applying the rule:

*If it has gone wrong once, it is likely to go wrong again*

In the history of airplane maintenance, we have encountered maintenance errors that have adversely affected safety and/or economics of airplane operation. Following such events, engineers, mechanics and managers try to develop methods to ensure that the maintenance error does not occur again. If eliminating the possibility of the maintenance error is impossible or unrealistic, methods are explored to ensure that the effects of the maintenance error are minimized. An example of this is the loss of all three engines on an airplane enroute to Miami from Nassau. In this case, all three engines lost oil pressure due to magnetic chip detectors in the engines being installed without O-ring seals. After this incident, the FAA, manufacturers and airlines developed methods to address this problem. At a few airlines, it was addressed through better mechanic training and communication. At other airlines, it was addressed by reducing the impact to the airplane by staggering the maintenance checks of the chip detectors.

I will give you a few examples of lessons learned. One example that directly affected airplane design was the staggering of hydraulic fittings on adjacent hydraulic lines to prevent mismatched assembly. Another example is dissimilar hydraulic and electrical connectors to prevent cross-tubing and crossed wires. A third was the relocation of access panels and equipment to allow convenient inspection and servicing.

Clearly, though, a system of "lessons learned" cannot act alone. Often, to learn the lesson, we must first suffer through the undesired event that serves to teach us that lesson. The commercial aviation industry thus has implemented a more proactive approach to agree with the application of lessons learned. Evidence suggests that the first predictive human factors principles were those dedicated to a fictional character we all know as "Murphy." According to one historical account, Murphy was a bungling mechanic in the U.S. Navy educational cartoons in the 1950s. We all know Murphy's Law, "*That which can go wrong will go wrong.*" Airplane manufacturers and operators have long been asking how equipment and procedures can be misused or misinterpreted. Imagine airplane designers standing around a drafting table, brainstorming the ways a line replaceable unit can be misinstalled. Also, imagine a maintenance manual writer trying to predict how a procedure can be misunderstood, or made simpler to ease the maintenance burden. This philosophy has been a mainstay of human factors application in maintenance. One of the most significant and far reaching applications of Murphy's law in the airline operation lies within the FAA's requirement to separate maintenance and inspection. This separation requires an independent inspector to verify proper accomplishment of any task that if performed improperly by the mechanic, or if improper parts are used, could endanger the safe operation of the airplane. These are known as the Required Inspection Items (RII).

You also can identify what would be a third type of human factors tool for maintenance. These are principles and practices developed from dedicated human factors research. In 1946 and 1954, when Ross McFarland wrote his books, *Human Factors in Air Transport Design* and *Human Factors in Air Transportation*, Ross provided very little direction on specific applications of human factors to maintenance. Even today the percentage of human factors research and development addressing the flight operations environment far outweighs the research and development directed at maintenance.

A few examples of human factors work in the flight operations environment include studies of circadian rhythms, crew workload and crew resource management. Human factors in maintenance does not have the long history of dedicated research as does the flight operations environment. The National Plan for Human Factors Research, along with recent funding through the Aging Fleet Programs, has changed this situation. Now, new emphasis is placed on developing human centered methods for the maintenance environment. The results of this research will be the development and production of new techniques to address human performance in maintenance.

## Accident Investigations

There's another example that addresses the evolution of human factors in maintenance. We can look at the role the National Transportation Safety Board (NTSB) has played in accident investigations. A review of accident investigations involving maintenance error provides an indication of a changing view at the NTSB. Similar to the history of accident investigation in the flight operations environment, the investigation of maintenance error has traditionally been limited to the person or organization that has made the error. An example of the NTSB's changed view can be seen by comparing two similar accidents that occurred in the 1980s.

On September 22, 1981, an airplane on takeoff roll at Miami International Airport suffered an uncontained failure of the number three engine. The NTSB determined that the probable cause of this accident was the failure of quality control inspections to detect the presence of foreign material in the low pressure turbine cavity. This error occurred during reassembly of the low pressure turbine modules after installation of the stage one pressure turbine disk rotor. Although the NTSB could not confirm it, it was thought that a maintenance tool had been left in the engine. Significantly, the NTSB did not mention human factors in the accident report. Instead, they chose to focus on the design aspects of the engine.

The above accident can be compared with the July 19, 1989 accident at Sioux City. In this accident, the center engine of an airplane suffered from an uncontained engine failure. In this case, the NTSB found that a fatigue crack originating from a metallurgical defect in the stage one fan disk went undetected by the airline's maintenance department. This time, eight years later, the NTSB determined that the probable cause was inadequate consideration given to human factors limitations in the inspection and quality control procedures at the subject airline. Included within the recommendations, the NTSB encouraged further research into non-destructive testing. Additionally, modified inspection techniques were specified to include a redundant second set of eyes for critical part inspection. My intent in comparing these two accidents is not to critique the NTSB findings. Rather, it is to illustrate the recent shift in focus (in eight years) toward human factors issues in maintenance.

## The Regulatory Authorities

Also, we can look at the regulatory authorities and see how human factors has evolved over the last thirty years. As stated earlier, the FAA has addressed human factors in the regulations through the RII system by requiring verification of tasks that could endanger safe operation. The investigation of the problem where we lost all three engines due to a chip detector loss has resulted in changes. The FAA now requires in certain operations that engine maintenance checks be staggered. The required staggering is designed to preclude the risk of multiple engine shutdown resulting from one common maintenance error.

The FAA has been addressing human factors in maintenance for many years. However, it is only since the 737 accident of 1988 that the FAA has begun to actively use research to develop methods and practices to address maintenance error. Through the aging fleet initiatives, the FAA has begun research into better methods for structural inspection. Additionally, the FAA has chosen to include airplane and airways' facilities maintenance as research elements within the National Plan for Human Factors Research. The methods developed through this research ultimately will result in rules or recommendations to improve maintenance safety.

## Airplane Design Considerations

We can also look at basic airplane design criteria to see the increasing emphasis put on human factors. A review of 727 and 777 design guidelines reveals significant improvement in the maintainability and human factors considerations from the 727 to the 777. The 727 design guide published in 1960 included only general considerations for ease of maintenance and accessibility for maintenance and inspection. For the 777, we have developed a dedicated maintenance design guide.

It includes both general and specific design criteria gained from thirty years of experience since writing the 727 design guide. From both safety and economic perspectives, industry experience has promoted specific guidelines. For example, guidelines have been developed addressing the allocation of specific elapsed time to remove a line replaceable component. Other guidelines address the evaluation of maintenance access using anthropometric man models. And finally, there has been a move to build an engine magnetic chip detector that can perform for a sufficient amount of time with the O-ring missing.

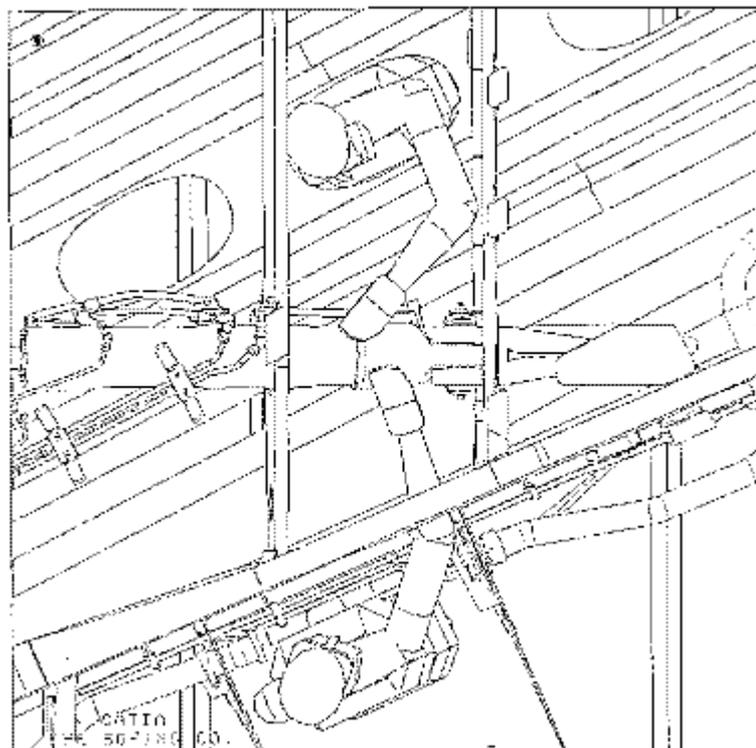
In the area of product support processes, manufacturers have developed methods to improve the human-centered characteristics of manuals and training. Manuals are now being made available in digital format to increase customer flexibility and reduce maintenance costs. The [simplified English](#) language has been incorporated into our maintenance and training manuals to provide easier understanding in the international maintenance community.

Computer-based training has been developed to improve training efficiency. New training technology is allowing "what if" situations to be explored in the classroom.

Additionally, on the 777 specifically, Boeing has implemented many programs that improve the human-centered characteristics of the airplane and its support. Design-build teams have been created that include members of design, customer support, and manufacturing areas. The function of the customer service's engineers on the team is to represent the customer's viewpoint regarding maintainability of the airplanes. Through these teams, each system and major component on the airplane is subjected to a detailed maintainability analysis. These efforts address ease of maintenance and review features to prevent improper maintenance.

Test maintenance teams have been established within our maintenance engineering organization specifically to implement lessons learned from our previous airplane programs. This program will include an analysis of anticipated maintenance costs associated with the new 777 airplane. Training is being focused to provide a performance based approach from initial task analysis, through media selection, to the final product. Additionally, for the 777, we have created a program to verify and validate maintenance procedures, and to assure that tools and training are correctly developed. Through table-top analysis, engineers will verify that critical maintenance procedures and tools will perform their intended function. Through on-airplane performance of tasks, critical maintenance procedures, tools, and training will be validated before delivery of the airplane. This validation may also detect human factors problems, such as inadequate access to line replaceable components and inadequate removal and installation times. Additionally, the need for specific cautions within the maintenance manual might be identified.

As seems to be popular, we are working with digital data. We built the airplane using digital data on our computer system with a digitally defined airplane. We are using computer human-models ([Figure 1](#)) which are integrated with the airplane to review accessibility features. We have a digitally defined airplane so all of our designers can access and use the man-model to look at any part of the airplane they want. Also, in using the digital format of the airplane, we can test suitability of ground support equipment since we are designing ground support equipment with the same system as the airplane. We can match our ground support equipment with the airplane without doing a physical mockup for every piece. Also, with the 777, we are bringing airline mechanics, instructors, and engineers to Seattle to review maintainability features of the specific airplane installations. Additionally, these teams perform specific maintainability demonstrations.



**Figure 1 Use of Human Models to Evaluate Access to the 777 Wing Fold Actuator**

Last, a Boeing Chief Mechanic, similar in function to the Chief Pilot, has been assigned to represent the mechanics' view in the design of the 777. This individual helps us build better airplanes and helps assure that we produce better documentation.

### **Airline Operations**

We can also look at the evolution of human factors application in maintenance in airline operations. In addition to the evolution of human factors in maintenance at the manufacturers, airlines have begun to address human factors in maintenance. As an example, Continental Airlines has implemented a very successful class to teach crew coordination concepts to its technical workforce. This class uses techniques learned in the flight operations application of crew resource management. It modifies the curriculum to specifically address issues pertinent to maintenance. Continental also has created the position of human factors auditor. These individuals are responsible for reviewing the maintenance and inspection operations and procedures and recommending appropriate human-centered changes. As you can see, in airline operations, we are continuing to evolve and apply human factors principles.

### **Looking Toward the Year 2000**

Looking toward the year 2000, it should be clear that human factors application in maintenance has grown over the last 30 years and is continuing to grow. With this growth in mind, I wish to provide the following insights as to where human factors applications in maintenance may be in the year 2000.

**Research.** The use of lessons learned in basic human factors principles such as Murphy's Law are prevalent in the application of human factors to maintenance. However, the maintenance environment has not seen a significant research effort. This is necessary to understand those factors in maintenance most influenced by human performance. Circumstances are significantly changing, however. Research efforts have been identified and initiated through the National Plan for Human

Factors Research and through the aging airplane initiatives. Accordingly, we will be better able to understand which factors in maintenance are most influenced by human error. We will learn what to do to reduce the recurrence or impact of human error.

**Advanced Human Factors Methods.** In the aviation industry today, you can find many pilots and flight operations specialists with an understanding of human factors. In the maintenance community, however, most professionals know human factors only through the application of lessons learned and Murphy's Law. New emphasis is now being given through advanced human factors methods such as job task analysis and systems integration. Through conferences such as this, airplane designers and aviation maintenance professionals can better understand the positive role human factors applications can play in aviation maintenance. As a result, we will continue to see human factors additions to the tool box of techniques to improve maintenance safety and reduce maintenance costs.

**Integration of Advanced Technologies.** As we move into the 21st century with human factors techniques in our tool box, we can begin to use human factors application as a review gate for the application of advanced technologies. As new equipment technology becomes available, human factors evaluation will ensure that these new technologies are successfully integrated into our human-centered maintenance system.

As a maintenance specialist with responsibility for human factors, over the last few years I have come to appreciate the positive effect human factors application has had in aviation safety and economics. For those of you with a flight operations counterpart, I encourage you to talk to them about human factors applications in the flight operations environment. Quite possibly, where the flight operation environment is today is where human factors in maintenance may be in the year 2000.

## HUMAN FACTORS CONSIDERATIONS OF THE 777 ON BOARD MAINTENANCE SYSTEM DESIGN

*Jack Hessburg  
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### Introduction

I have been asked to discuss with you an application of human factors in the maintenance design of the 777.

Let me establish some perspective relative to my credentials. I am a mechanical engineer with an airframe and powerplant mechanics license, who has worked for several airlines as well as the Boeing Company. I do not purport to be a human factors engineer or an expert on psychological or physical behavior, but I know something of man-machine interfaces. I'm just an individual who has spent his adult life flying and fixing airplanes. I've scraped a few knuckles and been trapped into making stupid mistakes by the machinery with which I have been working.

### Airplane Description

The 777 is truly a new airplane. Not only did we begin "with a clean sheet of paper," as designers often say, but from the beginning in the design process the end-user community has been heavily involved. A number of related airline designs were investigated to determine such items as size, range and payload. Boeing took this investigation one step further and included the daily users. Concurrent engineering design of the airplane directly involved pilots, mechanics and cabin crews.

The airplane is a low-wing twin-engine wide-body commercial transport employing a semi-monocque metal and composite structure. The 777-200 is the first of a family of new airplanes.

The design incorporates several unique features. Among these is the use of a fly-by-wire flight control system. High bypass ratio turbofan engines generate 80000 pounds of thrust at takeoff. A folding wing tip assembly is used. Additionally, the design incorporates a fiber optic Local Area Network (LAN), a unique cabin management system, and an on-board maintenance system. Also, the design incorporates an electronic library, a dedicated maintenance terminal and several fault tolerant design systems.

The design incorporates numerous features intended to enhance maintenance. I want to limit my discussion, however, to one maintenance feature that is intimately associated with Human Factors Engineering; the Onboard Maintenance System (OMS).

## The 777 On Board Maintenance System

The On Board Maintenance System (OMS) installed in the 777 provides direct computer access to several maintenance functions aboard the airplane. It embodies a Central Maintenance Computing Function (CMCF), as well as peripheral maintenance functions, such as a Condition Monitoring Function and maintenance functional testing. It is the next evolutionary step in the development of Built In Test Equipment (BITE).

Although similar to central maintenance computing found on the 747-400 and other current airplanes, OMS is a refinement of the concept. It includes a dedicated maintenance access terminal for the mechanic. It is located in the cockpit directly aft of the first officer's position. Additionally, there are connection provisions throughout the airplane for the installation of a portable maintenance access terminal.

## The Problem with BITE (Built In Test Equipment)

Before we can discuss the OMS design, we must first discuss BITE. It is a central feature of OMS. OMS displays BITE results.

All too frequently, the problem with BITE is that mechanics have been *bit* by *BITE*. It lies to them and is difficult to use. They don't trust it. Let me explain what I mean by these statements.

The original purpose of Built In Test Equipment (BITE) was to provide fault isolation information regarding a given component or system. Fault information was derived from a series of monitors within a component or system. In turn, this information was translated into some form of user interface that provided diagnostic information to the mechanic regarding the condition of the component or system being testing.

## Early BITE

BITE is not new. The C-46 anti-skid system had a built in test capability. Transport series airplanes of the late 1960s' and early 1970s' all employed analog BITE. These systems essentially monitored individual devices (boxes), not systems as a whole. The boxes were usually interrogated directly by pressing a button on the front of the box to initiate the test. Fault information was displayed on the front of these boxes in a number of diverse ways -- red or green lights, alpha codes, alpha-numeric codes, fault balls, light codes, etc. The analog BITE of this era was confusing, not reliable and difficult to use. Mechanics rapidly learned to distrust it. They had been bit by BITE for the first time.

## The Digital World of Computers

The arrival of digital avionics and "glass cockpit airplanes" saw a maturation of BITE. The demand for comprehensive reliable BITE increased. Engineers and maintenance managers began to demand more information from BITE to assist them in their tasks. Consequently a greater number of BITE monitors were used and the number of boxes monitored, or capable of reporting upon their own

condition, increased by several orders of magnitude.

Airplane systems became more integrated and complex in this brave new digital age. Digital techniques permitted more parameters to be better monitored. In turn, these could be consolidated into accurate fault reports that isolated the root cause of a malfunction. Accordingly, it became necessary to rely upon BITE to effectively troubleshoot.

We as an industry led mechanics to believe that this new digital BITE was an answer to all their prayers. True, analog BITE was unreliable. But complex integrated digital airplanes were now so smart they could diagnose their own problems and save endless troubleshooting. This magic in the box would solve all problems. Well, it wasn't the solution and it wasn't magic.

Reliable BITE again proved to be a daunting goal for the designer. Frequently subtle relationships existed between systems that were not fully understood. While more parameters could more accurately be monitored, we did not really understand nor have the methodology for effective fault consolidation logic. For example, BITE frequently falsely reported component failures that did not exist. Individual components were reported failed when they were fully functional. Rather, the "failure" was caused by the true failure of another component that fed data to the second component. This is known as "cascading faults."

Digital circuits were sensitive to power interrupts, voltage transients and the like. Fault monitoring circuits had insufficient time delays in them and their attendant logic to prevent setting faults when these conditions arose. Consequently, nuisance faults were frequently displayed.

Anyone who has ever run a computer knows what it is like to have the computer "lock-up," or as I call it, "go to Mars and forget to come back." This is a frustrating condition for a mechanic trying to rapidly turn an airplane around at the gate. It is simply not acceptable.

Unfortunately, the methods of displaying BITE results remained essentially unchanged from the previous generation of airplanes. BITE messages were diverse and non-standardized in their presentation. Box designers and component vendors interpreted in their own way the few display criteria that existed. No common standard of performance existed. The BITE was still on the front of the box and it still consisted of lights and unintelligible codes. This problem was compounded, however, because the number of boxes with BITE capability had increased markedly over previous designs.

BITE was now more complex than ever and still less than a reliable diagnostic tool. Mechanics continued to distrust it. BITE struck the second time.

## **Central BITE and the Message Explosion**

The late 1980s' saw the introduction of Central Maintenance Computers (CMC). The CMC attempted to solve three of the problems associated with previous BITE systems.

First, it relieved mechanics from going on a treasure hunt to interrogate the front of a number of diversely located boxes. Fault information could now be obtained from a central source.

Second, mechanics were given a BITE display that was intended to better present fault diagnostics. "Maintenance messages" were now displayed in English on a cathode ray tube rather than as arcane BITE codes. They were logically grouped by ATA chapter.

Finally, it provided a central computing function that could solve some of the problems associated with nuisance messages by providing a fault consolidation capability that was more comprehensive than previous BITE systems. Further, it did a better job of correlating maintenance faults with EICAS messages displayed in the cockpit to the flight crew.

BITE was again expanded. More systems and boxes were monitored than ever before. More systems were integrated. It was now possible to obtain large amounts of data. In a word, we could collect a favorite data item in the engineer's repertoire. We could sure collect data.

It was now possible to present fault messages that conveyed more than just simple diagnostics. We overwhelmed the maintenance community with information. There was an information explosion of dubious benefit.

Let me give you an example. Since the late 1920's when we first put retractable landing gears on airplanes, we presented pilots and mechanics with three messages; Up, Down and Unsafe. These three messages were universally understood by all. Today, on one airplane, there are 138 BITE messages describing the condition of the landing gear. Why? Am I any safer mechanic or a better maintenance manager because I know that much more about the gear. I don't think so. Has the mechanic been confused by all of this intelligence? Yes. He doesn't know what to do with most of it.

How have we as an industry done with this new generation of BITE? Not well. The additional features incorporated by Central Maintenance Computers have not solved many of the old complaints. In some instances, it has compounded problems and added a few new ones. The system remains too complex and difficult to use. There are too many operating modes. Although the device now speaks English, it communicates in an unintelligible dialect that is couched in baffling abbreviations and contractions. It does, however, speak to the mechanic from one location. We are still plagued with nuisance messages and computers still go to "Mars." BITE still lies. We don't seem to be a lot better off than we were 10 years ago. We just seem to have more unreliable messages telling us ever more about the airplane that we care less and less about knowing. But we do gather data.

Mechanics continue to distrust [BITE](#). Their feelings are reinforced by this latest experience. BITE has struck a third time.

In fairness, it should be pointed out that as Central Maintenance Computing has matured in the last two years, it has greatly improved reliability. Nuisance messages have been diminished; correlation to EICAS messages is complete. There is no doubt in my mind that now the concept of BITE and Central Maintenance Computing is invaluable to aircraft maintenance.

## The 777 OMS Design Approach

Mechanics are pragmatic individuals. If a device does not make their job easier or gets in the way of doing their job, they will reject it. Well, mechanics have now been lied to three times about [BITE](#) and what it can do for them. They are not going to take it any longer.

It is immaterial how good a job has been done improving the reliability and sophistication of [BITE](#) and central maintenance concepts if mechanics will not use the device. We lost a generation of mechanics trying to introduce a marvelous, albeit poorly executed concept. We must now do two things to gain credibility with mechanics; make the [OMS](#) and BITE more useable and make it truly reliable.

On the 777 we are approaching OMS design with a deep understanding of the past. From the technical end, we are being more meticulous in monitoring systems and in consolidating and reporting faults. From a human factors perspective, we are doing a number of things to assure an acceptable man/machine interface. Among these:

- We have defined a principal user and his requirements;

- We are representing and consulting with mechanics in the design; and,

- We have established a common user interface.

## The OMS User and His Requirements

A lesson from the past is that as BITE capability grew many disciplines saw benefit. Consequently designers tried to satisfy everyone's needs; their own design needs, engineering at the airline and the

manufacturer, hanger maintenance, bench mechanics and line mechanics, maintenance planners and statisticians. Now no device can be truly successful if it tries to be all things to all people.

Perhaps one of the biggest mistakes we as an industry made in the development of BITE is that we never really answered the question "Who is the principal user and beneficiary of BITE?" This is central to a successful system.

Let's define the primary user of the device. Mechanics will eventually fix anything that is broken. It is, after all, their forte. How rapidly they do it is a function of the design being accommodated to their needs.

A common statistic shared by manufacturers and carriers is mechanical schedule reliability. It is used as a measure of the "goodness" of the design. It says the airplane and its systems are dependable. Much mention is made throughout the industry regarding the value of this number.

Manufacturers can contribute to mechanical reliability in two ways. First, their airplane should be designed to be inherently long lived and reliable. And, second, their design should be such that when it does malfunction it may be easily and quickly returned to service.

Mechanical reliability begs a question, "How bad do you want to go flying?" If you state that you want to meet schedule "xx%" of the time, then how do you get there? Decide who in the maintenance community most influences your ability to get the airplane off the gate on time. Is it the engineering department; the hangers, the shops, stores? No!

The entity that most influences on-time departure is line maintenance -- the gate mechanics. They effect repair or deferral. They touch the airplane more frequently than anyone within the maintenance community. They most frequently "return the airplane to service." They work under the most demanding maintenance requirement; that of having the airplane operating within the time restraints of the published revenue schedule. They will give you "xx%" reliability.

The principal user of the [OMS](#) then is the line mechanic. Of course, there are subordinate users who are not second class citizens. Their needs also must be accommodated and met. But, when a conflict of interest develops between the varying needs of the maintenance community, the needs of the line mechanic must be given first priority in the OMS design.

For purposes of the 777, we defined the principal user and his needs in a document titled *On Board Maintenance System User Requirements*.

This document states to the design community that the primary goal of maintenance systems information is maintenance of the airplane. The primary goal is not running computers or gathering data.

Included in this document is a characteristic profile of the line mechanic, including his responsibilities and the environment wherein he must operate.

We listed simple design requirements to satisfy the mechanic's needs, such as:

- Optimize the mechanic's performance. Liberate the mechanic as much as possible from the burden of operating the computer;

- Design from the mechanic's perspective;

- Remember that these mechanics are not necessarily dedicated to working on the 777. They work several models of airplanes. Consequently, operation of the OMS should be intuitive;

- Understand that the [OMS](#) will be used by many nationalities. There are cultural and linguistic differences that may affect how a mechanic will use the device; and,

- Be consistent in the design. It should have a common look and feel.

Automation of the maintenance function shall be mechanic-centered. That is, the mechanic must be in control of the airplane and its systems, as well as the OMS. In a word, permit the mechanic to

look at or do what he wants when he wants -- not the way a computer programmer thinks it ought to be.

There are some basic guidelines for maintenance messages. For example:

Messages should not be generated or displayed unless they add value to the maintenance process;

They should not be generated for systems that are inherently monitored.

Don't use the computer to tell the mechanic that the airplane has a flat tire or that a light bulb in the galley is burned out;

Tell the mechanic what he needs to know to restore airworthiness;

Don't use abbreviations or contractions. Construct the message using [simplified English](#). Not all mechanics speak English; and,

Messages should be directed toward the root cause of a fault. If you can't tell the mechanic unequivocally what the fault is, say so and then state what you do know.

Heady stuff! Some is as plain as the nose on your face. But unless we remind ourselves, we forget where our noses are.

## Represent the Mechanic in the Design

We nominated an advocate for the mechanic to the design community. The position of Chief Mechanic was created to bring to the design table the needs of the mechanic community and an understanding of the environment wherein they operate.

One of the Chief Mechanic's responsibilities is for the design philosophy and output of the [OMS](#). He is to translate the lessons learned from previous systems. He is the arbiter of type, format, content and inclusion of maintenance information to be displayed by the OMS.

The Chief Mechanic, however, is merely a surrogate. Assisting him are practicing line mechanics from our customer airlines. Design reviews will continue throughout the OMS development. This will include the use of prototype devices. We have the mechanics test the design as it evolves.

## Common User Interface Document

In addition to the [OMS](#), there are several computer systems on board the 777 with which mechanics will have contact. These include the Flight Management System (FMS), Cabin Management System (CMS), and the Electronic Library System (ELS). All of these computer-driven systems are run from CRT displays with some form of operator interaction with the device.

We formed a working group to establish a common interface for all computer systems. This working group is composed of the Chief Mechanic, design representatives for each of these devices, Maintenance Engineering and Training and Human Factors personnel.

The charter of this group is to ensure that there is a common look, feel and operation to all the devices. The basic objective is that a mechanic shall not be required to learn how to operate four different computer systems. He should not have to worry about the application he is in. He should be able to move interactively between applications. Typing should not be a requirement.

## Conclusion

In conclusion, we are using experience gained from the industry, as well as our own from past programs. We have better fault monitoring and fault consolidation to build a device that meets the specific needs of the mechanic. Our device will be a simple-to-use, simple-to-understand diagnostic

tool that tells the truth without superfluous information.

I frequently joke with my colleagues on the project, "It says on my mechanic's license that the ratings and limitations are Airframe & Powerplant. It is my sincerest desire that in 1995 I do not find myself with a third rating -- "Typist and Computer Operator."

I believe we will avoid this third rating. I believe BITE will tell the truth this time. I believe that it will not require a rocket scientist to operate the OMS.

## TOMORROW'S PROBLEMS AS SEEN BY MAINTENANCE MANAGERS

*Robert Lutzinger  
United Airlines*

By way of introduction, I would like to give you some background relative to the Airline Inspection Panel, which my three colleagues and I represent. In 1988, after the incident with Aloha Airlines, the airline inspection managers convened on an ad hoc basis. Our purpose was to address recent events and concerns in airline maintenance; namely, skin lap inspections and Airworthiness Directives (AD). Our normal experience of from 10 or 15 ADs in one year soared to 150 ADs the following year. It was a difficult increase in workload to address. We were frustrated and needed to discuss this with people who were in the same boat. Our initial meetings were designed to study the various inspection techniques, methods, procedures, administrative policies, training programs and other means of managing effective inspection programs. It was a good experience. All of us benefitted from these ad hoc meetings. We collected large amounts of usable information and made changes in our own operations to better equip ourselves to take on this additional workload. One thing led to another, and we addressed the Air Transport Association (ATA) and asked for full-time status as an active panel. That recommendation was received and approved.

We are now meeting to discuss and evaluate certain inspection processes, procedures and behaviors. It is our purpose to review and develop common inspection practices and standards and to insure that airline inspection programs are at acceptable levels of safety and quality. We believe that exchanging knowledge back and forth among carriers enhances the inspection process. For example, we have arrived at a consensus on the wording used for the various levels of inspection - from walk-around to intensified.

Today I want to give you some insight as to how we perceive changes coming down the road in the next five or ten years. Additionally, we will indicate potential problem areas and opportunities to improve what we perceive.

A number of problems will influence our ability to manage change. We will be dealing with a variety of equipment types and a growing fleet size dispersed at several locations. We must reduce maintenance costs. Our workloads are getting larger. We have a more demanding, labor intensive maintenance process on our hands. We have gone from flashlights, wrenches and pliers, to sophisticated equipment. The maintenance world is much different from what it has ever been before.

In inspection, we are no longer quality verifiers. We have become work generators. We now take on the inspection of a thousand inches of skin laps on narrow body airliners, do it effectively, and do it in a short time. That is a different way of doing things than the way we worked before with a flashlight from ten feet away. Things have changed and we need to learn to manage the change process.

**Workload Increases.** The number of air carriers has been reduced as many have gone out of business. Some of our individual workloads have doubled or tripled because our fleet sizes have doubled or tripled. At United, we're looking to have a 700 airplane fleet. This year we will receive 66 new airplanes. That is more than one new airplane a week.

Wide-body airplanes at many of the carriers are undergoing maintenance that takes three months out-

of-service time and 200,000 hours of technician time. Boeing personnel have advised me that it takes approximately 49,000 hours to build a wide-body airplane and that it will now take 200,000 hours to fix it. This does not compute. We will have to learn to manage the fleet and to do our jobs smarter and better. We cannot accept the extended out-of-service times. If you think about that for a minute, that means that we have at least one airplane out of service at all times, and possibly two. There are very few businesses that can afford having \$240 million worth of inventory out of service not producing income.

**More Skilled Workers.** Within the airline industry today, there are several carriers planning to build new maintenance facilities; for example, American, Northwest and United. In Indianapolis, we estimate we will need 6300 new technicians. That's a lot of people needed during a time when we are already having trouble meeting our technician and inspection personnel needs. But if we are going to manage a 700 airplane fleet, we are going to have to meet these maintenance and inspection needs. We will have to meet our requirements effectively, without the loss of quality, produce reliability and do it within costs.

How are we going to get these skilled workers? We must depend on our local communities, colleges, and A&P schools to produce viable, well-equipped technicians who are ready to perform. We must maximize our in-house training dollars so that our new technicians are productive as soon as possible. We cannot afford unnecessary training costs to bring them up to speed. We owe them the resources to become effective technicians. We have to learn to manage our training.

**Scheduling and Cost Priorities.** Dealing with a 200,000 hour maintenance airplane, coordinated scheduling of manpower and activities requires us to control our visit cycle time. That's how we cut maintenance costs. By delivering maintenance through-put as quickly as possible, we increase our reliability and cut our cycle time. Costs will go down without any loss of quality. There's no magic to that. Our plan involves giving our internal customers quality services. These are not the passengers sitting in the seats. Our customers for maintenance are flight operations and ramp operations people. They're the ones that deliver the product to the customers. They expect a reliable, on-time aircraft to do that. When they get it, they can deliver quality service.

We're getting a lot more into establishing priorities and in scheduling systems. We now are a worldwide operation and the opportunity for substitutions isn't there as it once was. A lost departure slot from San Francisco to the Orient because the maintenance crew is out of time costs dollars. If the departure is delayed for a maintenance fix, it generates about \$47,000 in hotel bills for those who are deplaned. Our reliability and our ability to react timely to fixing airplanes are very, very important. Many carriers are virtually going out of business because they cannot get that magic balance between quality and reliability, cycle times and priorities down to where it results in a positive return on the investment. In today's world, maintenance costs impact profitability. We are affecting bottom-line financing more than ever before!

For United Airlines, our maintenance operations budget at San Francisco nearly exceeds the budget for the City and County of San Francisco. This last year, our maintenance operations budget was approximately \$1.7 billion. I'm not sure what it will be for this next year. But it's going to be big.

**Personnel and Staffing.** In the area of personnel and staffing, we are going to double or triple our staffing and add facilities to increase our capacity for the growing fleet. We need people that are effective, able to be integrated into our systems and able to use the required tools. We must give these people resources that are reasonable, accessible and understandable so they can carry out their mission effectively.

Our experience levels are down. I remember the day when you could not become an inspector unless you had 15 or 16 years of experience. Of the 800 or 900 inspectors that we have at San Francisco, the average seniority now is about two years. We have lost our experience base. This loss of experience requires our attention. We need to train personnel and give them resources to do their jobs effectively.

**Training Requirements.** We are conducting training on the visual side of inspection and on hands-

on maintenance. We are experiencing increasing training costs to bring people up to speed to use the technical and complicated equipment now part of our daily activities.

There are areas where savings can be made. We need to find them! I will give you an example. One task involves inspection of door seals and adjacent structures on a narrow body aircraft. It appeared to require the removal of structure and the inspection of this area visually. It was initially estimated to take 12 shifts for every airplane in the narrow body fleet by type. A Non-Destructive Inspection (NDI) process was developed. The task was accomplished in less than a shift. The airplane was available and no lost time resulted. Hundreds of thousands of labor hours were saved by using this procedure.

**Environmental Changes.** Consider the paint/no paint question, the hanger environment, the resources we use to evacuate the fumes and the stripping methods we use. All of these necessary environmental controls are costly. These costs are multiplied repeatedly by the fleet size. We are committed to comply with environmental requirements -- we need to do so effectively.

**New Technology.** We need to manage new technology to our advantage. We need to use new technology to improve the process so we can manage cycle time. We need to perform efficient inspections and maintenance task on large airplanes. We must give every advantage to the inspector and the mechanic at the working level.

**Maintenance Management.** We must manage the maintenance process to take advantage of every possible improvement, without a loss of quality. That is our priority goal. We think we can contribute to lowering costs without compromising quality. That's what we intend to do.

**Evaluation, Measurements and Audits.** We need to evaluate and measure our in-house efforts. We need to concentrate on the critical goals, objectives and activities. We need to spend less time on those activities that are not contributors to our success. As an industry with regulators and vendors, we need to establish common ways of measuring our work. It is very difficult to respond to audits that are more dependent on a given auditor, rather than on a well-defined audit process. The outcome can be as different as day and night. We need to work together so that we are satisfying the auditors; for example, providing the necessary signals and indices, and yet are not causing confusion. We need to clearly understand audit goals. Obviously, the goal for maintenance is to produce an airworthy, quality airplane, on time and at the lowest possible cost.

**Understanding and Controlling the Human Factors.** We open to change on how we manage one another. We have to communicate clearly and honestly with the worker on the floor who does the work. Often we send a very complex message. Communication is a process that we need to learn to do better. We need to work on team building. We must equip our people to do their job right the first time. When you do the job right the first time, many other good things come for free. The cycle time is shorter, the quality better and your customers get the product they look for on time.

In summary, we have to emphasize maintaining and improving quality. We have to be aware of the cost of doing business. We must avoid adding more cost to our product. We must make sure that we are cost effective in our practices. As an industry, we have to recognize who our customer is. Our maintenance and inspection efforts support the operating group. The operations group, in turn, supports the line group. In our system, it may be the flight crew or the in-flight crew. We have to recognize our customers' needs and give them a timely product that they can depend on. They must consider our efforts to be reliable.

Last year, we had 22,000 write-ups on passenger seats. Of these 22,000 write-ups, 89 caused a delay or cancellation. It might not have been a long delay, but if it was in London and you missed your departure slot, it was a long and costly delay for the passenger. There are 14 different kinds of attachment lock mechanisms in a narrow body aircraft seat. The risk of mistake or risk of overlooking a poorly locked seat is enormous. A departure slot delay in London that stops a flight can cost \$46,000 worth of hotel bills alone. These kinds of costs affecting efficiency in the maintenance process must be avoided. Our contribution is to lower cost for our companies and our industry if we are going to survive as a viable air transportation system.

There are many opportunities for us. There also are frustrations. However, we are working together. We share our frustrations and we learn from one another. I believe the maintenance process will be better for it.

## PANEL DISCUSSION

### *Members ATA Inspection Panel*

ATA Inspection Panel members were introduced, including:

John Spiciarich, TWA;  
Frank Sitterly, American Airlines;  
Ray Chelberg, Northwest Airlines;  
Steve Krause, Delta Air Lines; and,  
Robert Lutzinger, United Airlines.

It was noted that the ATA Inspection Panel members collectively have 157 years of maintenance experience.

**Question No.1:** Earlier, Robert Lutzinger stated that for the 800 to 900 inspectors that United has in San Francisco, the average seniority was 18 months. I am a little concerned about the lack of seniority. Can you clarify this situation?

**Answer, Robert Lutzinger:** Our inspector seniority ranges from 18 months to two years. However, keep in mind the process by which one becomes an inspector. Before taking the inspector qualification test, an applicant must have at least 18 months in maintenance. Before that, the technician would have had between 2 to 3 years of formal schooling. So if our average inspector has been functioning as an inspector for upwards of 18 months to two years, we are talking about a person having been involved in maintenance for 7 or 8 years. But, compared to what we had before, we don't have a significant cadre of technicians having upwards of 20 years of experience. We have a tremendous base of quality people and we are moving along to train them to be active participants in our maintenance program.

**Question No. 2:** I think you said the United Indianapolis maintenance base would house about 6200 personnel. Is this correct?

**Answer, Robert Lutzinger:** I believe that is the target number.

**Question No. 3:** This is a two-part question. Has United Airlines researched Indianapolis to find out where these technical people are going to come from? If your inspection seniority is low in San Francisco, what will your seniority be in your Indianapolis inspection department?

**Answer, Robert Lutzinger:** I can tell you that the site selection at Indianapolis was based on several things, one of them being the demographics which can provide the necessary technical people.

San Francisco, our maintenance operation center, is currently a difficult place to staff. It's hard to take an anxious 25 year old aviation technician out of school in Pittsburgh or New York and bring him to California. He typically will have to commute upwards of 50 miles so that he can get an apartment for less than \$800. He or she would find it difficult to afford a typical San Francisco home in the \$350,000 range. It is very difficult and very frustrating for our new hires in the San Francisco area. As a result, our marketplace for skilled workers has been lean. We have been fortunate to get the caliber people we currently have on board.

Some of you saw the recent California earthquake coverage on television. Simultaneous to the

earthquake striking San Francisco, we had about 200 people signed on to report within two or three weeks. We lost about 60 percent of them by phone call following the earthquake.

**Question No. 4:** Since San Francisco is not that appealing, do you see a mass migration out of San Francisco to Indianapolis? Is that going to leave you a void in San Francisco?

**Answer, Robert Lutzinger:** Yes, I expect that a considerable number of people will move from San Francisco to Indianapolis. We do have a large base of young employees who are willing to relocate. However, we also have the older employee who has been in San Francisco for years. He may be in a house for which he paid \$20,000 that is currently worth \$800,000. He is not going to go. At least, he won't move until he sells his house. There are many people who are going to stay in San Francisco because they're comfortable in their environment.

There will be many people who will relocate. We are hoping they'll do that. We see that transfer of technology and transfer of experience as a good thing.

**Question No. 5:** To me, the quantity of paperwork is one of our industry's major problems. If we can save a half hour a day in processing paper, that should add up to about \$300,000,000 a year that we can save. We are getting layer upon layer of material we don't use.

**Answer, Ray Chelberg:** It is probably worthwhile to give you some background as to how we got into some of the paperwork problems we have today at Northwest. Keep in mind that it is the result of merging two airlines, creating a new paperwork system and adding some new maintenance programs. Some of our paperwork is duplicative and some of our paperwork is required by the reporting requirements imposed by the Aging Aircraft Program. Frequently, we end up reporting the same findings three times in meeting various reporting requirements. It is confusing to the mechanic and confusing to the inspectors. Anytime you have two pieces of paper that accomplish the same reporting job, you stand a good chance of not getting the job done appropriately on either piece.

**Answer, John Spiciarich:** At TWA, we've had many budget cuts. There are fewer people available to resolve our paperwork problems. However, we have always encouraged mechanics and inspectors to offer proposed changes. We have made progress with check C cards. We are actively trying to make paperwork easier and more understandable.

When it comes to Airworthiness Directives (AD), we need help and guidance from both the ATA and the FAA. We need to make sure that we are all interpreting the ADs the same way; also, ADs need to be communicated at the inspector and mechanic level in clear, concise and understandable terms.

**Answer, Frank Sitterly:** I agree that saving time by reducing paperwork is certainly worthwhile. However, you have to be very careful to document any work done on an airplane. Paperwork is a nightmare. We have put in place a system where production, quality assurance and engineering reviews are all required before any new card is generated. In so doing, we're trying to streamline the paper flow as much as is possible. It's certainly well-worth an on-going effort.

**Question No. 6:** Our drug testing programs are costing upwards of \$1 billion a year from budgets out of an industry that cannot afford it. We are all pleased that we really do not have a drug problem. Yet these drug testing costs continue to be expended.

**Answer, Robert Lutzinger:** Nothing should be sacred from challenge if we are truly going to address the problem of proper maintenance to produce reliable airplanes. If we are encumbered by things that do not add value to that product, then we need to look at them. The drug testing program at United was a papermill problem. We have made several improvements and currently the program works well. It is a mandated program. It is one that we are required to accomplish and it is very important that appropriate documentation is made. Given the fact that drug testing is mandated, I think there would be problems in attempting to get rid of it. We should, however, work to improve the process where we can.

**Comment from the Floor (Question No. 6):** I don't think there is anybody here who would argue

that it's not appropriate to do some drug testing. We have gone through the testing now; as an industry we tested 0.4 percent positive. Well, that leaves 99.6 percent that were drug-free. That's pretty good. I'm proud of that from the industry's standpoint.

It would be appropriate for the FAA or DOT to consider continuation of the drug testing program on a random basis only. The cost would certainly go down if we tested fewer people on a random basis.

**Answer, William Shepherd:** I would like to add a personal observation relative to drug testing. My comments are by no means an official position of the FAA. The drug testing issue is a political issue. The things that FAA and DOT are doing with respect to drug testing have been mandated by Congress and the administration, following some well-known and spectacular accidents involving drugs, mostly surface transportation accidents. I don't think there will be changes in the drug testing program that will come about through FAA or DOT bureaucratic initiatives. Any changes that will take place will ultimately result from political action. For those of you in the industry that deal with drug testing problems, your source of relief ultimately is not the FAA or the DOT. That's my personal view.

**Question No. 7:** I understand that United has an electronic log book process. Are you going to use electronic records in other areas as well? **Answer, Robert Lutzinger:** Yes, United is using the electronic log. There are built-in auditing and back-up systems to ensure that appropriate records are maintained. In our overhaul docks, we are employing a bar code system. This serves to enhance routine and non-routine recordkeeping.

There are many advantages. As an example, the inspector can increase his review process and shorten the time necessary to allow for clearance items. All activity that took place during a visit can be reviewed electronically, giving the inspector a higher level of confidence giving clearance for closing.

It also will give us more efficient surveillance of repeat problems. At present, we have a hard time reviewing the thousands of write-ups and non-routine activities, categorizing them, and selecting those items that are repeats and subject for review.

**Question No. 8:** Do you have any preliminary figures relative to cost savings annually on the system you've installed?

**Answer, Robert Lutzinger:** Not yet. The cost savings will come downstream. Right now the cost of implementation is high.

## MAINTENANCE ADVANCES IN THE F-15 AIRCRAFT PROGRAM

*Thomas Nondorf  
McDonnell Aircraft Corporation*

The F-15 aircraft certainly performed as advertised in the Middle East war. In terms of maintenance, there was no maintenance deferred. Everything that was supposed to be done was done. The biggest problem was with the anti-skid system in Saudi Arabian sand that has the consistency of flour. The struts on the airplane were serviced at an 81,000-82,000 pound take-off gross weight. After coming back there were some problems with the anti-skid system. That was the biggest problem the user had.

The aircraft flew one sortie a day that lasted anywhere from five to seven hours, this being something unusual for a military aircraft. In terms of availability and sortie generation, the aircraft did exactly what it was supposed to do. We're quite proud of that.

As we consider the F-15 and its maintenance, we should first review the U. S. Air Force maintenance structure. The Air Force has three levels of maintenance. The first level, Organizational Level (O-Level), would be analogous to your line maintenance. Once items are removed, if they can be repaired locally, they go to an Intermediate Level (I-Level), usually located on the base. In some cases, it is a consolidated facility that takes care of three or four Air Force

bases (AFB). For items that require extensive repair above and beyond what the base can offer, repairs are made at the Depot Level. The Depots are Air Logistic Centers (ALC) through the United States. The prime Depot for the F-15 is Warner Robbins AFB in Georgia. San Antonio AFB does the engines and the secondary power systems. Hill AFB in Utah does the radar. Accordingly, the airplane gets dispersed throughout the continental United States to get fixed.

When we began to build the F-15 in 1969 and early 1970, we had a very proactive maintainability program. We built in features we felt were essential. In terms of accessibility, we got 570 square feet of access doors and panels. We gave the responsibility to the design community to ensure that the F-15 would have 85 percent of the items packaged within the airplane available without workstands. Most of these items are side mounted. The fuselage is fairly densely populated. Almost everything is available without the use of a workstand. We do not have to drag around a great deal of yellow gear on the flight line.

If access bays on the F-15 had to be opened in less than every 20 hours, we had quick release fasteners put on the doors. Design criteria such as these had been included in the design process. It is hard to add maintainability or human factors after the fact. We had to be proactive and ensure that these concepts were incorporated.

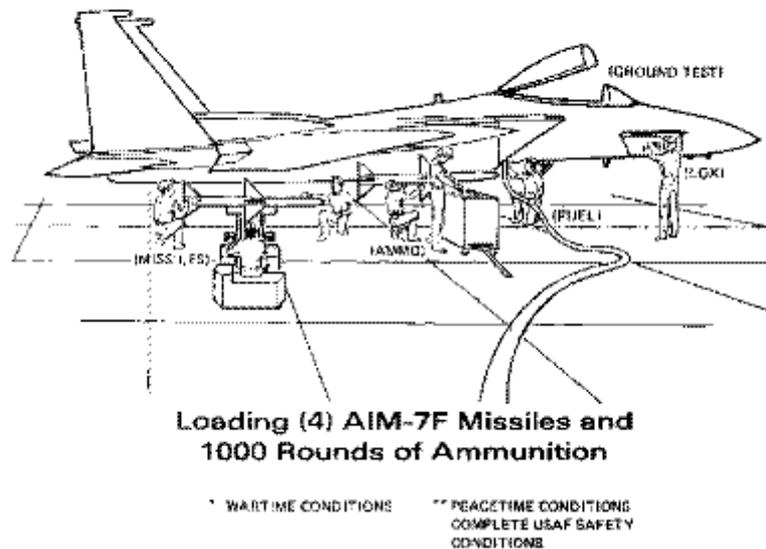
One concept we have pursued is "inter-changeability." We have a great deal of inter-changeability on the airplane. All hydraulic pumps, generators and the engines (left and right) are interchangeable. All the motors that drive the electrically actuated valves within a particular family of valves are interchangeable.

One result of our maintenance program is that servicing times are low. Our servicing times likely do not compare to anything in the civilian world.

- Engine Oil Check (Per Engine) 1 Min
- Time for Internal Fueling 5 Min
- Time for Internal/External Fueling 11 Min
- Liquid Oxygen (LOX) Converter 1.5 Min  
Exchange
- Time for CSD/IDG Service 7 Man-Min
- Time for Engine Oil Service 4 Min  
(Per Engine)
- Time for Complete A/C 9.2 Man-Hrs  
Lubrication

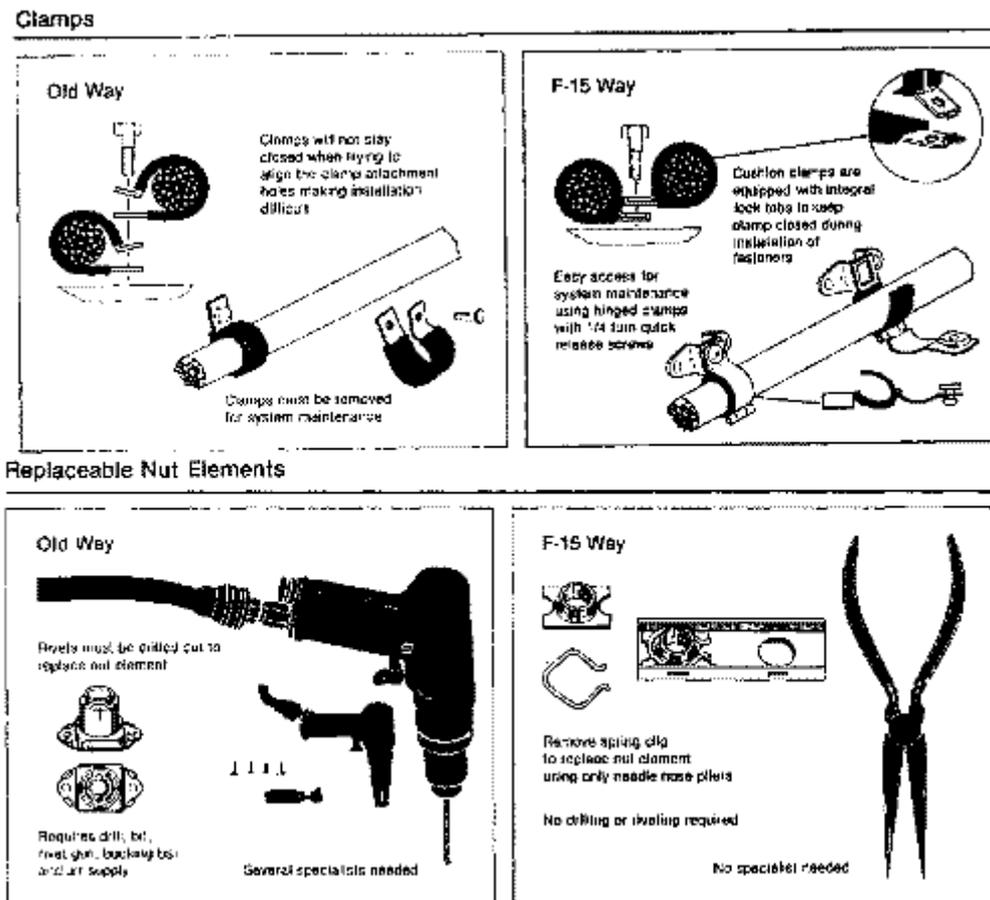
The F-15 holds about 26,000 pounds of fuel internally. All the fueling, a one-man operation, is done from a central receptacle right behind the nose gear. A refuel checklist and all the panels necessary to perform refueling are located right there as well. As shown in [Figure 1](#), the turn-around time relative to reloading and refueling takes 6 to 12 minutes in a standard air-to-air configuration. That includes loading four AIM-7 missiles, a thousand rounds of ammunition and the LOX converter exchange. Using a hot turn, with one engine running, we can do it in six minutes under a combat situation. We do not have to drag a great deal of yellow gear out there to supply power. We can do all the maintenance simultaneously, with the exception of the liquid oxygen (LOX). With the F-15E, we added 42,000 pounds of air-to-ground munitions and that takes significantly longer to load. But using the Multiple Ejector Rack (MER) concept where we preload those things and just slap them on the airplane, we can load 42,000 pounds of supplies in 18 to 20 minutes.

**6\* to 12\*\* Minute Turnaround  
("No Maintenance" Air-to-Air Configuration)**



**Figure 1**

We had to consider Chemical, Biological and Nuclear (CBN) as well as Arctic operations. When you're wearing big mittens and you are locked in a saran wrap suit, things like clamps can pose many problems. As shown in [Figure 2](#), we use preformed clamps that clip in place. You do not have to worry about pre-positioning both ends to attach them with a screw. Also, on items that must be moved to gain access to other items, we use clamps that incorporate a quarterturn fastener. You can just lift the item that's being secured out of the clamp without removing the clamp itself. These are a big benefit when mechanics are in Arctic conditions and in CBN gear. Also, these reduce the fatigue factor when you're considering CBN. Performance degrades rather rapidly, especially someplace like Saudi Arabia where it's 110 degrees and you have got to wear all of this bulky protective clothing.



**Figure 2**

Additionally, before the F-15, if we had to strip out nut plates, we had to drill them out. As shown in [Figure 2](#) we've incorporated a spring clip arrangement in a little track. All you need is a needle nose plier to replace the nut element when they're stripped.

We are quite proud of the F-15 engine design changes, summarized below:

- Quick release, captive fasteners on all engine access doors;
- Top access doors are quick release latch type;
- Clean engine bays; only plumbing or wire necessary to interface engine to airframe is located in engine bay.
- 13 engine disconnects, 9 are quick disconnect type;
- 18 minute 55 second demonstrated engine change; and,
- No defuel.

To make the airplane available and to ensure sortie generation, we've added built-in tests, failure cues/indicators and sight gages.

### Built-in Test

- Avionics
- Flight Control Servos
- Fuel System Check Out Panel
- Anti-Skid
- Fuel Quantity Gaging System
- Environmental Control

- Fire Warning System

### Failure Cues/Indicators

- Maintenance Status Panel
- Engine Event History Recorder
- Cockpit BIT/Ground Test Panel
- ECS Valve Position Indicators

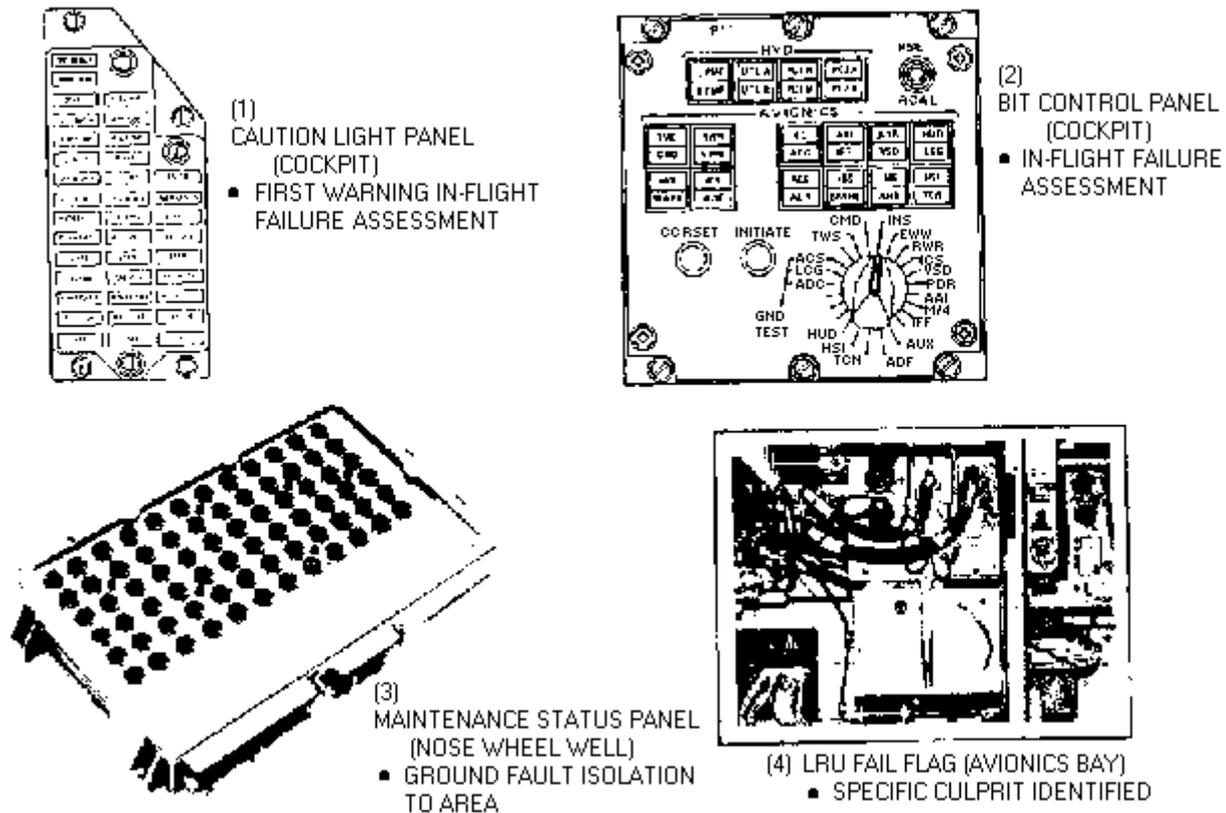
### Sight Gages

- Engine Oil
- L/R AMAD Oil
- CGB/JFS Oil
- CSD/IDG Oil
- Landing Gear Strut Pressure
- Brake Wear Indicator
- Hydraulic Accumulator Volume Indicator

With the engine events' history recorder, we are capturing critical engine events as well as events in the flight envelope that were in existence when these events took place. We are finding that this provides a very useful diagnostic tool beyond built-in tests. We can correlate what the airplane was doing at the time certain malfunctions happened. We have found that this provides significant information. With the F-18, we are using a mission computer and a maintenance signal data recorder and correlating fault indications with G-loads, pressures, outside temperature, stresses, vibration, etc. when the faults occurred. The correlation is time-phased and provides advanced diagnostics information. It also aids training and technical data development needed to support the weapons system.

Figure 3 shows the main built-in test indicators in the F-15. The standard cockpit caution and warning lights are on the upper left side. We have a built-in test panel that the pilot can use for some diagnostics. If a light comes on, the pilot can assess the relative degree of damage or degradation to any particular system. The panel is also used for ground induced or implemented built in test examination.

## F-15 Fault Isolation



**Figure 3**

On the lower left of [Figure 3](#), we have the status panel. This is located in the nose wheel well of the airplane. Each of these indicator lights notes a specific item that has been affected or has been diagnosed as being faulty by the built-in test. For the most part, the diagnostics are in English.

In the lower right illustration, there is a small circle in the middle of the that contains a fail flag to substantiate what was seen on the avionics status panel. This provides a back up system to ensure that failures indicated on the monitor panel or the avionics standards panel are really true. With the combination of these three indicators, the system is fairly reliable.

In terms of on-condition maintenance, we have:

- Minimum schedules maintenance;
- Minimum time change items;
- Visual cues and built-in-test;
- 4-one hundred flight hour phase cycles;
- No external power needed for pre/thru flight requirements; and,
- Engine inspection performed installed.

In the 80s, we went through the Multi-Stage Improvement Program (MSIP) where we took the F-15 C/D and made enhancements as shown in [Figure 4](#). We added a significant amount of capability to the airplane. One improvement is the Joint Tactical Information Distribution System (JTIDS), which allows airplanes to communicate with each other, with the ground, and with other AWACS-type operations in a secure mode. JTIDS is being promoted as a means of getting maintenance information down at the ground so when the airplane lands we'll have the parts necessary to fix it. We've added digital capabilities, digital electronics in the programmable armament control set and

increased the digital electronics in the electronic warfare update.

### F-15 C/D MSIP Enhancements

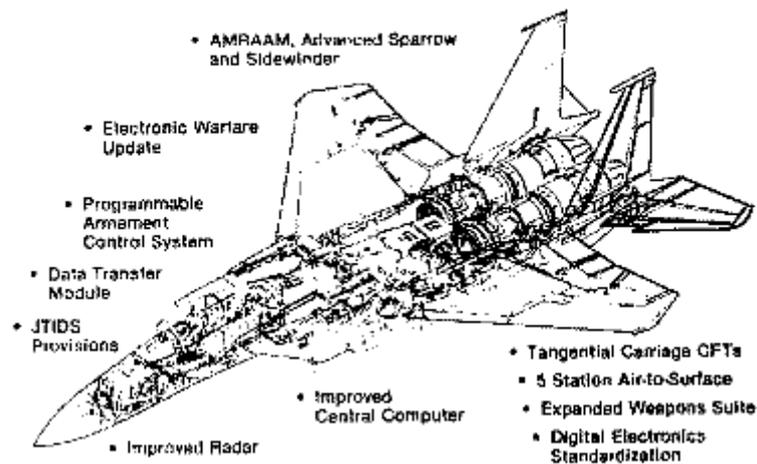


Figure 4

In the configuration shown in [Figure 5](#), we now have a 81,000 pound take-off gross weight aircraft, with a minimum of structural modifications. The principal modification is to the main load carrying structural members around the engine bays and the landing gears' attach points. We made the canopy, glass and the windshield totally replaceable at organization level. The windshield before was an intermediate level job because of the tolerance on the holes. We made the glass thicker, loosened the tolerances and got rid of the sealing. Also, we used something called double-backed tape so we could change the windshield in an hour.

### F-15E Enhancements

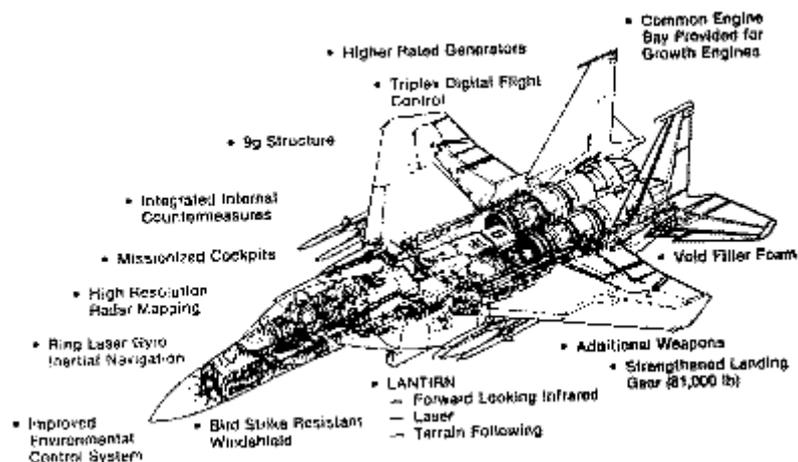


Figure 5

Next, I would like to address enhancements being proposed in order to carry the F-15 into the next century. The Air Force has indicated it has enough combat capability in the airplane. Now we want to redesign the airplane from a Reliability, Maintainability, Supportability (R/M/S) standpoint. This review provides an opportunity to look at 15 - 20 years of flying experience and design in a significant number of supportability options that were not incorporated the first time. This translates into human factors type issues in terms of reducing the number of people necessary to support the airplane, the number of skills necessary to work on the airplane, and training time requirements.

As part of this effort, summarized in [Figure 6](#), we are reducing the Inertial Navigation Set in size and

eliminating the depot maintenance repair requirements. We have improved the Mean Time Between Unscheduled Maintenance Actions (MTBUMA) from 140 to 500 hours.

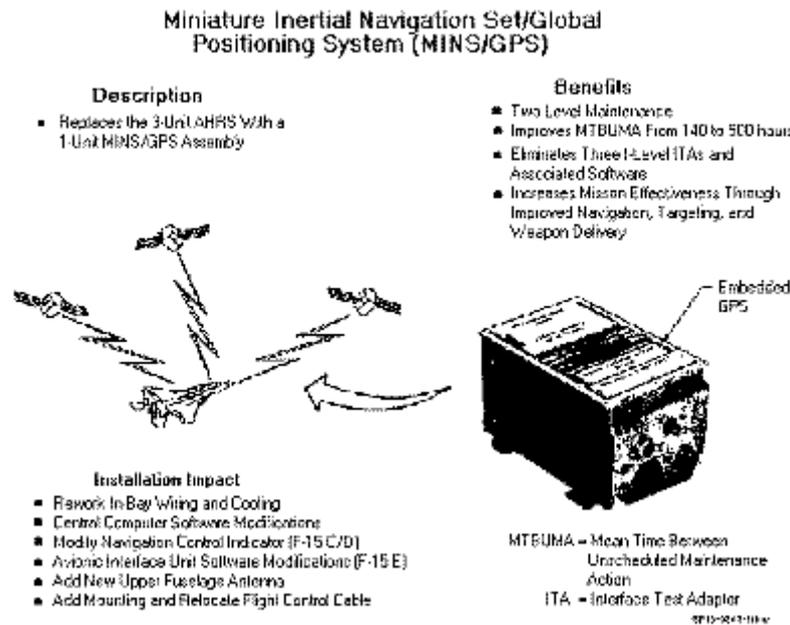


Figure 6

The Very High Speed Integrated Circuitry (VHSIC) improvements to the Programmable Armament Control Set (PACS), as shown in [Figure 7](#), are really at the heart of many things that happen in this airplane. We have improved reliability and we do not have the significant training requirements that we had with weapons loading crews in the past. Weapon loaders do a good job, but it's hard to carry check lists and hoist 2000 pounds of bombs. We have programmed a lot into memory on the PACS. Checklists and the verification of loads software are loaded in the PACS. We have reduced scheduled maintenance, support equipment at the O-level, scheduled maintenance by 51,000 hours a year and unscheduled maintenance by 9,000 hours a year. We also have allowed for growth for additional weapons.

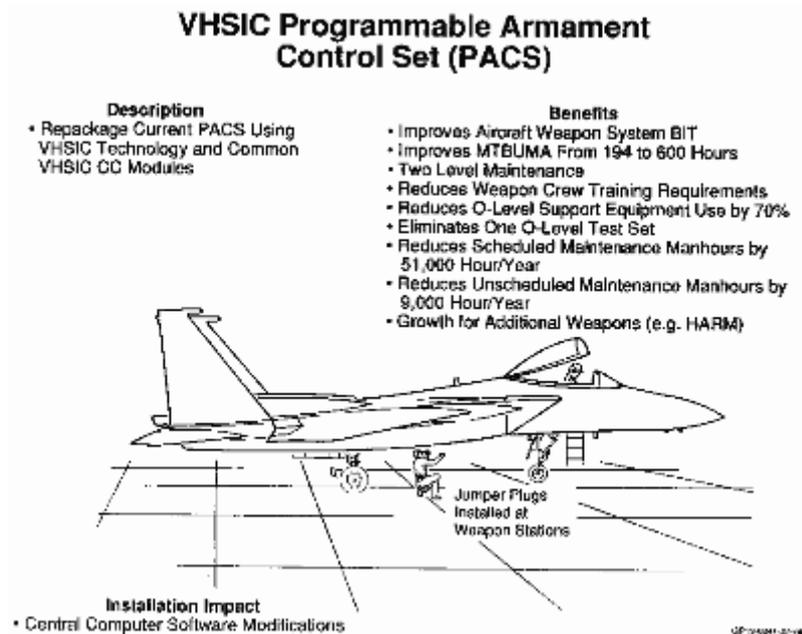
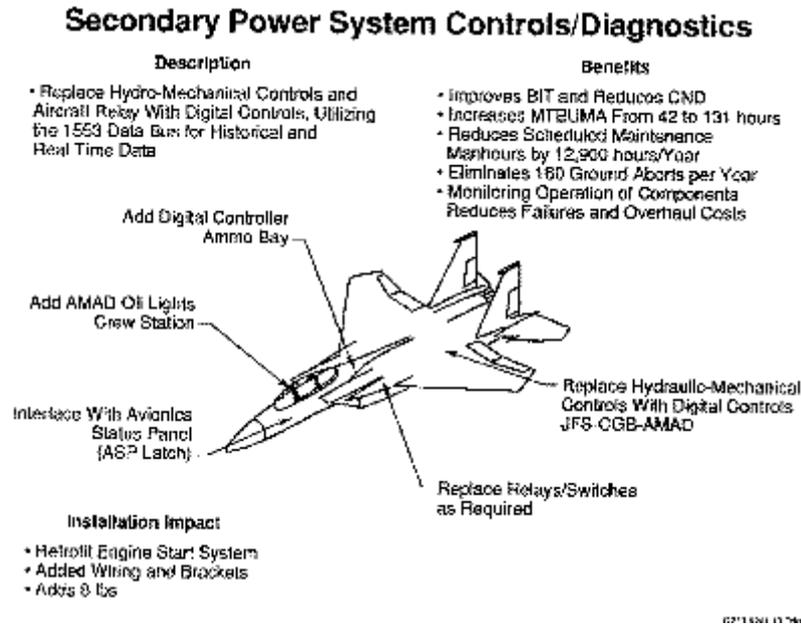


Figure 7

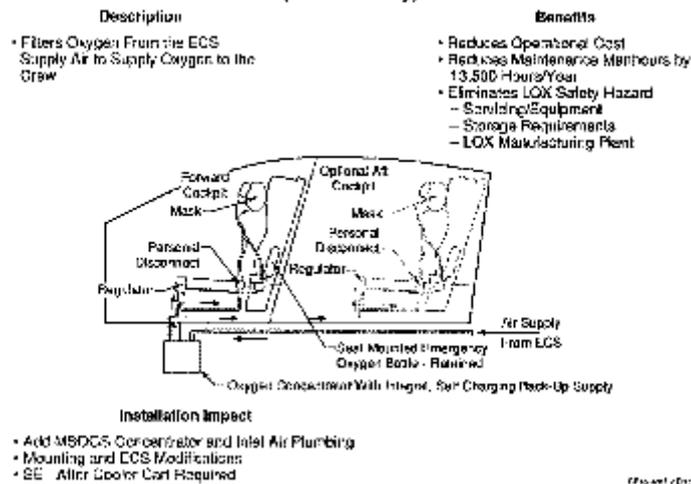
The big eaters of man-hours are non-avionic systems. These systems have problems that are hardest to diagnose. As an example, as shown in [Figure 8](#), we are redesigning the Secondary Power System Controls. We are replacing many mechanical components with digital circuitry and electronics. Accordingly, we are increasing the performance and fault-isolation capability within the secondary power system. There is much time involved in repairing the secondary power system on the F-15. We are trying to make significant enhancements. We are integrating secondary power readings with the avionics status panel in the cockpit. This should allow a better readout from the cockpit before we begin opening secondary power panels.



**Figure 8**

We are particularly proud of the Molecular Sieve Oxygen Generation System (MSOGS). In a wartime situation, use of liquid oxygen poses a number of logistics problems. The MSOGS design, as shown in [Figure 9](#), eliminates the requirement for liquid oxygen at a forward location. We do not have to change a converter and we do not have scheduled maintenance on the converter. That translates into a cost saving of 13,500 maintenance man-hours a year. By eliminating the liquid oxygen, we reduce the operational cost of deployment.

### Molecular Sieve Oxygen Generation System (MSOGS) (F-15C/D Only)



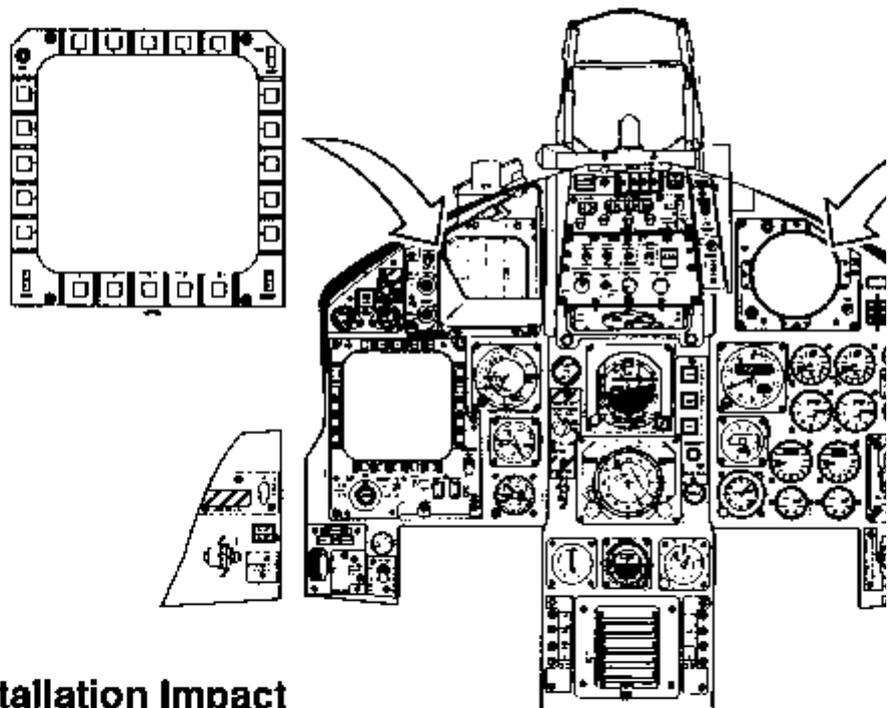
**Figure 9**

With the F-15 D/C Cockpit Upgrade, as shown in [Figures 10](#) and [11](#), we are addressing pilot workload and obtaining some maintenance savings. We are getting rid of less reliable cockpit instruments and replacing them with 6" color displays. We have had to redesign some things for the ejection envelope, redesign the crew station, and establish parts commonality with the F-15E. Pilots of the F-15E and weapons systems officers are quite pleased with the cockpit layout. With the upgraded weapons capability, Electronic Counter Measures (ECM) capability, and improved radar system, however, these two people are extremely busy. There are many things to do when flying at Mach 1 and watching all those instruments. Workload can be a problem. Through cockpit upgrades, we have managed work load a lot better.

## F-15C/D Cockpit Upg

### Description

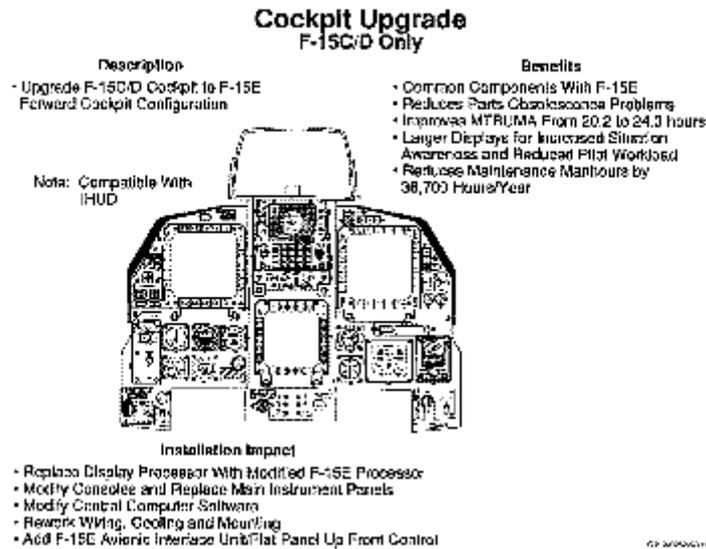
- Replace ANMI and TEWS Displays With F-15E MPDs
- Corr
- Redi
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- Redi  
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### Installation Impact

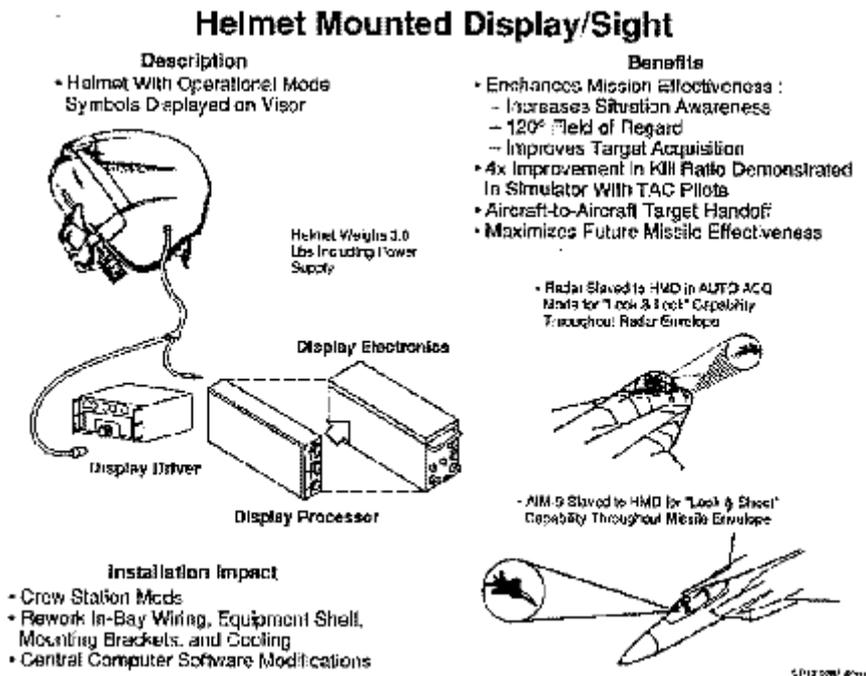
- Replace Display Processor With Modified F-15E Processor
- Replace Main Instrument Panels
- Modify Central Computer Software
- Rework Wiring, Cooling and Mounting
- All Redesigns Following F-15 Vision Loss an
  - Replace Eng
  - Remove AD and EHS!

Figure 10



**Figure 11**

Through the introduction of helmet mounted displays, as shown in [Figure 12](#), we are addressing pilot workload and enhancing the weapons capability of the airplane. We are looking at a 4x improvement in kill ratio as demonstrated in the simulator with the attack pilot.



**Figure 12**

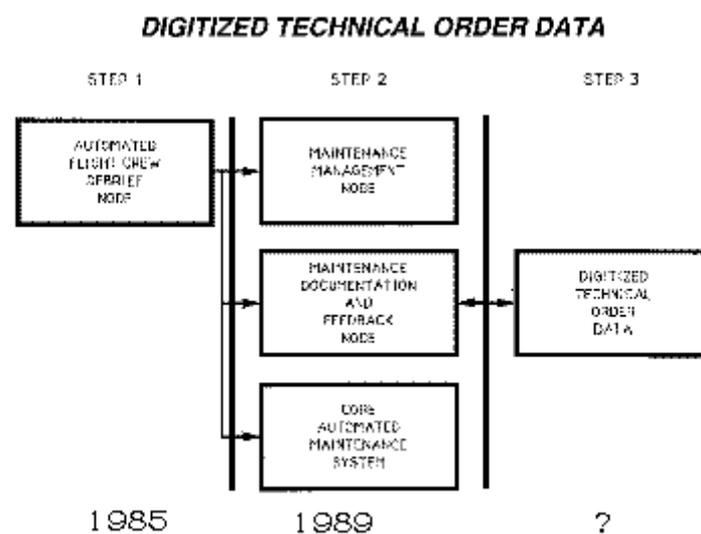
Below is a brief summary of Reliability, Maintainability, Supportability (R/M/S) enhancements on the F-15:

- Provides more two level maintenance;
- Reduces support equipment;
- Reduces maintenance manpower;
- Improves logistics;

- Improves deployability; and,
- Increases mission readiness.

One of the biggest problems facing the military concerns the skill of the maintenance technician and procedures for instruction. We are fielding systems that are capable and that really work; however, these systems have been designed by teams of Ph.Ds. We expect people with G.E.D. Certificates and high school diplomas to fix them. That combination does not necessarily work well. We are working on enhancements to make the job of the technician who has to maintain these systems a lot easier. For one thing, we are ensuring that he gets the technical data he needs to do the work.

As shown in [Figure 13](#), the Digitized Technical Order Data system is our proposed approach to providing necessary information at the technician level. The first step is called Automated Flight Crew Debrief. One issue here is data retrieval speed. Storage requirements are a big problem for us. We do not have the real estate on these airplanes to install mini-vaxes and micro-vaxes. Screen resolution is a big problem. Components have to meet MIL standard specifications.



**Figure 13**

In designing the data base for the Digitized Technical Order Data system, the following considerations and goals have been developed:

Consider:

- Data retrieval speed;
- Storage requirements;
- Screen resolution;
- Cost; and
- Producability.

Goal:

- Use existing data base;
- No author inputs;
- Maintain one data base; and,
- Exchange standards (MIL-STD-1840A).

Key issues to be addressed relative to Digitized Technical Order Data system were:

- Graphics modifications/simplifications;

- Size of the database;
- Type of data to be stored;
- Hardware configuration; and,
- Format/presentation of data.

Figure 14 illustrates the input content elements comprising the Digitized Technical Order Data system. Figure 15 illustrates the intended output. When a technician goes to an airplane to remove a left aileron actuator, we want him/her to have all the information associated with removing that particular item. This capability is provided by means of the Commodity Class Technical Order and Repair Assessment Tool. We can interrogate the data base and pull out the fault isolation procedures, the removal and replacement procedures, and the spares ordering information. In other words, we can retrieve everything associated with that item. We can give the technician everything he needs to do his job as long as he can figure out what job he has to perform.

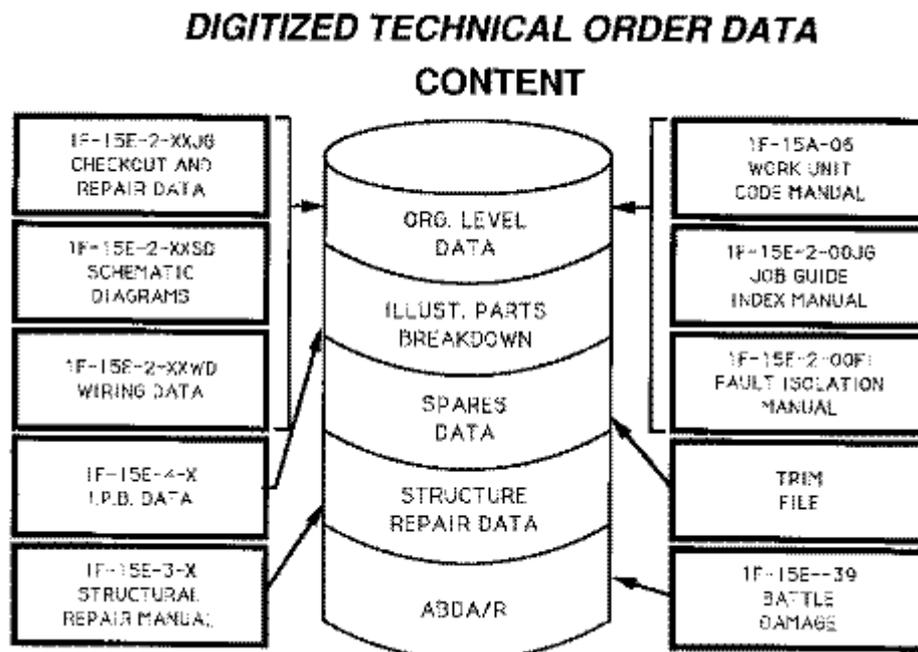
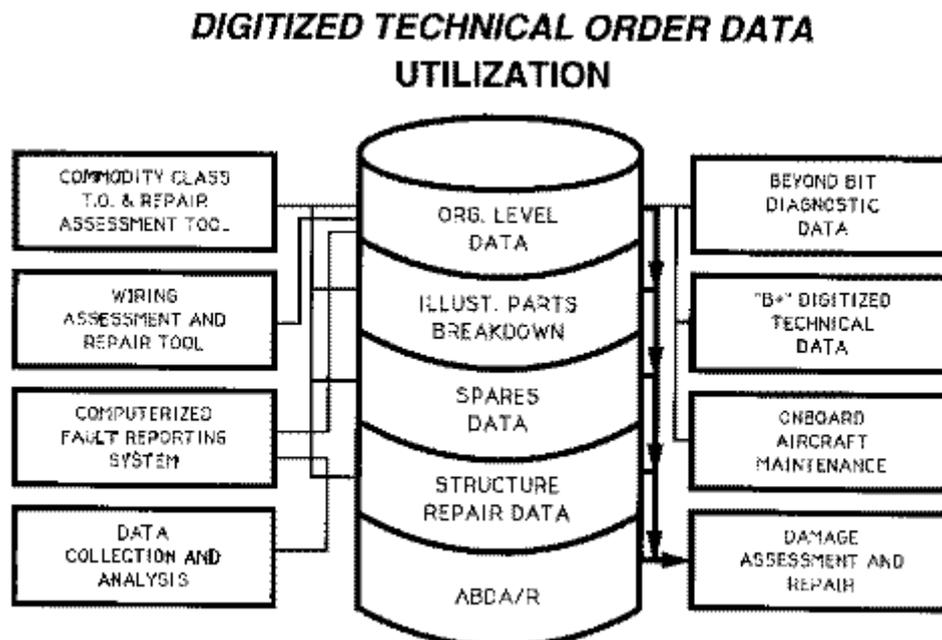


Figure 14



## Figure 15

The second output is the Wiring Assessment and Repair Tool. Wiring is a big problem on any airplane. You add a wire here and there, but you never take a wire out. You have these bundles of wires, some of which may do something, some of which may not. At one time, we printed wire identification every eight inches. Then this was changed so that we print cable identifications at each end of the wire and at each connector. You might have a wire bundle that runs from cockpit to tail, but you have nothing in between that tells you what it is. The Wiring Assessment and Repair Tool is a computer based simulation that creates wiring diagrams on the fly, working backwards. We have all the information digitally that says what this pin does and that it is connected to this wire. This information is stored in one data base. Another data base stores information that this pin hooks to this box and carries this signal. We solve the problem by working backwards and accumulating all necessary data. Once we have identified what wire harness we're working with and have some idea of where the problem is located, we can get down to which pins to check. We can cover this in one to five pages of tech data. We can produce that tech data either on a computer screen or the technician can print it out and take it with him. We can do this for the entire airplane. This is a significant enhancement.

The Computerized Fault Reporting (CFR) system uses a three-step process for the air crew debrief. The pilot answers a series of questions, "What were the avionics status panel latches? What were the caution lights?" The crew chief captures the exceedance counter's reading and the maintenance status panel readings. All of this information is entered into the computer program. The computer has the tech data fault logic built in. It generates a 23 digit fault code number that identifies the affected item and the tech data necessary to fix the item. The computer generates the work order. It tells the technician in the shop that he has this problem. It further describes what he must do. It also orders the parts from supply. When the part is removed from the airplane and goes into the intermediate repair shop or is sent off base to a depot for repair, it too is tracked. We thus have a cradle-to-grave idea of what has happened to that part and to that airplane from the time the pilot was debriefed until the problem was fixed. Additionally, we can track the history of the airplane. We update the Air Force data system through a file server. The system allows us to keep track of configuration by aircraft because all items are controlled by serial number.

The Data Collection and Analysis is merely an expansion of the CFR. We keep track of everything that has happened to the airplane in terms of overloads and where the exceedance counters are positioned. Accordingly, we can plan scheduled maintenance events more coherently.

We are still defining concepts beyond bit diagnostics. I do not want you to believe that it is currently available, however. Conceptually, we can look at the bit routines that are documented in CFR and we can look at the diagnostic data recommended to fix those problems. We can look at what really happened to the airplane and we can see what is working and what is not working in terms of fault data and technical data. We can make rectifications to the data and provide better beyond bit indications or trouble shooting indications. Additionally, we can interrogate ambiguities in the fault tree using what-if analysis.

Next, I want to address B+ Digitized Data. DoD has a requirement for Type-C data. Type-C data is merely all technical data controlled or contained within a relational data base. We are working in the military on what we call B+ data. We are a long way from getting all these data into a relational data base. We are a long way from getting it all digitized. B+ data represents a transition between data as we know it today and true digital data of the future. The next feature is Onboard Aircraft Maintenance. Recent technology allows us to store large amounts of data in relatively small spaces on airplanes. We are working with DoD in defining what goes in the onboard data base. We intend to load all weapons loading checklists. We plan on storing all the turn-around and conditional maintenance information so these maintenance actions can be done without auxiliary tech data, using the airplane onboard data base resources themselves. Also included will be normal servicing information, airplane configuration information, diagnostics data, and computerized fault reporting. We will feed the data base digitally by using the data transfer modules on the airplane.

We have learned a lot concerning damage assessment and repair from the Israelis. The key to damage repair is not necessarily the repair itself, but finding out what to repair. If you can assess the damage in a timely fashion, you have more time to repair it. The key is finding out what's wrong and determining if you can fix it. In damage repair, we interrogate the engineering data base to identify, by fuselage zone or station, where the damage is located. We then can look at the damaged area and assess where the damage is found. We have divided the airplane into ten inch cubes because of the amount of data and the density of the airplane. Ten inches contains enough information to give a rapid computer turnaround. Once you have identified the affected cubes, you can put together, by fuselage station and butt line, a three dimensional designation of the damage site. Then we can interrogate the file and get a picture. We can compare what the site is supposed to look like versus what it does look like. Finally, you can interrogate the automated data parts listing system to determine exactly the items that need to be replaced in the airplane.

## INFORMATION MANAGEMENT "LIKE NEVER BEFORE"

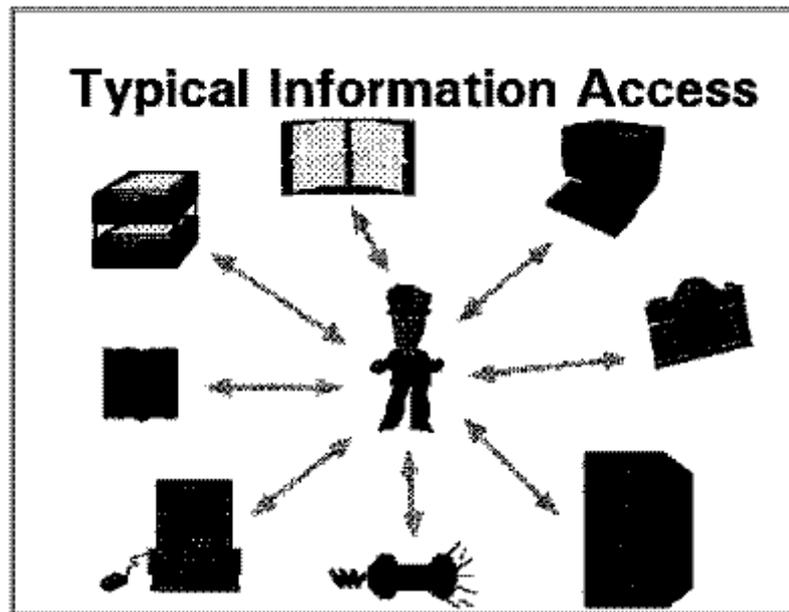
*Paul Singleton  
IdentiTech, Inc.*

IdentiTech has a distinct philosophy, different from that of other companies where I have worked. Most of us here today have been through the early proprietary computer days wherein end users were not considered in software design applications. "What's wrong with that user? How come he can't figure out just by looking at the screen what he's supposed to be doing?" At IdentiTech we took a different approach from that used previously by the software industry when we began our system. Initially we developed an imaging system designed to remove the paper problem inherent in the requirement to scan and store paper files and to retrieve them for display, print or fax.

Before we did any user interface design, we did something unique in the software industry. We prepared what we called "dream sheets" and met with end users. We told them "I don't care what you think can or can't be done. We want you to tell us how you would design systems. What kind of capabilities do you need? What are the features and the issues you want to be addressed?"

We used this information to design a software system around specific features that users wanted. We made many of our programmers fairly upset at us because the rule simply was "I don't care what you think should happen, this is what we're going to do." And it is a different approach. I will describe for you some of the results.

First, I would like to summarize some of the problems that you deal with in a human interface. [Figure 1](#) shows that information comes in from a wide variety of data types. Look at the typical workplace today. You are getting paper files, correspondence and all other kinds of documentation piled on your desk. In some cases, you have manuals accessible from a dumb terminal attached to a main frame. You may have photographs. You may have to plow through multiple filing cabinets to find what it is that you're going after. You may have audio, telephone or other kinds of sound communications. Typically there are multiple PCs in addition to your dumb terminals. You may have video that you want to capture. You may wish to see a training film or make a tape of a seminar you missed. All kinds of information needs to be accessed by the user.



**Figure 1**

As we reviewed and summarized the "dream sheets," these are the problems that users told us they wanted solved.

- Critical information is in multiple formats: paper, data, CAD, video, etc.
- Users not trained on computers need easy access to applications.
- Users have difficulty in training for multiple software applications.
- Cumbersome user interfaces exist on most software applications.
- Multi-lingual users need easy access to software applications.

Given these kinds of problems, the users told us they wanted to simplify the entire information management operation. They wanted to have a system created with the following characteristics:

- Multi-media storage & display system.
- Intuitive easy to use interfaces.
- One user interface for all applications with on board help (video/voice).
- Multiple human interfaces: keyboard, point and click, touch, voice.
- All system text in multiple languages: menus, buttons, help and error messages.

Users wanted human engineered software that took all of those pieces of data and presented them in one simple computer screen with a graphical user interface (GUI). The interface would allow a variety of access approaches. With the GUI system that IdentiTech designed, every textual entity in the system (menus, buttons, help screens, error messages, etc.) is editable and modifiable by the user himself in multiple languages. The entire system operates that way.

The major features of IdentiTech's solution are shown below:

- Open architecture.
- Multi-media software toolkit.
- Customizable user front end.

Any information you want will be accessible.

Here are some of the factors our users wanted in our software design:

- Not designed by hardware vendor to help sell more hardware.
- Not designed by programmers to be cryptic and difficult to use.
- Designed strictly from end user "Dream Lists."

The first design element that everybody wanted was open architecture.

- No proprietary hardware of any kind.
- Off-the-shelf hardware & software.
- Use of existing hardware and applications.

The next design element wanted by end users was adherence to industry standards. They wanted whatever data they were viewing to be in unmodified formats. Should something happen to the vendor, they would not be stuck with formats no one else can read or work with.

Users wanted to use standard off-the-shelf relational data base engines. They wanted an SQL data base engine because they wanted to avoid proprietary flat files or other kinds of data engines.

- Gupta's SQLBase, Oracle, Sybase, DB2.
- Accommodate multiple DBMS platforms: PC, UNIX Mini, Mainframe.
- From one to hundreds of nodes.

Finally, users wanted communications protocols to be industry standard and be able to talk to every kind of hardware.

- Ethernet or Token Ring.
- Novell, Banyan VINES, 10 Net, [LAN](#) Manager, AT&T Star LAN, Arcnet, etc.
- Wide Area or Enterprise Wide: Multiple DBMS & Optical Servers.

With IdentiTech's subsequent design, you can connect with just about every computer box in existence. You can run applications from a variety of platforms, whether it be PC DOS, UNIX, BMS or MVS. You have the flexibility to run anywhere from a single station to hundreds of work stations.

From the multi-media side, IdentiTech's system is designed to store entities as objects and not be concerned about data type. IdentiTech can handle:

- Scanned images.
- Spread sheet files.
- Word processor files.
- CAD drawings.
- Color images.
- Full motion video.
- Sound.

The system is designed to store multi-media as objects and retrieve them by means of a very simple interface.

Users also wanted the ability to create their own work-flow environment. The system allows you to automate manual procedures, paper procedures, or electronic forms. The system uses just about any fourth GL interface on the market. You can use whatever you like best to design your own front ends and make it as simple as possible.

The system was designed to have full audit trail capabilities so that it tracks everything. It has field level security control, with audit trail features built-in. Data fields are designated by the System Administrator. He decides how many data fields a given user can view, or whether the given user can modify, alter, or delete specific data fields. If a user is allowed to modify a given data field, the system has full revision control tracking, so that any changes made automatically bump up the revision level. New copies of the data field are automatically made so that a cumulative review of changes can be obtained.

An example of an audit trail application of IdentiTech's package is at the Johnson Space Center in support of the automated briefing system for the Orbiter Project. All data entities are submitted as objects into the system and pulled together as a folder. Design engineers can go in and make

multiple modifications at one specific object in that folder. When they are done, the System Administrator says when it is ready for release. He pulls all the latest versions and automatically moves them across the link from Downey, CA, to Houston, TX. NASA gets an E-mail message that tells them they have a briefing. The NASA Administrator pulls up the briefing and approves it. He then would send it to responsible design engineers and other people in the review and approval loops. Reviewers can make their red-lines using the original data elements, CAD drawings or whatever method appropriate. Upon receipt and approval of coordinated review comments and incorporation into a master update, the revised master can be distributed to all parties concerned.

Summarized below is another application that illustrates for you how IdentiTech's system might work. IdentiTech designed, developed and implemented a pilot Material Data Safety Sheet (MSDS) system at the NASA Kennedy Space Center (KSC). The MSDS system was to allow NASA-wide access to the MSDS files, as well as incorporating the following features:

- Centralized MSDS database accessed through PC Wide-Area Network (WAN) or telephone/fax.
- MSDS images stored on optical disk at both central and local servers.
- Local systems able to store additional information: building schematics, training films, memos, correspondence, etc.

At the KSC site, MSDSs require dispatching to 200 different centers around the Cape. If you know the rules, you don't deliver the product without the MSDS. KSC wanted to solve what previously had been a major copying and distribution problem. They created a centralized data base accessed through either a PC-wide area network or through touch-tone telephone and fax. The MSDSs are stored on optical disks. For the NASA-wide system, they will have access to a central repository. Also every site will have its own local capabilities and features.

Figure 2 presents a diagram showing how the system is to be implemented. First, you have a Central System, a Local Area Network (LAN) with a data base server, and storage systems that function as the repository for the shared information. Those things common among all agencies or centers are stored on the Central System. Next, using a WAN Bridge and using satellite links, the system ties in with Local Systems that also may have their own unique data bases and storage servers. Access to that information can come from any PC.

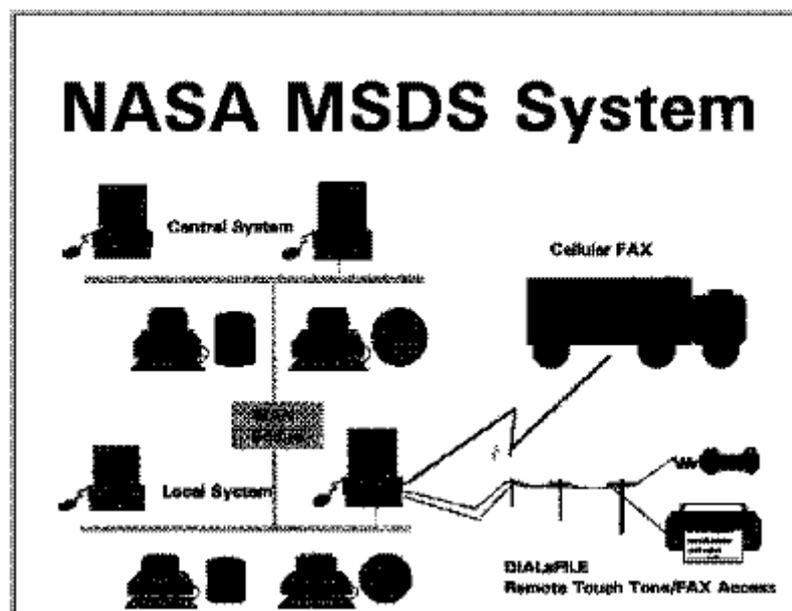


Figure 2

Our system has no limitation on the number of work stations that can attach to the servers. For example, the NASA Johnson Space Center (JSC) site will have at least 3000 nodes that can access

information across a large WAN. Therefore, anyone on the network can access the information throughout the data base. They can retrieve any files they need.

Since there will be many people who do not have PCs nor access to the WAN, a DIALaFile feature has been added. This feature is like the one you use when you reach your bank by touch-tone telephone. You dial in, give your account number, password, query your account and make transactions, etc. Correspondingly, a person at the remote site can pick up the telephone and dial the system. A recorded voice will walk that person through a menu system. The remote user uses the touch-tone telephone to query the data base. Output is then faxed automatically to the remote user's site.

Additionally at KSC, cellular faxes will be installed in emergency vehicles so that a dispatched emergency vehicle enroute can have relevant MSDS information forwarded by fax (e.g., toxic spill problems). Also, corresponding site plans can be faxed to the emergency vehicle as applicable to the given emergency. This feature allows emergency personnel to have relevant emergency information available upon arrival at the site.

There are a variety of other applications. The system is designed for just about any application a given end user might want. Another example we have developed is called Maintenance Planning and Control (MPAC). In this example, images are integrated into an existing application. The person on the shop floor can walk up to a machine and do a query through the data base. He can get parts information or information on the subset of components he's concerned about. By hitting one key, he can retrieve all corresponding manuals, Material Safety Data Sheets, CAD drawings, schematics, diagrams, photographs or parts explosions. All information is available by simply hitting one key.

In summary, I would like to advise you that in 1990 IdentiTech was ranked by *Dataquest* as one of the top ten companies worldwide for number of work-group imaging installations. This means IdentiTech is one of the most experienced full service data and image processing software vendors in the market.

IdentiTech is transforming existing operations into systems so practical and powerful that it is revolutionizing business. This is just one reason the industry predicts the image processing market will exceed \$2 billion by 1994.

IdentiTech provides a complete range of services to meet specific needs of OEMs, VARs, government agencies, and corporate accounts worldwide. The services include standard maintenance, technical support, consulting and training. IdentiTech offers continuing education and training on a regularly scheduled basis. The company also promotes the integration of third-party applications and maintains a list of integrated solutions from its distributors.

I hope that my presentation today has generated additional ideas in your group as to ways in which image processing systems can be of value in maintenance and inspection programs.

## THE MANNEQUIN COMPUTER PROGRAM

*David Rome  
Humancad*

Humancad is a software company that is a subdivision of a larger company called Biomechanics Corporation of America. Biomechanics Corporation is a publicly traded, ergonomic consulting company that does consulting for some of the Fortune 500 companies, such as Grumman, Lockheed, Steel Case, Sikorsky Aircraft and others.

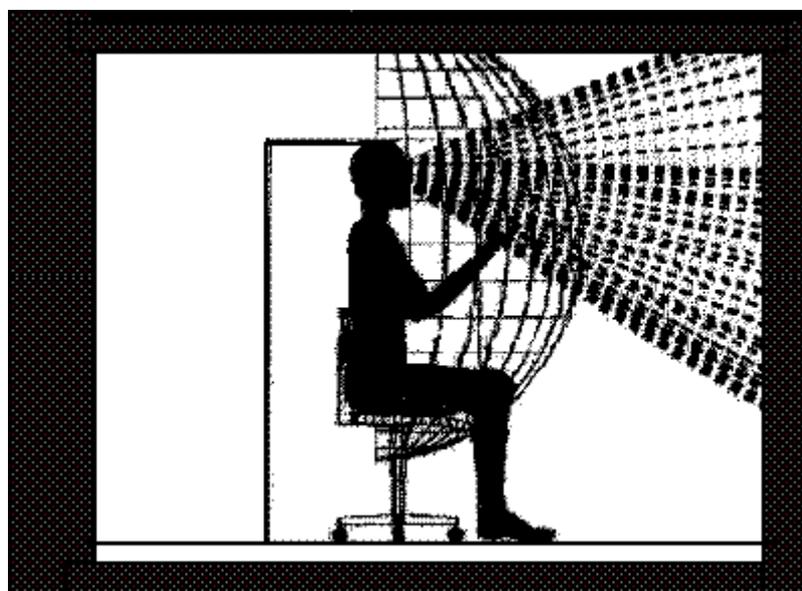
Humancad developed *Mannequin*, our human computer-aided design package, originally as an in-house tool. We soon realized that there are millions of PC CAD users who are using CAD and designing everything from hand tools to aircraft. None of these PC CAD users were taking human fit into consideration in their CAD design. The *Mannequin* program helps overcome this problem by

incorporating ergonomic concepts into the design process. The *Mannequin* program, an analytical design software package, is simple and easy to use.

The goal of ergonomics is to minimize incompatibilities between job requirements and human capabilities. The ergonomic method focuses on improving aspects of the workplace, work method, and tools so they complement the capabilities of the human body rather than fighting them.

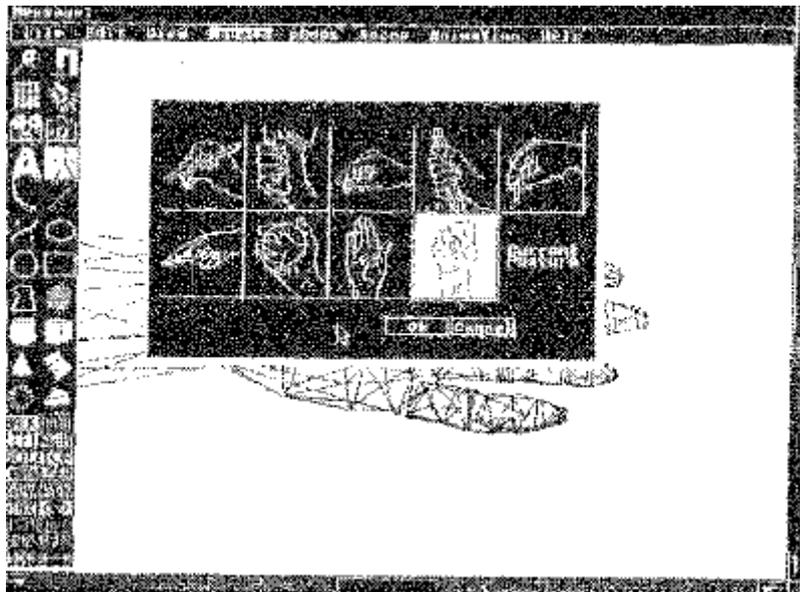
*Mannequin* is the first PC-based ergonomic drawing and design program that lets you put people into your designs and assessments. You don't have to draw them yourself. With *Mannequin*, drawing people is easy. You can create moving, full dimensional 3-D human figures of different genders, age (adult, child), different body types (heavy, average, thin), population percentile (2.5%, 5%, 50%, 95%, 97.5%) and any of 10 nationalities (USA, Britain, Germany, France, Sweden, Poland, Hong Kong, India, Switzerland, or Japan) with just a few clicks. Using extensive ergonomic data, these figures can see, walk, bend, reach and grasp objects.

Figure 1 displays a *Mannequin* output screen showing maximum vision and range of motion for a seated figure. The entire *Mannequin* can be manipulated down to the joints of each finger. However, *Mannequin* can only do what real humans can do. For example, heads cannot be rotated 360 degrees and elbows cannot be bent backwards.



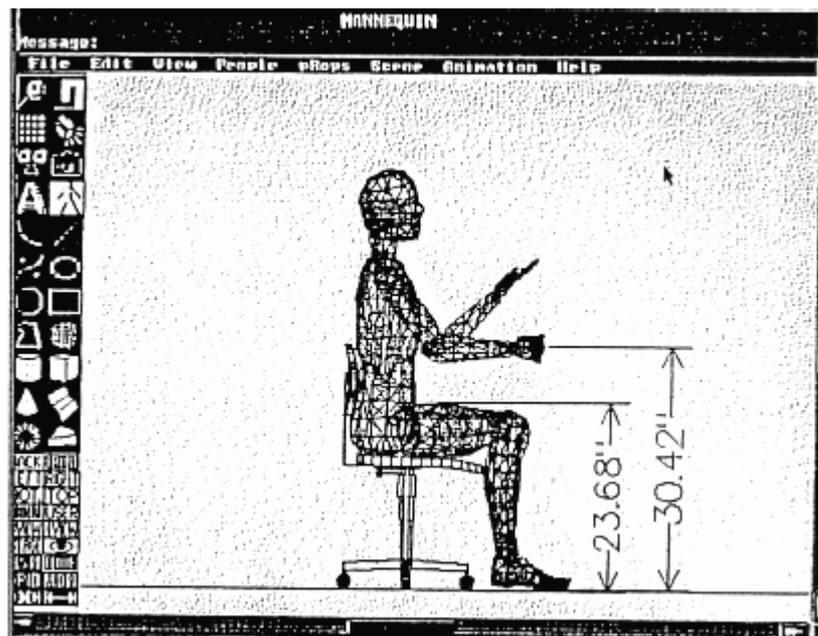
**Figure 1**

The hand is manipulated similarly to the whole body. As shown in [Figure 2](#), you select a hand starting posture closest to what you need and then move each individual finger. This can be used to test specific tools for human fit (e.g., guns, drills, wrenches, etc.).



**Figure 2**

Figure 3 illustrates how *Mannequin* is being used to determine leg clearance for a desk. Although *Mannequin* is capable of using both metric and English units, in this example the output is represented in inches and decimal.



**Figure 3**

Another unique feature of *Mannequin* is the torque calculator. This feature allows you to input a load (how much weight the person is lifting) on the person's hands and calculate the torques (forces) on the different joints of the body. Figure 4 displays the output of torques on the different body joints and presents them in both tabular and graphical forms.

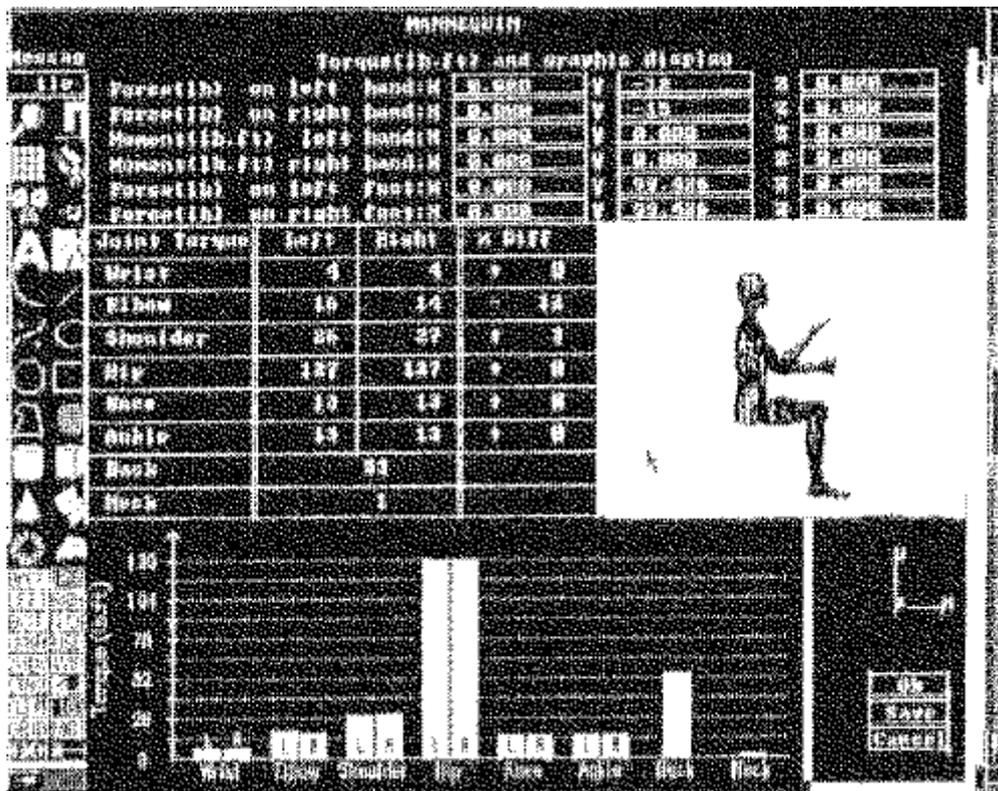


Figure 4

Import your workstations' products into *Mannequin* and test them for "human fit." Or, export *Mannequin* into desktop published documents, CAD drawings, illustration programs, presentations, story boards and animation packages to add a dramatically realistic element to professional presentations. With *Mannequin*, you will achieve cost savings from improved productivity. From simple presentations to complex product development, *Mannequin* is the ergonomists' competitive edge.

*Mannequin* can work with most popular animation, presentation graphics packages, draw and drafting programs, and presentation graphics and desktop publishing applications:

- FLI for animation: *Animator*, *Microsoft MN Extension*.
- *Autodesk 3D Studio*, *AT&T Topas*, *Autodesk Animator Pro* and

*Grasp*.

- DXF for *Autocad*, *Generic CAD* and *Topas*.
- PCX for *Storyboard Live*, *Autodesk Animator Pro*.
- Publishing and draw program that use .TIFF, .EPS.
- Draw and drafting programs: *Corel Draw*, *Micrografx Designer* and

*PC Paintbrush*.

- File compatibility with presentation graphics and desktop publishing applications: *Harvard Graphics*, *Lotus Freelance*, *Ventura Publishing*.

The *Mannequin* package sells for an introductory price of \$499 and runs on any IBM or compatible 286, 386 or 486 computer with two megabytes of RAM. *Mannequin* will change the way your products are designed and inspired. Designers can increase productivity and quality from conception to prototype by including human fit in the design process. *Mannequin* adds the human touch.

## ADVANCES IN ARTIFICIAL INTELLIGENCE FOR AIRCRAFT MAINTENANCE

Mark Husni  
Naval Air Warfare Center

Today, I will present a brief overview of Artificial Intelligence (AI). While I'm doing this, give some thought as to how these principles and concepts might apply to your areas of expertise in aircraft maintenance.

## Artificial Intelligence

The word "Artificial Intelligence" came into being in the mid-50's. It was introduced by John McCarthy, a Ph.D. at M.I.T. AI is concerned with developing computer systems that produce results that we would normally associate with human intelligence. AI is that branch of computer science that is concerned with the automation of intelligent behavior. Major components of AI include natural language processing, robotics and expert systems (e.g., prediction, planning, diagnostics and design). AI picked up some speed in the 80's and has subsequently become fairly popular.

The two aspects of AI that we will look at today are expert systems (or knowledge-based systems) and neural networks. There are many other aspects of AI, but I will only touch on these two components.

There are a host of applications for which you can use AI. You have been talking about paperwork trails in aircraft maintenance and how mechanics are having a hard time with paperwork. We in the Navy are no stranger to paperwork. Accordingly, we've developed an AI tool to consolidate the paperwork, specifically in writing Purchase Requisitions for contracts. It has been a real blessing to the Navy.

Another AI application that might be of interest is the *Pilot's Associate* being developed by Lockheed for the new F-22 fighter. In essence, it is using a computer to replace the operator in the back seat who tries to help the pilot manage fuel, mission, and navigation requirements. Additionally, should the pilot engage a bogey, the system would advise him whether or not to go into battle.

## Expert Systems

I would like to first address that component of AI having to do with expert systems. I will address the theory and then describe an application found to be particularly helpful in the Navy.

Figure 1 shows the basic components of building an expert system, or knowledge-based system. You are trying to capture someone's knowledge or some specialized area of expertise. Once captured, you then are manipulating the acquired knowledge.

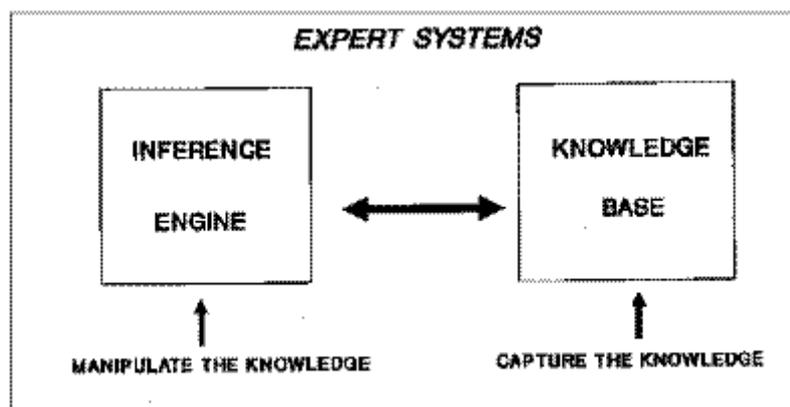


Figure 1

If we were going to develop an expert system on A&P maintenance, we would go to somebody who was expert in it. We would want to look for expertise represented by someone who has been doing it successfully for 20 years. Also, we would go to manuals and schematics. Essentially, we would acquire the knowledge from the best sources possible.

Once collected, knowledge would be represented by symbols, rules or frames. However, the most popular form of representation is IF/THEN rules (IF the oil flow is low, THEN the oil pump may be bad). If a given situation is present, then something else also must be affected.

What you do with the rules is another story. Typically you have what is called a search space. Your rules are organized in a logic tree sequence as shown in [Figure 2](#). You try to search through the logic tree and get to your answer. We start from the goal and work our way backwards by analyzing the symptoms. In attempting to determine if the goal is correct, the system backs up to the IF clauses of the rule and tries to determine if they are correct. This form of control strategy is called backward chaining.

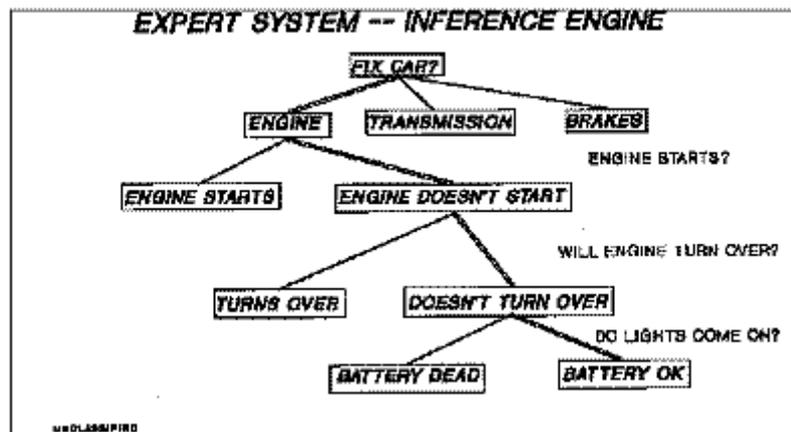


Figure 2

The other control strategy, forward chaining, involves identifying the symptoms first, then working forward to the goal. If an animal has a long neck and is a herbivore (plant eater), a quadruped (having four feet), and has a blackblotched fawn or cream coat, then it might be a giraffe. Forward chaining begins by asserting all the rules whose IF clauses are true. Given the facts it has already established, it then checks to determine what additional rules might be true. This process is repeated until the program reaches its goal or runs out of new possibilities.

As shown below, in building an expert system, you start by in-putting the knowledge. The system:

- needs large amounts of knowledge (the more, the better).
- represents the knowledge in symbols.
- reasons logically.
- can explain its own decisions.
- cognitive thinking--great for diagnostic problems.

The expert system is only as good as the breadth, depth and validity of the knowledge put into it. A well-developed expert system can explain its decisions. Also, many expert systems can indicate how a given conclusion is derived. Since expert systems reason logically, they have had the best applications in diagnostics.

[Figure 3](#) presents a crude model of avionics testing in the Navy. A sailor removes a black box from an airframe, puts it on the bench and connects a piece of Automatic Test Equipment (ATE). The interface between the ATE and the black box is called a Test Program Set (TPS). The TPS is very expensive and takes much development time. One TPS is needed for each particular black box on the airframe.

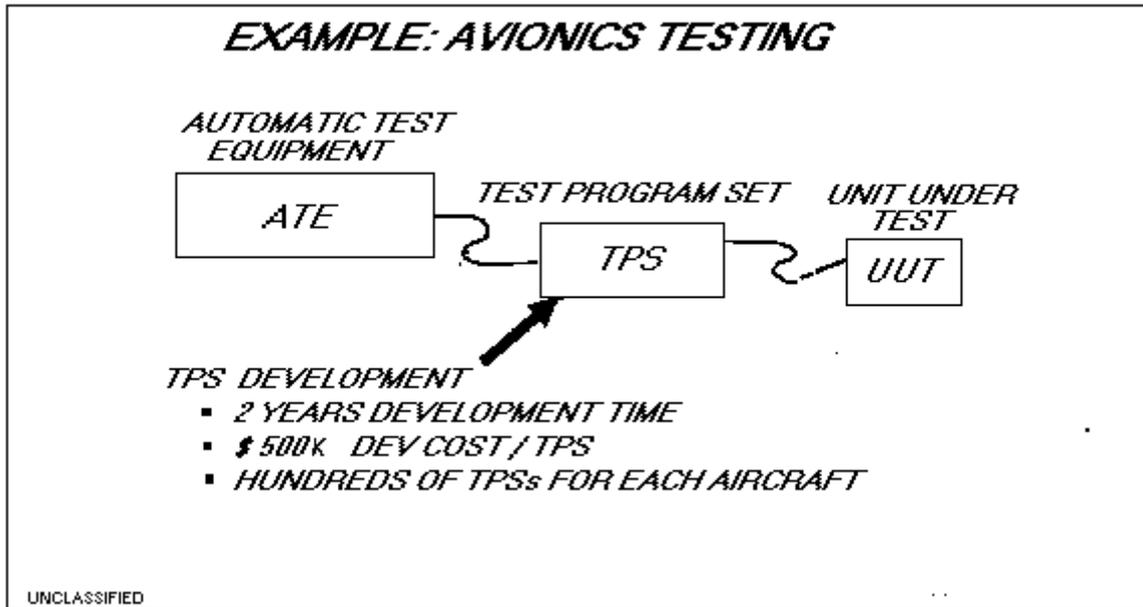


Figure 3

We found that we were able to save around \$30 million by applying expert systems in the development of the TPS. Rather than having engineers and systems analysts spend all their time programming the TPS, we can use our expert system to develop "casual rules." This process takes about a month as opposed to two years when human inductive reasoning is used to develop TPSs.

Figure 4 is a simplified model of the F-18 radar receiver. The box represents a given card in the radar receiver. The user can manipulate this box as he chooses. He can control what cards go in the receiver and can vary the INSIG input into the box as you would in using any Windows application. Output is qualitative rather than quantitative. It will tell you if something is high, low or good. It gives you probabilities. We display output with colors. White indicates there is a very low chance that the card is bad. Yellow means that there is a 70 percent chance the card is bad. Red means the expert system thinks this particular card is the bad one and should be removed.

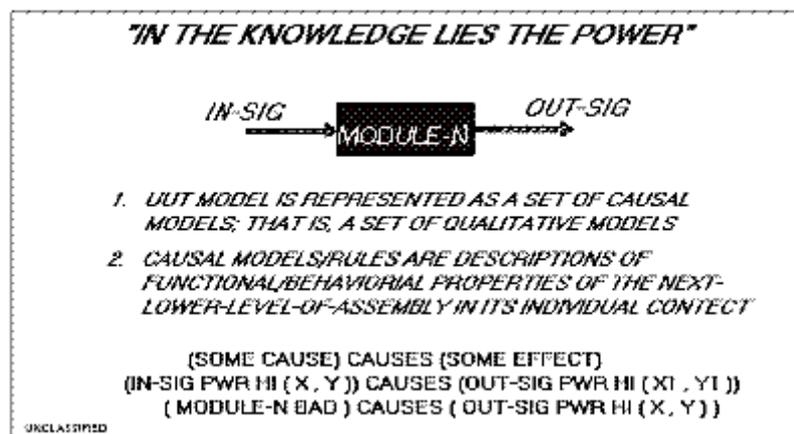


Figure 4

Figure 5 provides background as to how the expert system works. We use qualitative rather than quantitative reasoning. The IF/THEN rule really becomes a causal rule -- something causes some effect. If in the first module the frequency is bad, this causes the frequency to be bad in the module afterward. The other part of the knowledge base contains information:

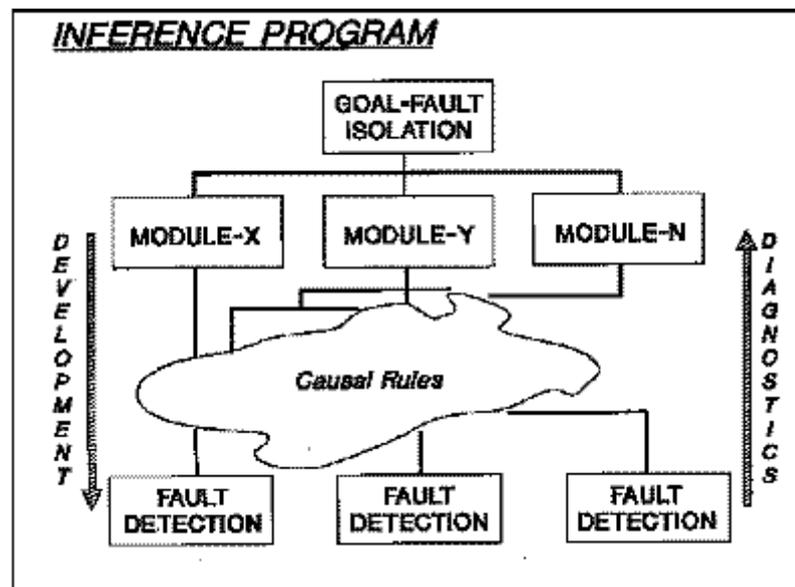


Figure 5

- List of tests with Test Numbers.
- Test Set-Up Descriptions.
- Test Data
- Test Costs
  - Built-in-Test = Negligible
  - Internal/Autonomous = Minimal
  - Manual Intervention = Heavy

Figure 6 shows the inference program for the radar receiver. In diagnostics, you start with the fault and you go up to find the fault isolation goal. This is an example of forward chaining.

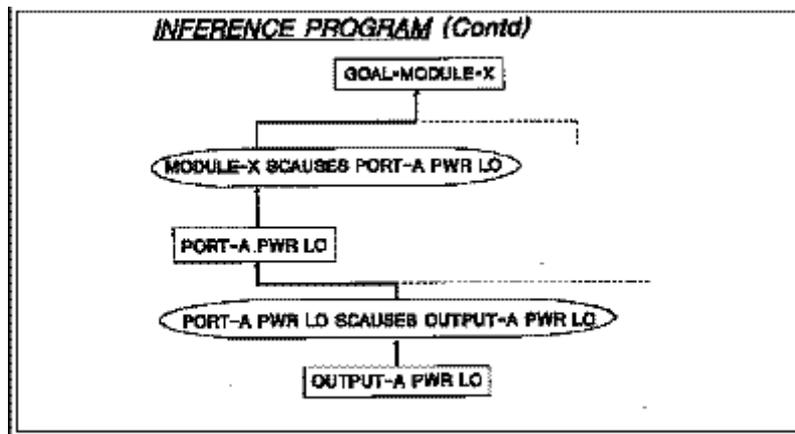


Figure 6

If the output was low on a particular module or card, it would go through the logic tree. The system would search for the module that was bad. That's how it goes about finding its solution.

**Neural Nets.** Some might say that what I have described thus far is not how humans really think. We don't say "If I need to go to the store, then I'll get in my car." We don't think in IF/THEN processes. Much of what we think is just intuitive.

Back in the late 70's and early 80's, teams of psychologists and computer scientists attempted to develop a new paradigm. This model would be based on the neuron structure of the brain. By

creating an artificial neuron and layering it, they found that they were able to adjust the weights. [Figure 7](#) and [Figure 8](#) provide a very crude model of a neural network and the basic theory behind it, respectively.

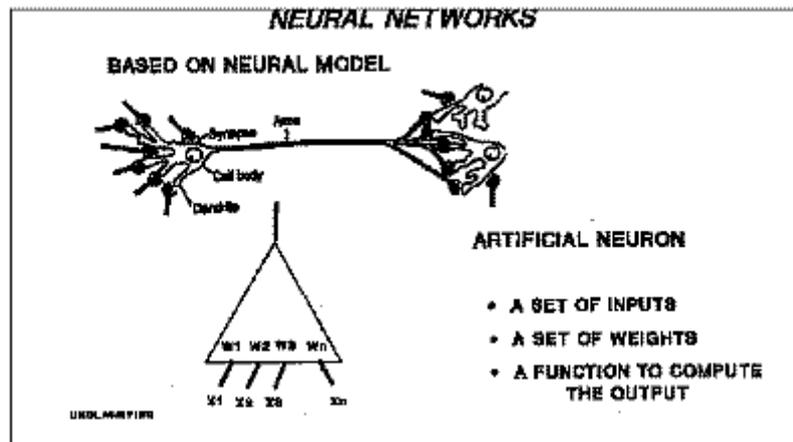


Figure 7

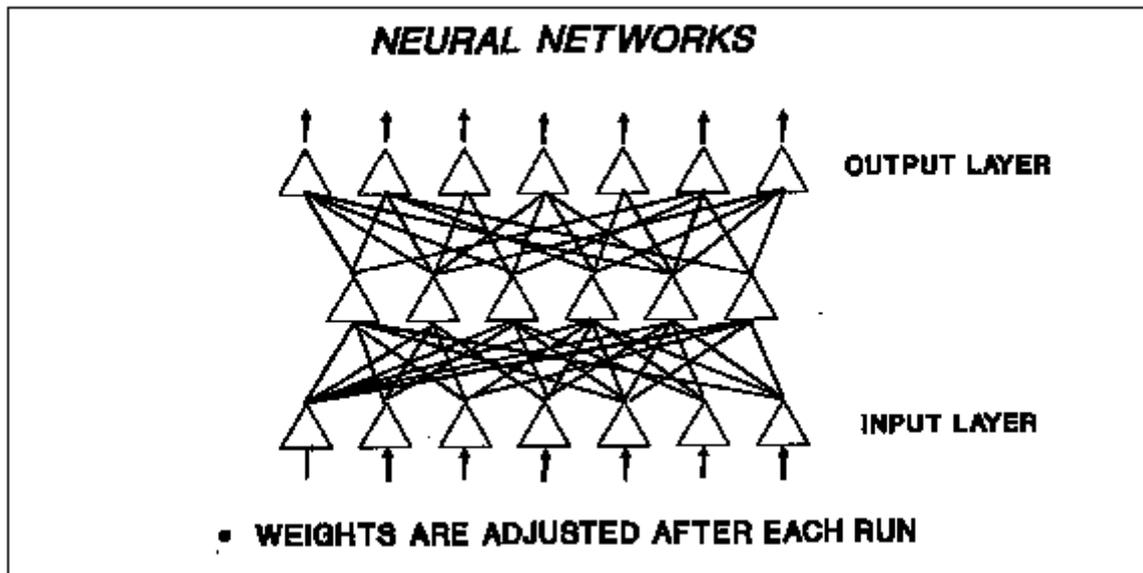


Figure 8

[Figure 9](#) shows neural net characteristics. A good neural net characteristic is that it is not brittle. For example, if you have an ink blotch on the "A," a human can recognize that it is still an "A." But the thing to remember is that you have to give the neural net the knowledge. You do what is called "training the neural net." You go through iteration after iteration to get the neural net to learn what an "A" looks like and what visual contexts of an "A" look like. It is a painstaking process.

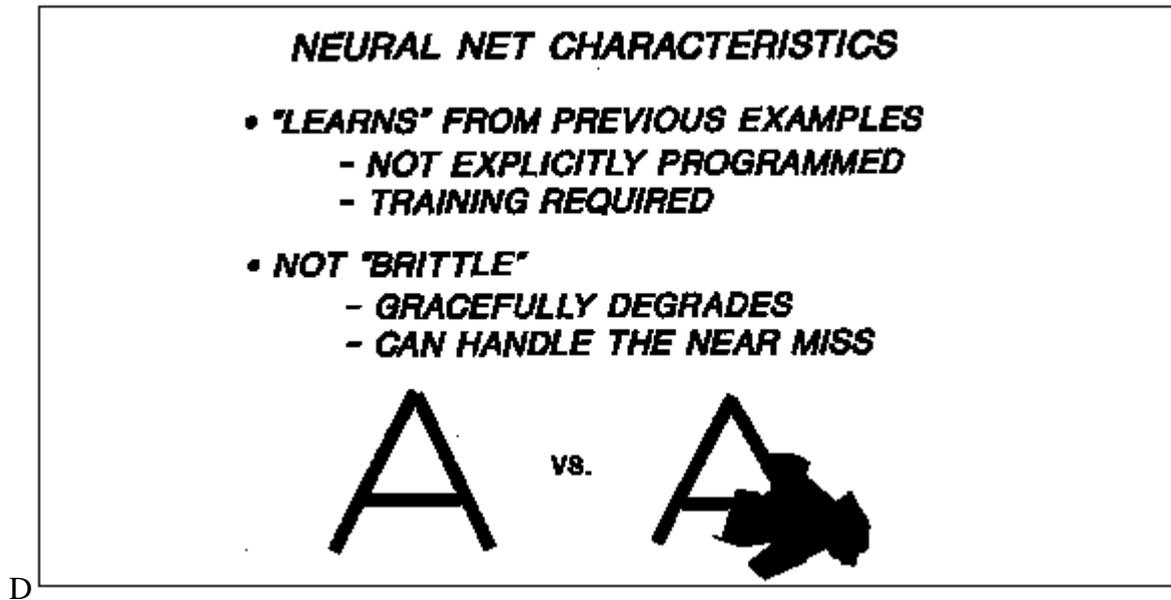


Figure 9

A neural net cannot reason about its logic in the same manner as an expert system. Neural nets are good for intuitive thinking, however, and can handle pattern recognition.

The research and development (R&D) group I represent is working on technology 20 years into the future. We currently are trying to use neural nets for jet engine diagnostics. As shown in [Figure 10](#), we are monitoring the exhaust of the engine to determine if something is wrong with the engine. The benefits are:

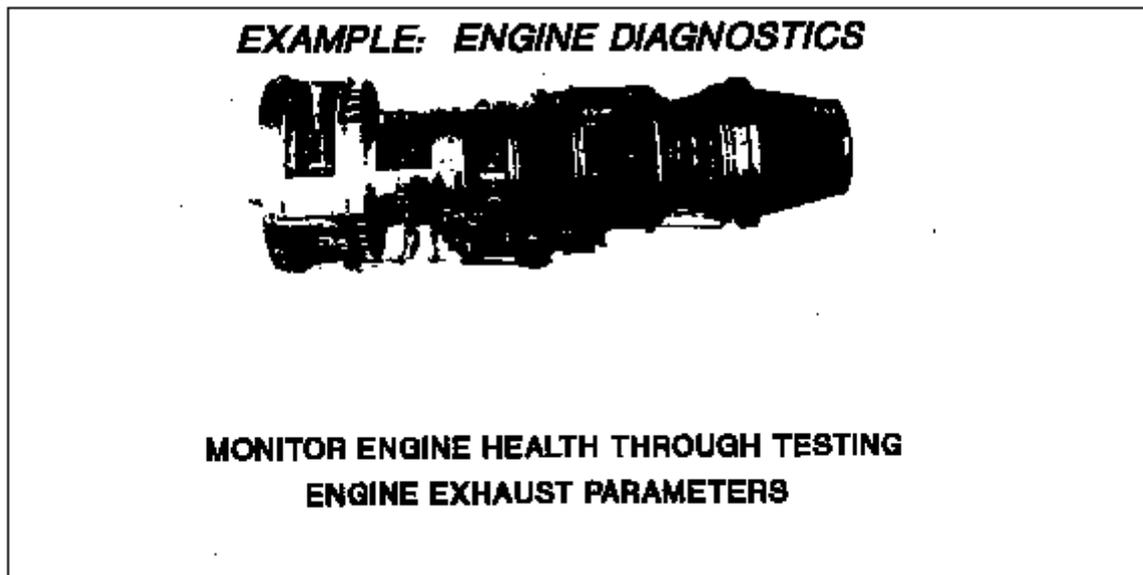


Figure 10

- Removal of engine unnecessary
- Less engine time on test cell.
- Testing time cut
- Better diagnostic capability

The key to this neural net application is the sensors:

- Acoustical

- Electrostatic
- Thermal
- Active atomic absorption
- Vibration
- Oil analysis
- X-ray analysis
- Fiber optic sensors --- "Smart Skin"

We employ acoustical sensors to hear what a good engine should sound like. An electrostatic sensor from Sikorsky also is used. There is a hoop mechanism that goes around the exhaust end of the engine. If there are any metallic parts (e.g., turbine) scraping against the side of the engine, you would sense different magnetic fields. Thermal sensors provide another diagnostic input. Active atomic absorption, developed by NASA, uses a wide-band laser beamed through the exhaust. This process identifies particles that might be in the exhaust. Other sensors work with vibration, oil analysis, X-ray analysis and fiber optics.

Once you have graphed the sensor outputs and have trained the neural net, as shown in [Figure 11](#), then hopefully you will be able to pick up specific diagnostics. For example, you might be able to detect a loose electrode, identify turbine blade erosion, or abnormal after-burner functioning. This is not intended to replace traditional engine diagnostics. This is merely an aid to augment the tools and procedures that we currently have in engine diagnostics and possibly save time in troubleshooting.

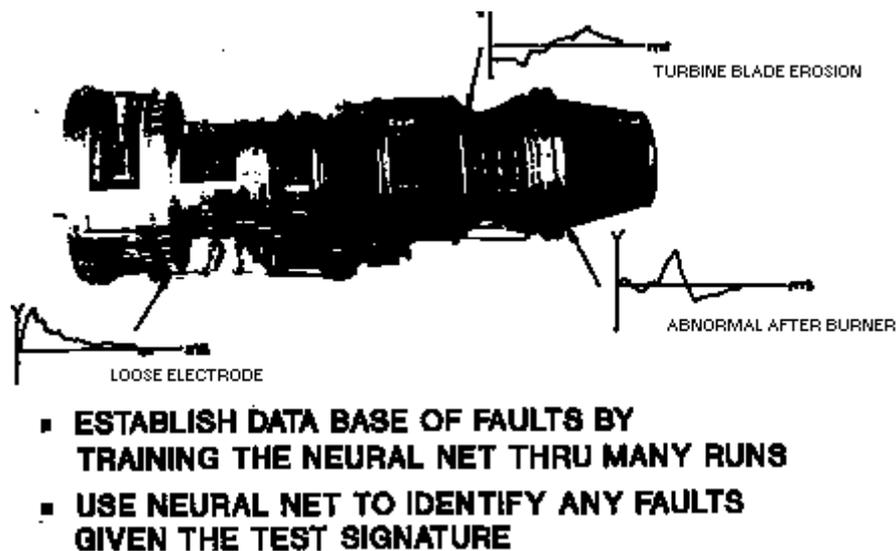


Figure 11

Sensors used for diagnostic testing must be better than the system being tested. Right now, we do not have excellent sensors. They are not as good as the systems they are being used to test. However, this is where we are today, given the present state of our technology.

Last, I would like to discuss analytical modeling. AI could be a good tool for applications modeling. Efforts along these lines are being pursued by the David Taylor Research Center in Maryland. As shown in [Figure 12](#), by taking faults and mapping them on a model, using multiple iterations, one might learn what the future holds for your wing, transducer, etc. Using the modeling concept, you try to predict when a fault might occur and thus gain a better understanding of the health of your aircraft at a given time.

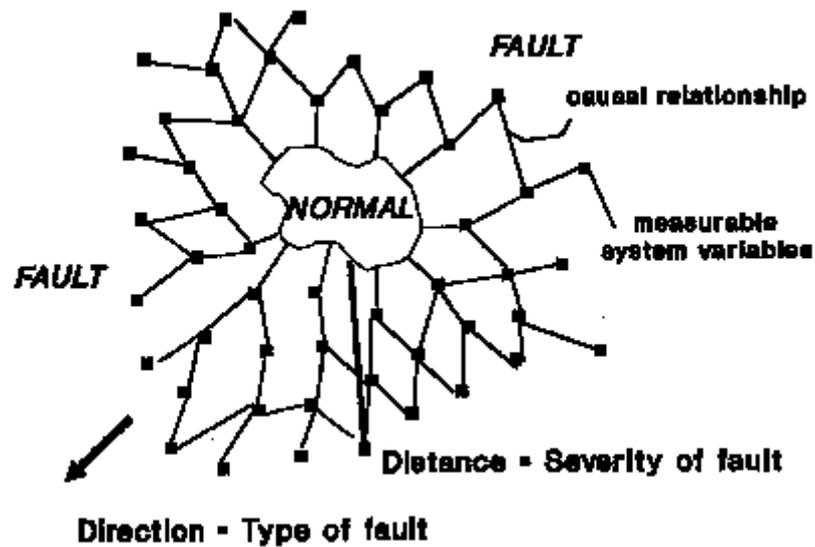


Figure 12

In summary, we have found that AI can be quite useful in testing avionics. Among the advantages of AI are that it can:

- Forecast future states
- Estimate failure-free operating time
- Given "symptoms," get a diagnosis
- Given a diagnosis, get "symptoms"
- Produce cost savings

Given the demographic projections concerning skilled technical workers during the next 10 years, perhaps the problems can be helped by having mechanics employ AI systems. Certainly you want people doing the maintenance to be active participants when an AI system is being designed and developed. Also, be certain you use an expert system for its particular capabilities and a neural net for its particular capabilities. AI is a powerful tool for testing and diagnostics. Use it wisely. Put a square peg into the square hole.

## Appendix B: Meeting Program

### 6TH FAA OFFICE OF AVIATION MEDICINE MEETING ON HUMAN FACTORS ISSUES IN AIRCRAFT MAINTENANCE AND INSPECTION

- MAINTENANCE 2000 -

Old Town Holiday Inn Alexandria, Virginia

21 - 23 January 1992

*Tuesday, January 21, 1992*

Arrival day for many participants.

Registration in afternoon (3:00 - 4:00 p.m. or so). **Wednesday, January 22, 1992**

#### MORNING PROGRAM - CARLYLE I & II

7:45 a.m. Registration/Continental Breakfast

#### INTRODUCTORY PRESENTATIONS

9:00 a.m. Welcome/Keynote Address *Jon Jordan, M.D., J.D. Federal Air Surgeon* Federal Aviation Administration

9:30 a.m. Meeting Objectives *William T. Shepherd, Ph.D. Office of Aviation Medicine* Federal Aviation Administration

10:00 a.m. Break

10:15 a.m. Changing Air Carrier Maintenance Requirements *Joseph Vreeman Vice President, Engineering and Maintenance Air Transport Association* Washington, DC

#### ADVANCES IN AVIATION MAINTENANCE

11:00 a.m. Aircraft Design for Maintainability with Future Human Models *Anthony Majoros, Ph.D. Douglas Aircraft Co.* Long Beach, CA

11:45 a.m. Lunch - 101 Lounge **Wednesday, January 22, 1992**

#### AFTERNOON PROGRAM - CARLYLE I & II

#### ADVANCES IN AVIATION MAINTENANCE - (Cont'd)

1:15 p.m. Looking Toward 2000: The Evolution of Human Factors in Maintenance *David Marx* **Customer Services Division Boeing Commercial Airplanes** Seattle, WA

2:00 p.m. On-Board Maintenance System (OMS) on the Boeing 777 *Jack Hessburg* **777 Chief Mechanic Customer Services Division Boeing Commercial Airplanes** Seattle, WA

2:45 p.m. Break

3:00 p.m. Tomorrow's Problems as Seen by Maintenance Managers *Robert Lutzinger* **United Airlines** San Francisco, CA

Panel Discussion *Members* **ATA Inspection Panel**

4:30 p.m. Adjourn

5:00 p.m. Social Hour - Snowden I-IV

*Thursday, January 23, 1992*

**MORNING PROGRAM - CARLYLE I & II**

7:45 a.m. Continental Breakfast

**ADVANCES IN AVIATION MAINTENANCE - (Cont'd)**

9:00 a.m. Maintenance Advances in the F-15 Aircraft Program *Thomas Nondorf* **McDonnell Aircraft Corporation** St. Louis, MO

9:45 a.m. U.S. Navy Carrier Maintenance **Video Presentation**

10:15 a.m. Break

**NEW TECHNOLOGIES**

10:30 a.m. Information Management "Like Never Before" *Paul Singleton* **IdentiTech, Inc.** Melbourne, FL

11:15 a.m. The Mannequin Computer Program *David Rome* **Humancad** Melville, NY

12:00 noon Lunch - 101 Lounge **Thursday, January 23, 1992**

**AFTERNOON PROGRAM - CARLYLE I & II****NEW TECHNOLOGIES - (Cont'd)**

1:15 p.m. Advances in Artificial Intelligence for Aircraft Maintenance *Mark Husni* **Naval Air Engineering Center** Lakehurst, NJ

**RECOMMENDATIONS AND CONCLUSIONS**

2:00 p.m. Group Discussion *William T. Shepherd, Ph.D.* and *James F. Parker, Jr., Ph.D.*

3:00 p.m. Adjourn

## Appendix C: Meeting Attendees

### Sixth Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection 21 - 23 January 1992

#### MAINTENANCE 2000

#### MEETING ATTENDEES

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

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Mike Brandewie, FAA Tech. Center Engineering Research & Development Service, ACD-1, Atlantic City Airport, Atlantic City, NJ 08405

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Gary Clemmer, Northwest Airlines, 5101 Northwest Drive, St. Paul, MN 55111-3034

D. Coudray, Aeroformation Airbus Industrie Flight Safety, Avenue Pierre Latécoère P.B. 36 31700 Blagnac FRANCE

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 Suzanne Morgan, Galaxy Scientific Corp., 2310 Parklake Dr., Atlanta, GA 30345

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Jerry Taylor, FAA-ACE 290, Kansas City

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**Meeting 7: Science, Technology, and Management: A  
Program Review (1992)**

**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 gratefully 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.  
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## **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*

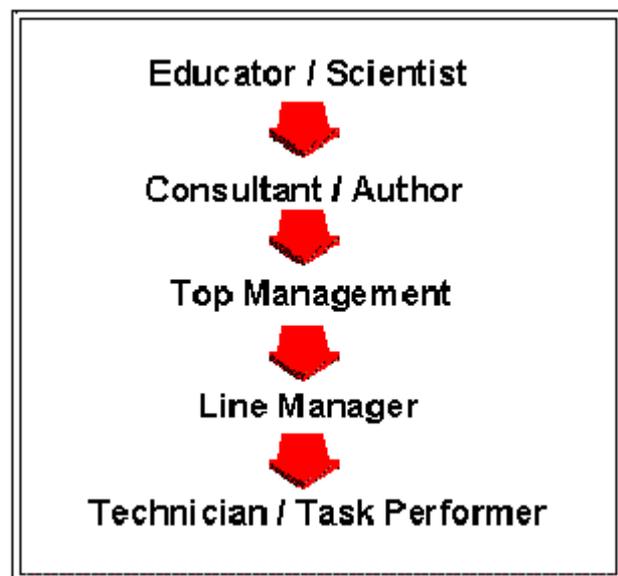
## 1.0 INTRODUCTION

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](#).

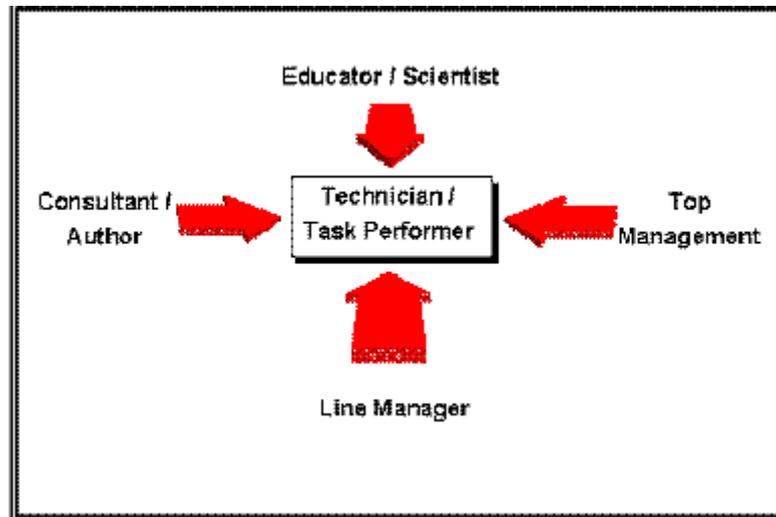


**Figure 1 Human Factors Arenas**

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.

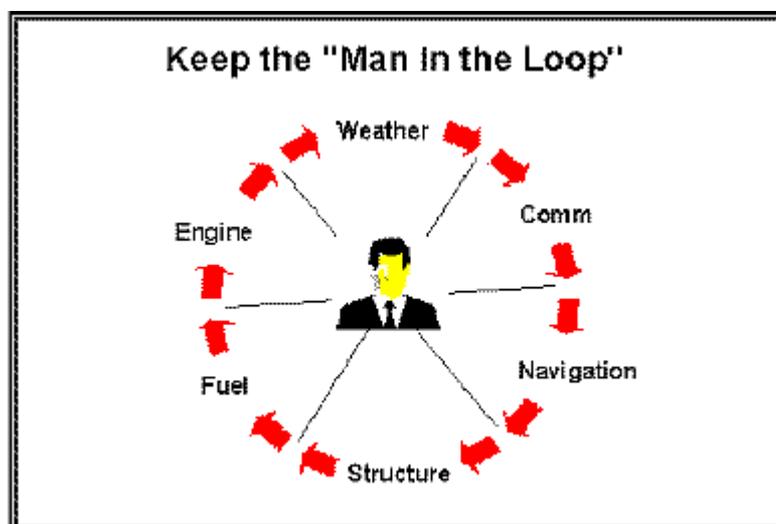
All too often, we concentrate intently on the individual and the immediate task ([Figure 2](#)). Each group relates to and engages in one-on-one communication with the Technician/Task Performer and endeavors to enhance the influence of human factors through this link. We ignore or do not integrate the 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 we 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

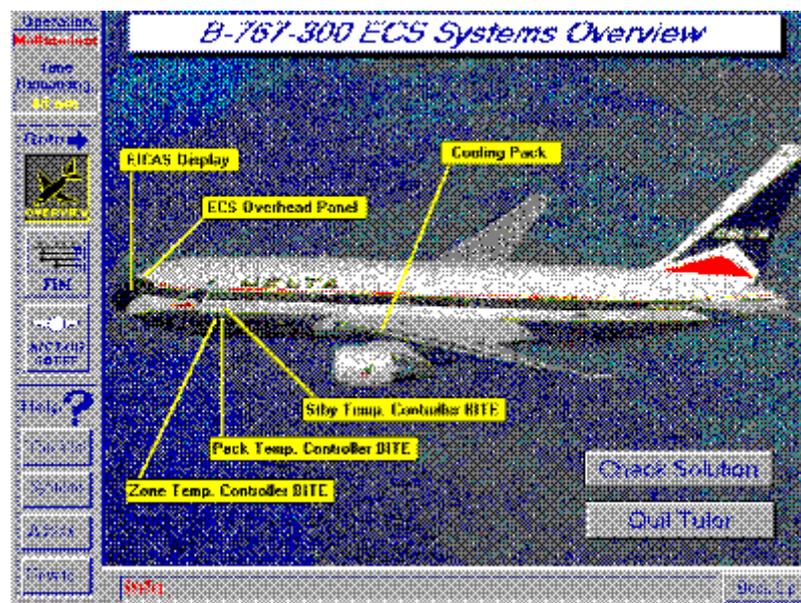
Research to enhance human performance in aircraft maintenance can focus on several dimensions, such as the human, the tools, the work place, work procedures, and management philosophies, as examples. The research must be useful to maintenance practitioners, as well as to the human factors research community.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

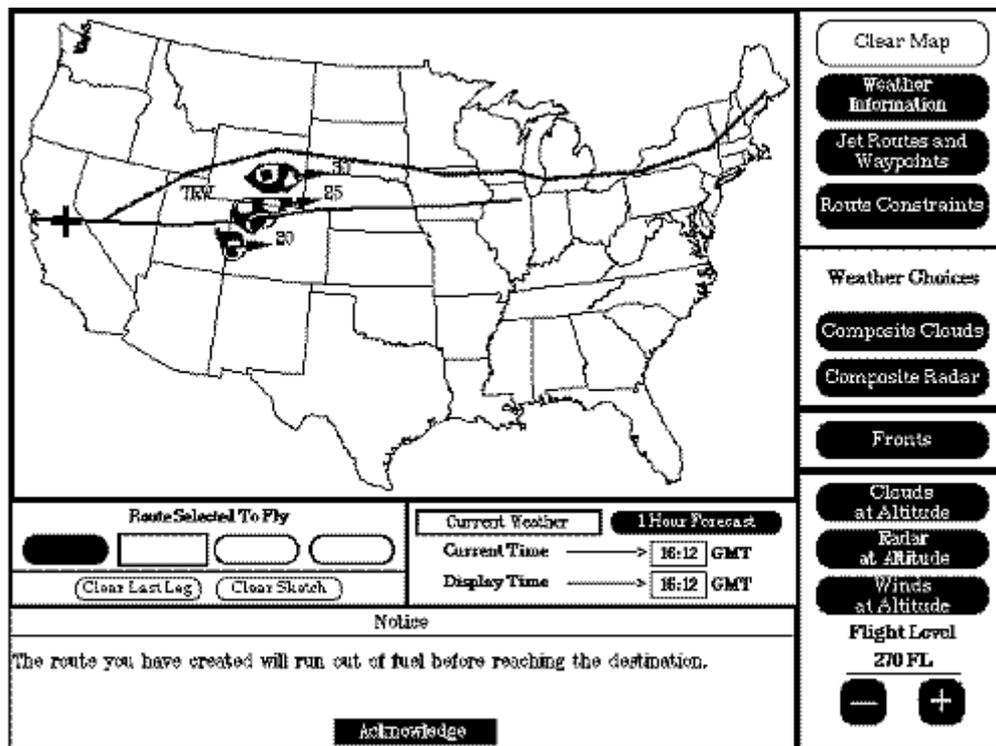
Accordingly, the research calls for a 'cooperative system' approach to designing such systems; a cooperative system is one in which a human and a computer are actively involved in the problem solving process. Findings present a study which used this approach in developing a job aid. Some of the results 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**

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

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

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

# A FRAMEWORK FOR HUMAN RELIABILITY IN AIRCRAFT INSPECTION

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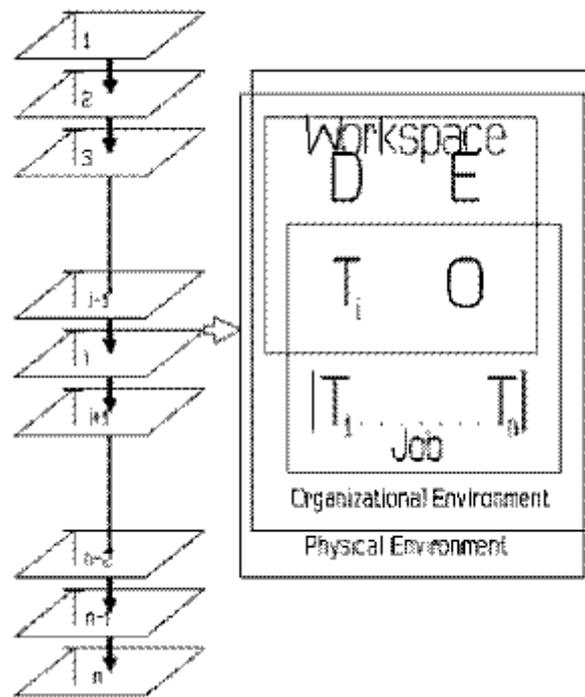
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## 1.0 INTRODUCTION

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**

<p><b>1.0 Personnel</b>            1.1 Physiological            1.2 Psychological            1.3 Personality</p> <p><b>2.0 Equipment</b>            2.1 Hand Tools            2.2 Displays            2.3 Control</p> <p><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)</p> <p><b>4.0 Task</b>            4.1 Physical Requirements            4.2 Informational Requirements            4.3 Characteristics</p>	<p><b>5.0 Job</b>            5.1 Physical Factors            5.2 Social and Organizational Factors</p> <p><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</p> <p><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</p> <p><b>8.0 Workspace</b>            8.1 Proximity            8.2 Anthropometrical Constraints</p>
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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
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	18,17,18,20	16,17,26,29		13,19,22,24,26,27,29	1,18,19,24		17,16,29
INTERFERENCE	Skill	12,14		23,30		14,24,30	24		
	Rule	11	20	23		3,11,22,24,31	24		
	Knowledge	18,32	18,17,20	15,16,17,23,32		3,19	1,18,19,21,32		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	1,18,19,24,33,34		17
STOCHASTIC VARIANCE	Skill	6,12,14	18,17,20,21,35	23	5,9,7,8	3,5,8,7,9,10,14,22,24,35	6,24	8	
	Rule	11	16,17,20,21,35			11,22,24,35	2,24,35		
	Knowledge		18,17,20,21,35	18,17		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

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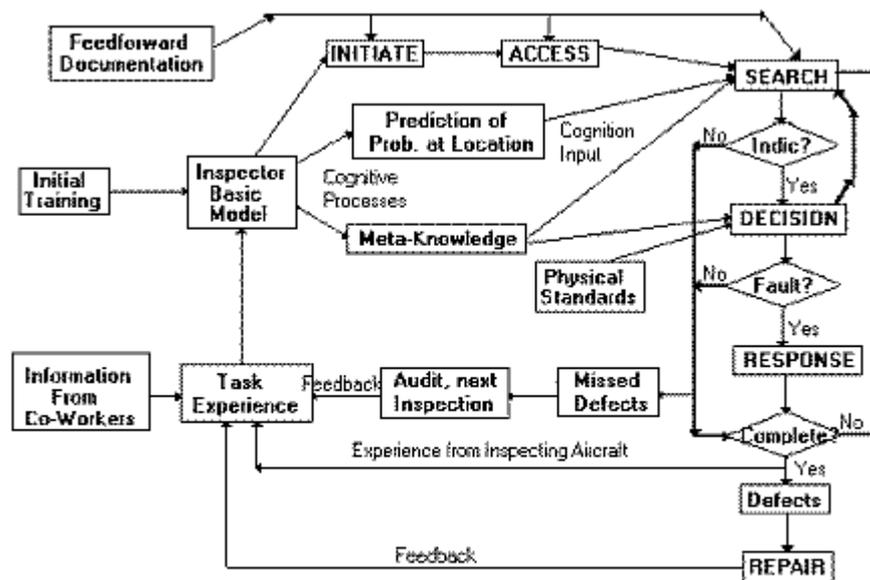
## 1.0 INTRODUCTION

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 ensuing 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**

**1. Missing Rivets      4. Cracks      7. Pooched or Dished Rivet**

2. Hole in Skin      5. Ripples in Skin      8. Wear  
 3. Dents            6. Loose Rivets      9. Corrosion

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)		* Steaks 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

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## 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.

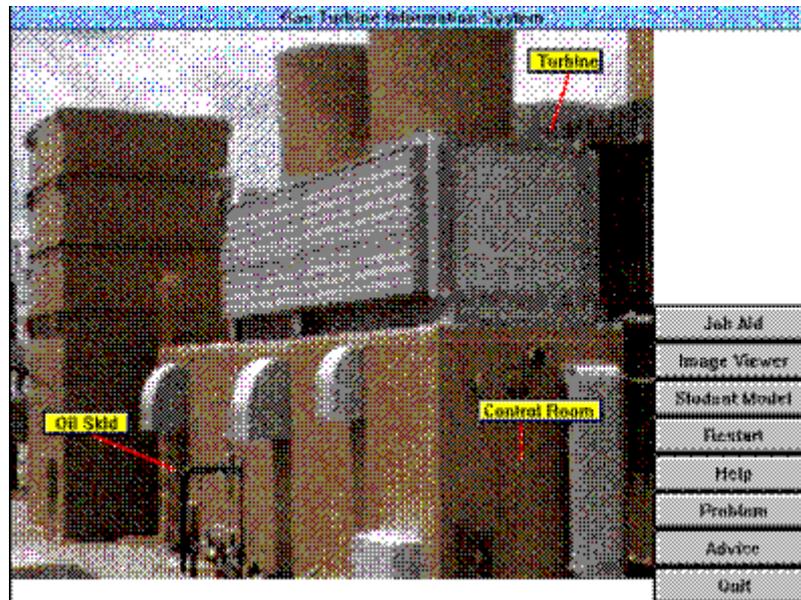
**Table 1. Integrated Information Systems in Development**

<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.

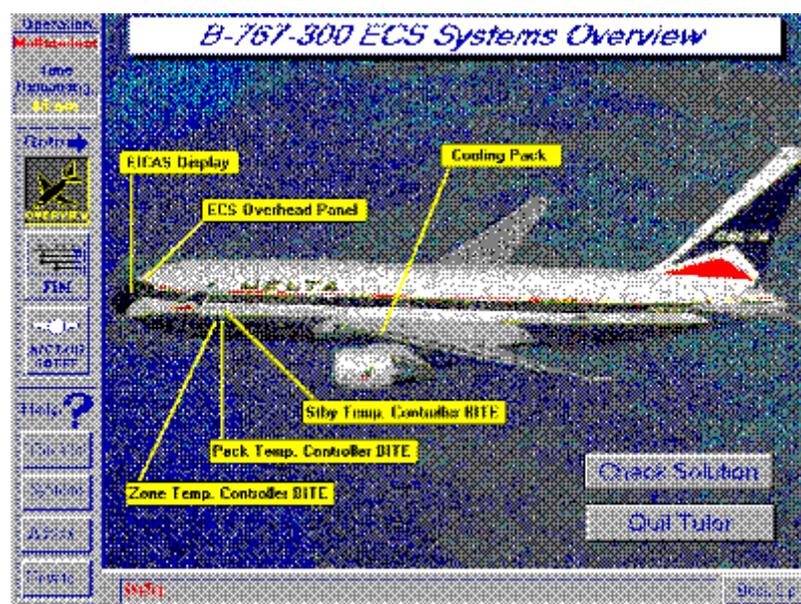


Figure 3 ECS Main Screen

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.

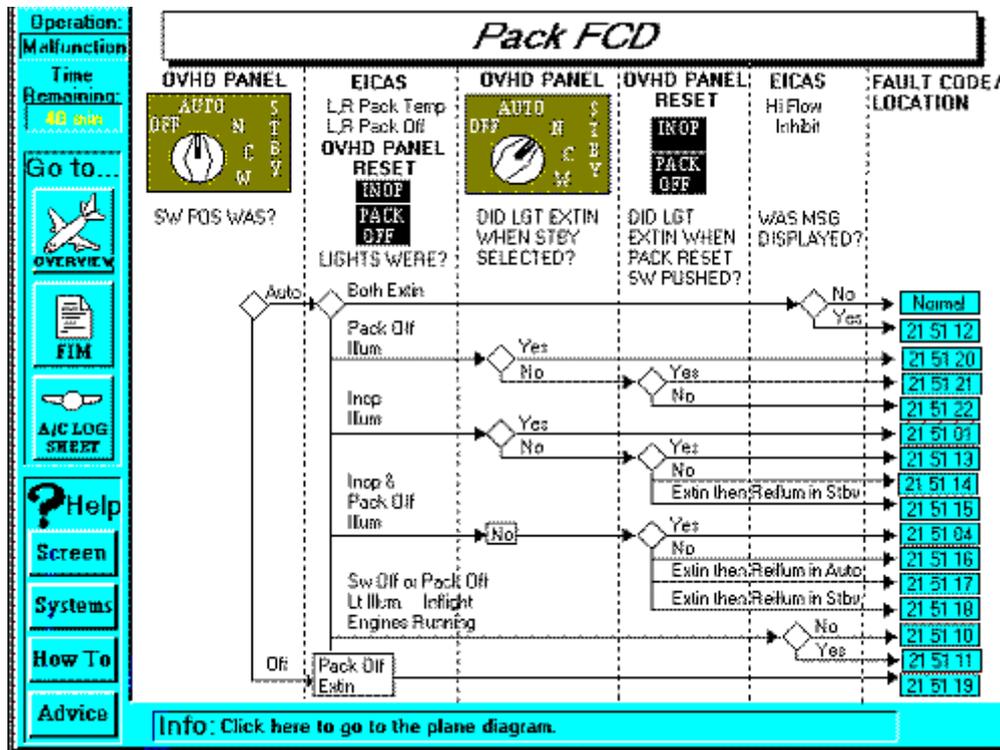


Figure 4 ECS Fault Isolation Manual

#### 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.

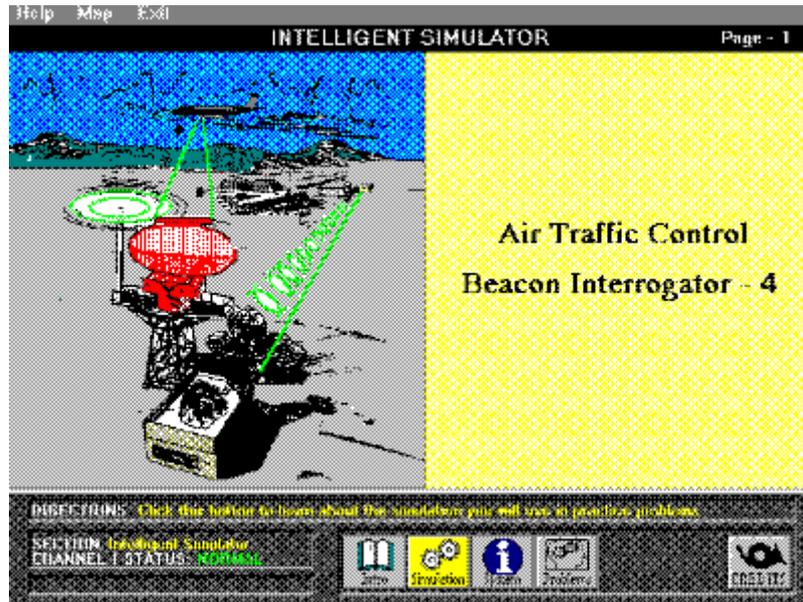
##### 4.4.1 Radar Simulation Tutor

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.

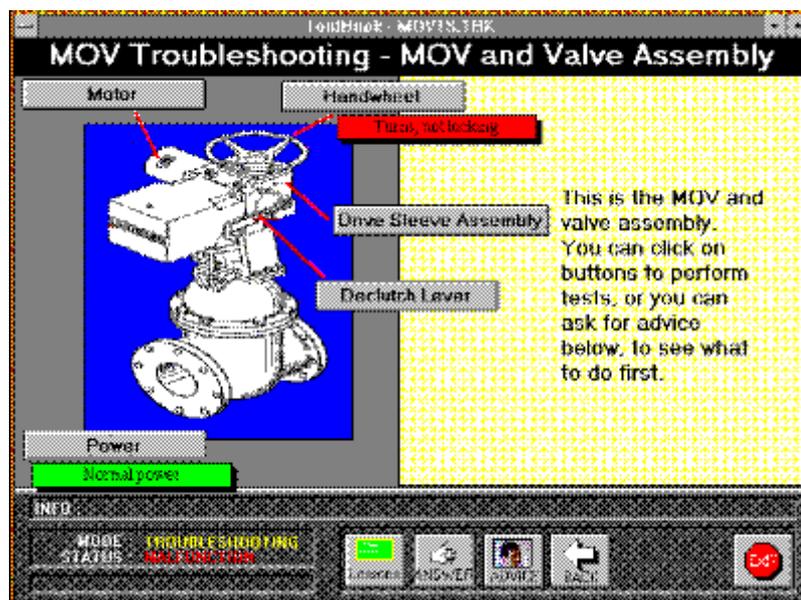


**Figure 5 Radar Simulation Screen**

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

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## 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.

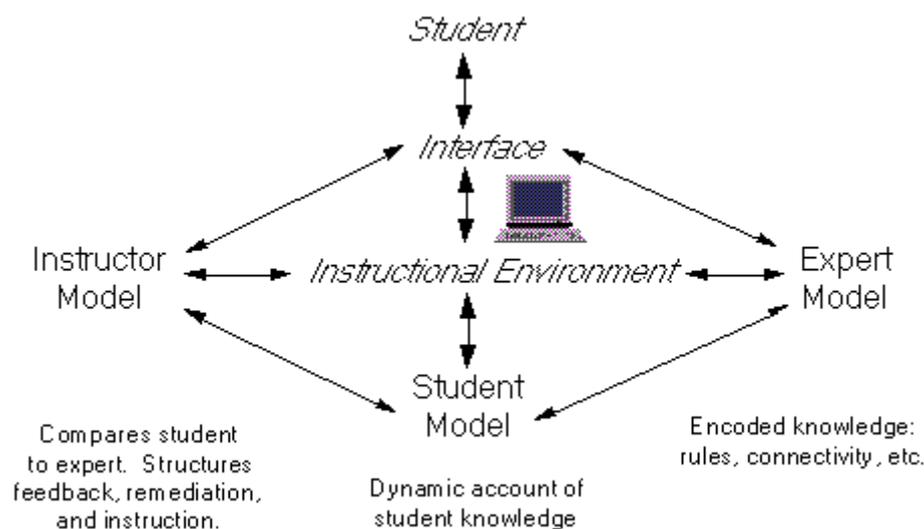
## 2.0 INTRODUCTION

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, Psootka, 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.

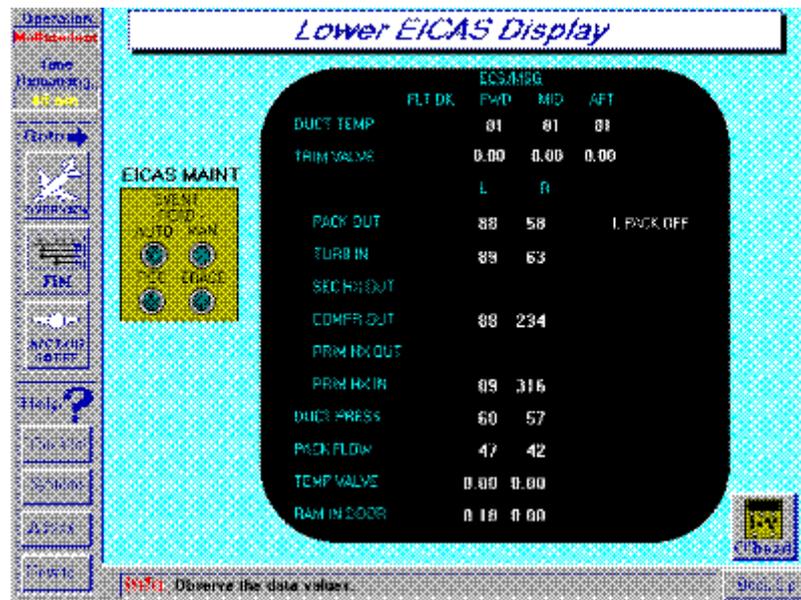


**Figure 2 The ECS Tutor**

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.

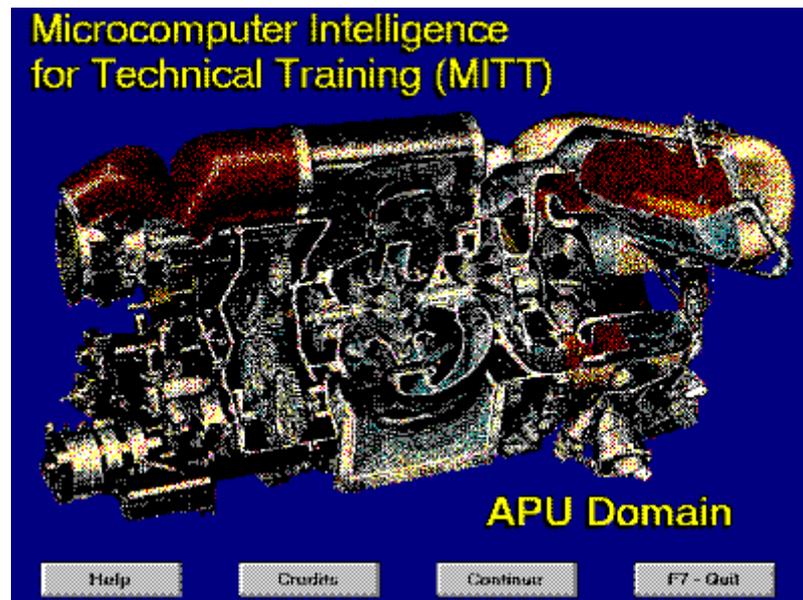
The GTIS simulation uses a static "look-up table" scheme to generate data values. Data values are pre-defined for each malfunction. The simulation uses a "snapshot" of the state of the gas turbine at the time of the failure for data values.

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

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## 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.

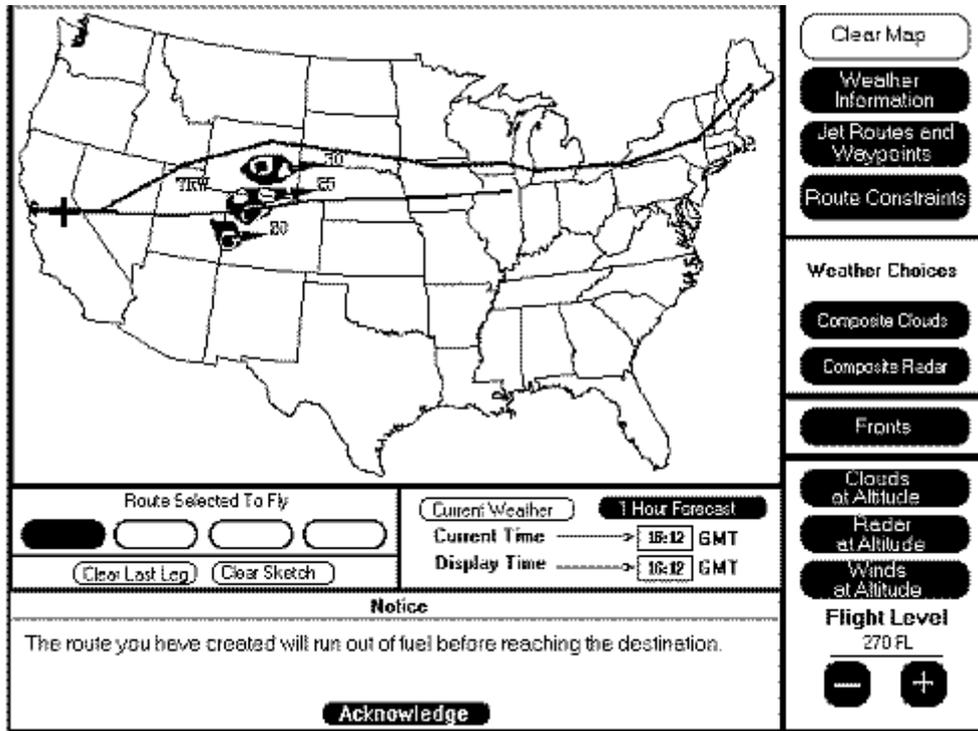


Figure 1 Left Monitor Displays and Controls

		DTA	DS4	EKR	DS4	SNY	DS4	OBH
Save	Clear	Route:						
Copy		Altitude:	FL 330		FL 330		FL 330	
Calculate		Speed:	Mach .72		Mach .72		Mach .72	
Time of Arrival (G.M.T.):		1708		1720		1812		1842
Fuel Remaining (1000 lbs):		30		26		22		18
Distance (miles):			216		233		216	
Turbulence		FL 330	moder		moder			
Wind Components		FL 290	moder		moder			
Wind Direction/Speed		FL 270	moder		moder			
Least Fuel Altitude		FL 250	moder		moder			
Planned Altitude		FL 230	moder		moder			
		GRND						
Time of Arrival: 19:45 GMT		Time of Arrival: 21:56 GMT		Time of Arrival:		Time of Arrival:		
Time Enroute: 3:45		Time Enroute: 5:58		Time Enroute:		Time Enroute:		
Fuel Remaining: 11047 lbs		Fuel Remaining: 6226 lbs		Fuel Remaining:		Fuel Remaining:		
Total Distance: 1578 nm		Total Distance: 2511 nm		Total Distance:		Total Distance:		

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

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## 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.

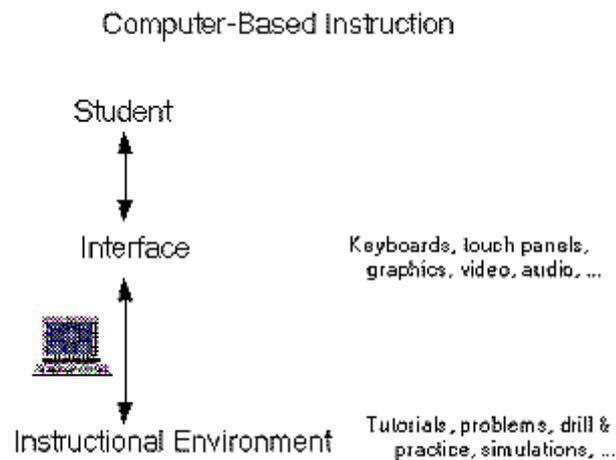
## 2.0 INTRODUCTION

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

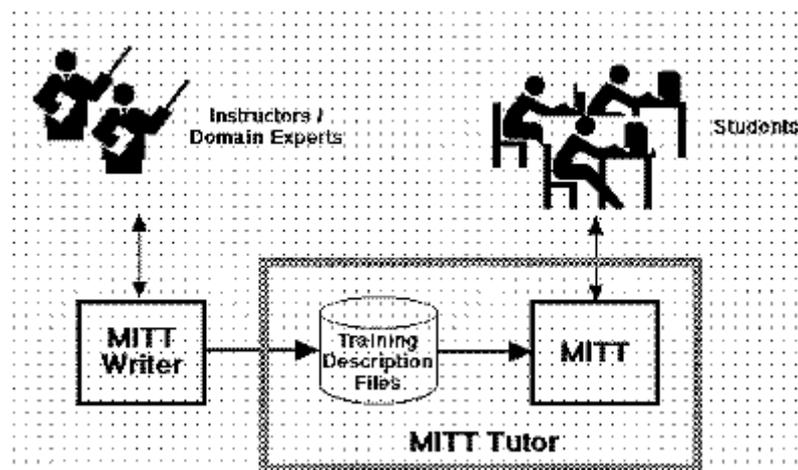
The first step in developing a prototype advanced technology training system was to identify a piece of AF equipment that is appropriate for this type of training and for which additional training is needed. FAA personnel identified the following as candidates for the training system: the Paradyne modem,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

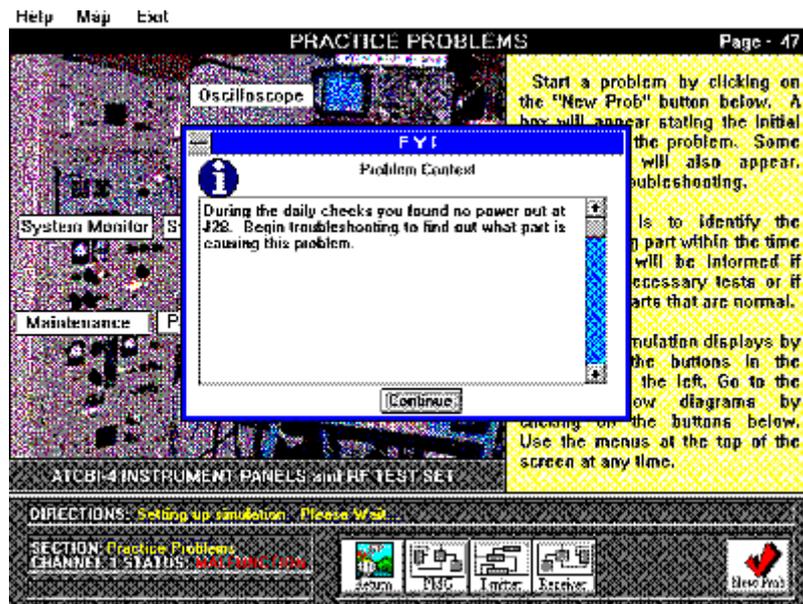
Although MITT Writer was designed to aid an instructor or domain expert in developing a MITT tutor, this tool was used by a member of the research team to quickly produce and modify an initial prototype system. The MITT program was then used to run the training system to obtain input and feedback from 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.

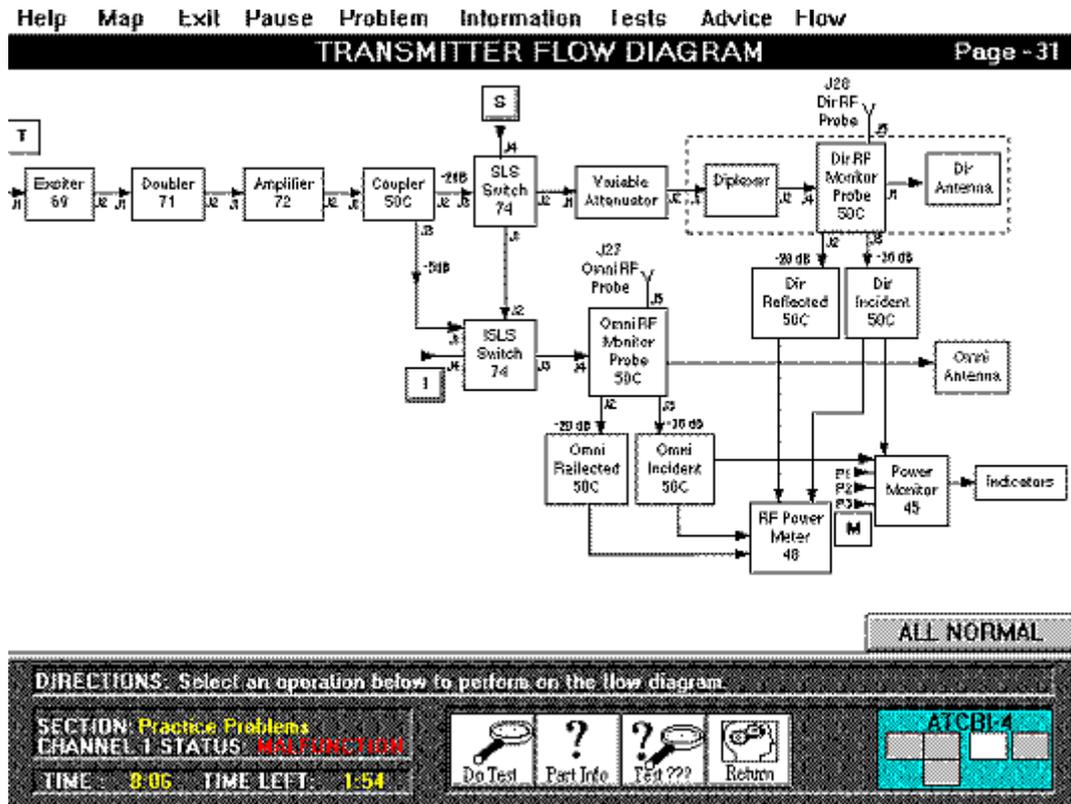


Figure 6 Example Flow Diagram

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.

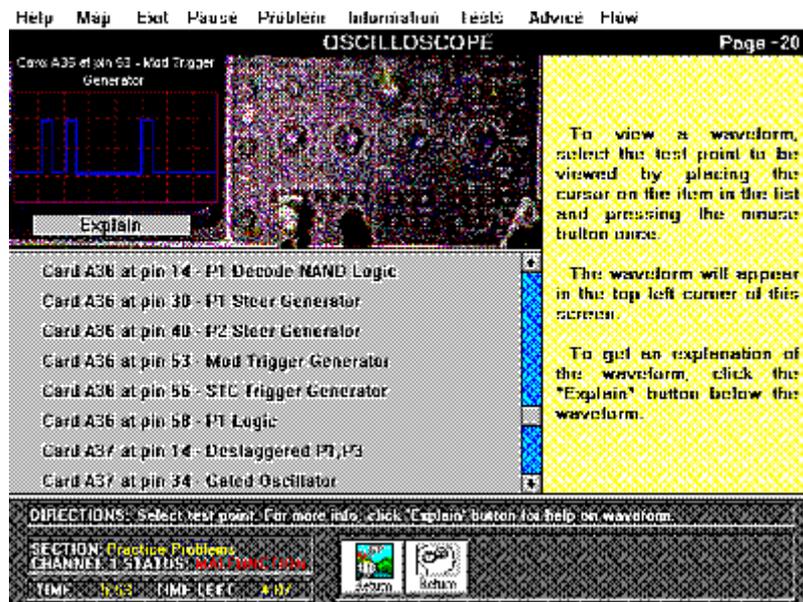


Figure 7 Example Oscilloscope Test

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

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## 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 re-fixations. 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  $T_1$ ,  $T_2$ , 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).

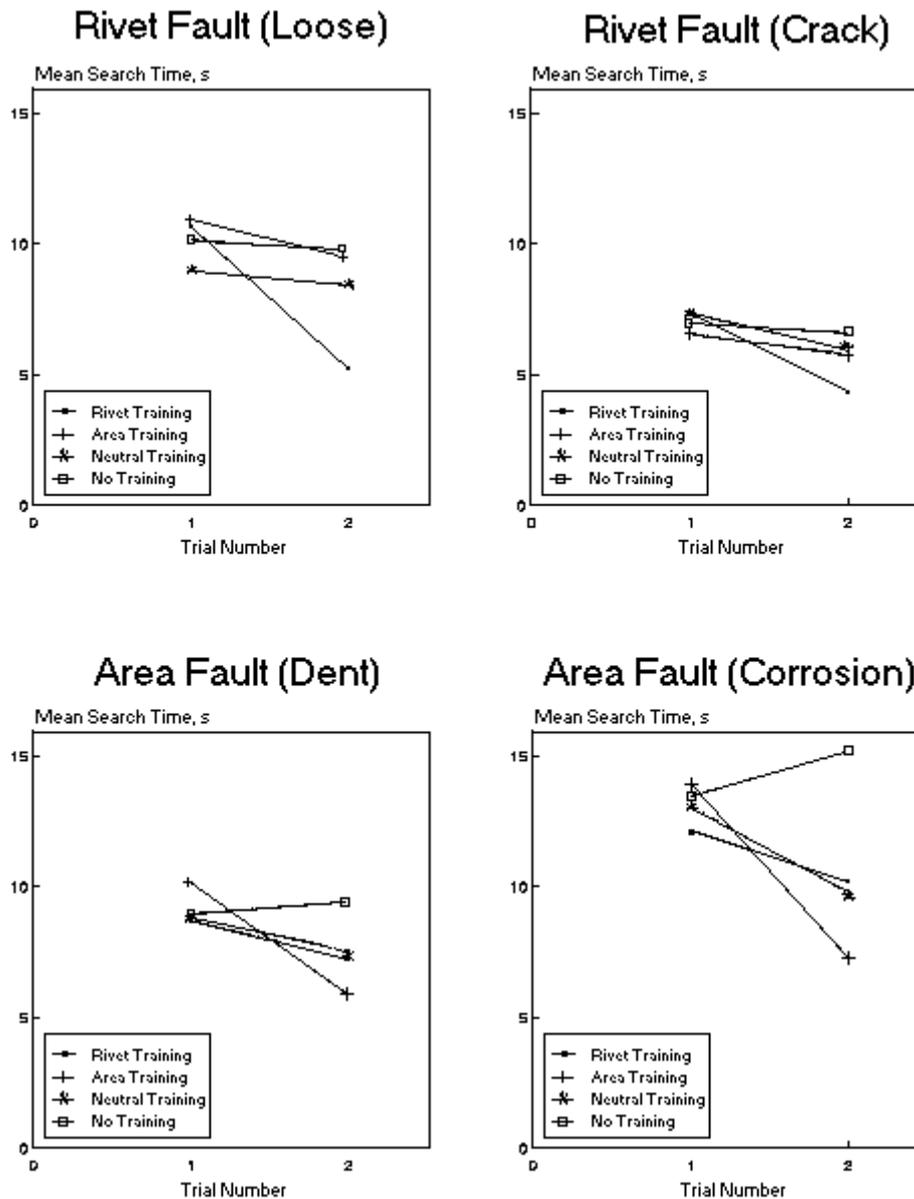
The task was unpaced. During each of the four visual search tasks, the subjects had to search for one of the predefined faults. Subjects were instructed to work as rapidly as possible consistent with accuracy. Subjects verified their response by clicking on the fault with the mouse button. Once a fault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

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## 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

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## 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

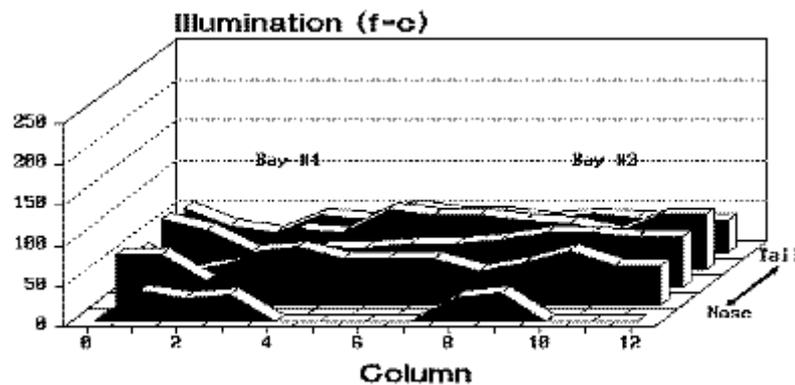
**Classification of Light Sources.** The lighting sources employed in aircraft inspection include the following: *ambient lighting* which is comprised of daylight, area, and specialized lighting (built into aircraft), and *task lighting* which includes portable lighting (set up at the inspection site) 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).

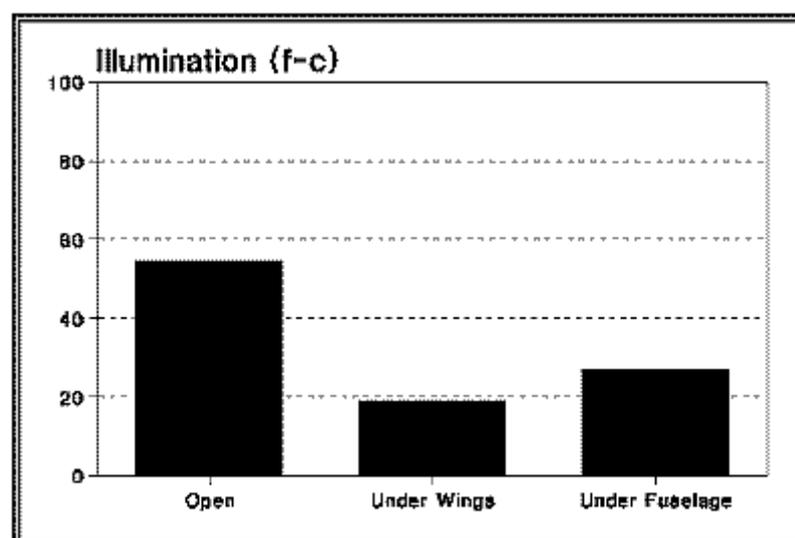
### 4.0 EVALUATION OF EXISTING VISUAL ENVIRONMENT

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.

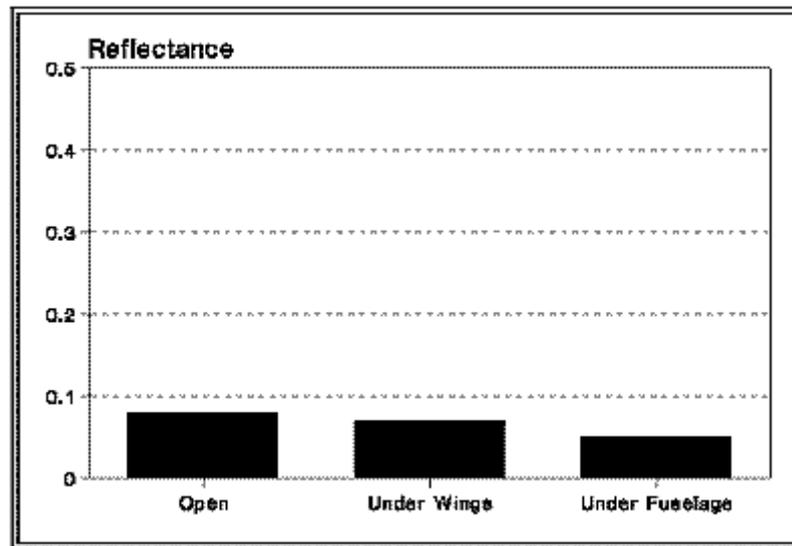
**Evaluation of Ambient Illumination, Luminance, and Reflectance.** The survey measured the illumination and luminance levels produced by the ambient light sources only. Lighting characteristics of the personal and portable lighting were not considered at this stage. The illumination and floor luminance 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, noswell, 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	Justite Headlamp Specialized, General	182 SD=72.4
Fuselage-Nose	3D-Cell Mag Lite General	97 SD=46.0
Noswell	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

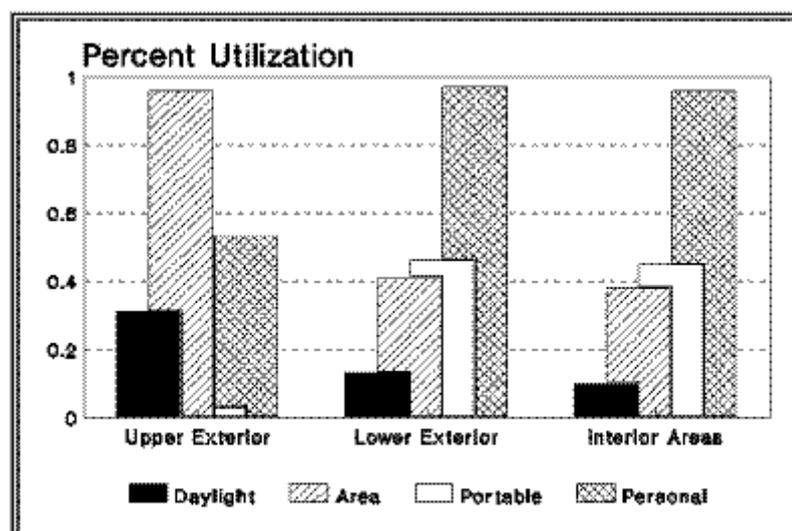
the task requirements.

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 assess 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 #800-25	Fluorescent 13 watts 85 f-c"	0.8	No	Adequate	NEC #410-35(a)(b),38,42(a)(b),44,45 OSHA #1926.405(E)(F)(i)(ii)(iii)(A)(E)(V) UL listed	Hook
Ericson Portable Lamp #1227	Fluorescent 27 watts 164 f-c"	10	No	Adequate	NEC #410-35(a)(b),38,42(a)(b),44,45 OSHA #1926.405(E)(F)(i)(ii)(iii)(A)(E)(V) UL listed	Hangers, Magnets
Fosteria 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  Yes	Dynamic  Static	2D,3D-Cell Mags Justrite Headlamp  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

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## 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](#).

* PDS*	JOB DESCRIPTION	* MECH *	* INSP*
* DI * 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 ALDEL 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**

<b>1. INFORMATION READABILITY</b>	
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 cueing, 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>
<b>2. INFORMATION CONTENT</b>	
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>
<b>3. INFORMATION ORGANIZATION</b>	
A. Information Classification {2.4.1}	<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 organizations {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>
<b>4. PHYSICAL HANDLING &amp; ENVIR.</b>	
	<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

## Responses

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.

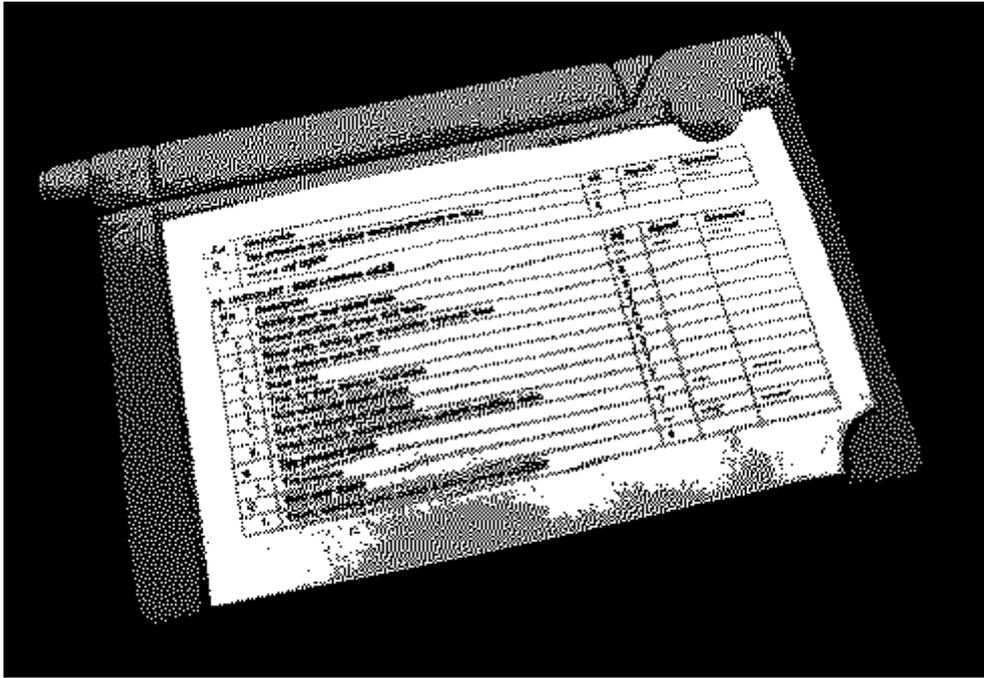
S.#	Description	P#	Signoff	Comment
<b>A</b>	<b>Landing gear and wheel wells</b>	---	-----	-----
1.	General condition, damage, fluid leaks	5		
2.	Wheel wells, landing gear assemblies, hydraulic lines	5		
3.	Brake deboost valve limits	5		
4.	Brake limits	6		
5.	Tires, for wear, damage, fluid leaks	6		
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

<p><i>2A&amp;B LANDING GEAR (Nose &amp; Main)</i></p> <p>Check systems condition</p> <p><b>A. Landing gear and wheel wells</b></p> <p>(1) <i>Check:</i> - general condition damage and evidence of fluid leaks.</p> <p>(2) <i>Check:</i> - wheel wells                  - landing gear assemblies                  - chafing of hydraulic lines                  for broken aldel clamps on hydraulic lines on the  <b>Note:</b> Discrepancies on the above item must be corrected prior to the dispatch of the aircraft.</p> <p>(3) <i>Check:</i> - Brake deboost valves                  for being within limits  <b>Note:</b> See attachment for PEX effected ACFT deboost valve check</p>	<p><b>Continental</b></p> <p><i>Work Control Card: Landing Gear SCT/CAAC</i></p> <p><i>03Feb92 07:51 Rev date 090490</i></p> <p><i>JCCR No. 02189 MFG P/N: J07 3200-21-020-001 Proc. A/C 3200, B727, ATA32, M&amp;E P/N: 07-0521- 1-0017</i></p>
<p><b>Page 5</b></p>	

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

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## 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 is 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 illustrate 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.

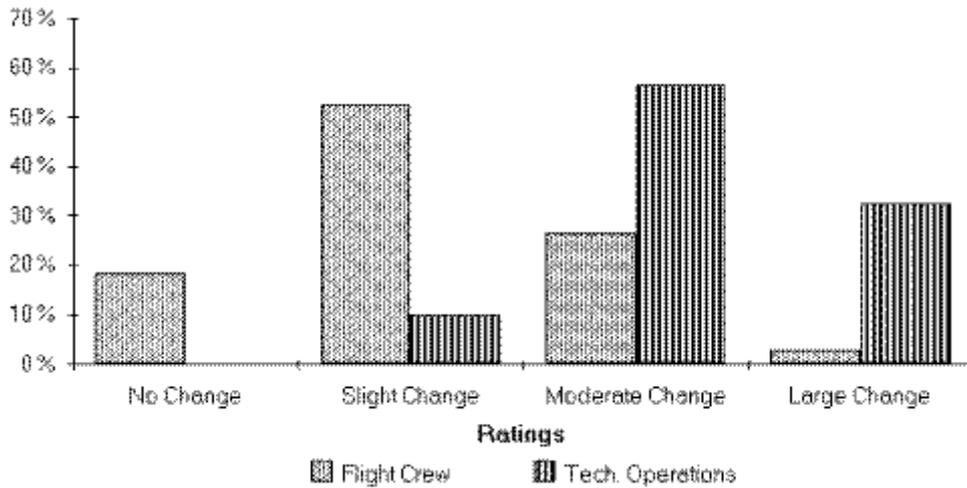
**Examination** of the stability of those training-related shifts in attitudes over time (6-months after training).

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

## 12.3 THE RESULTS

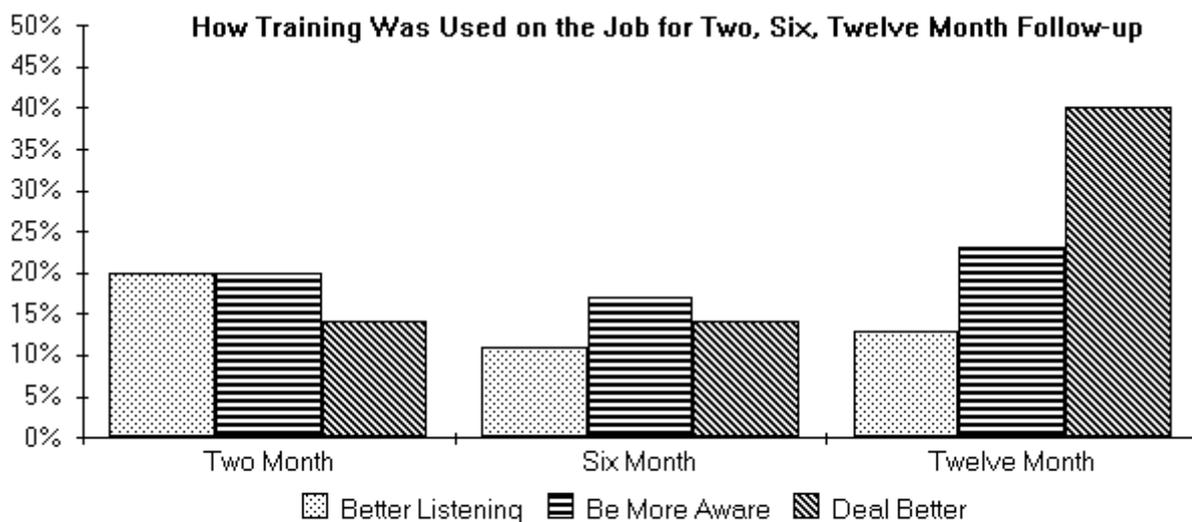
**Figure 1:** "Rating Behavioral Change." In completing the questionnaire immediately following training managers answered how much change in the company's way of doing things they would

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.

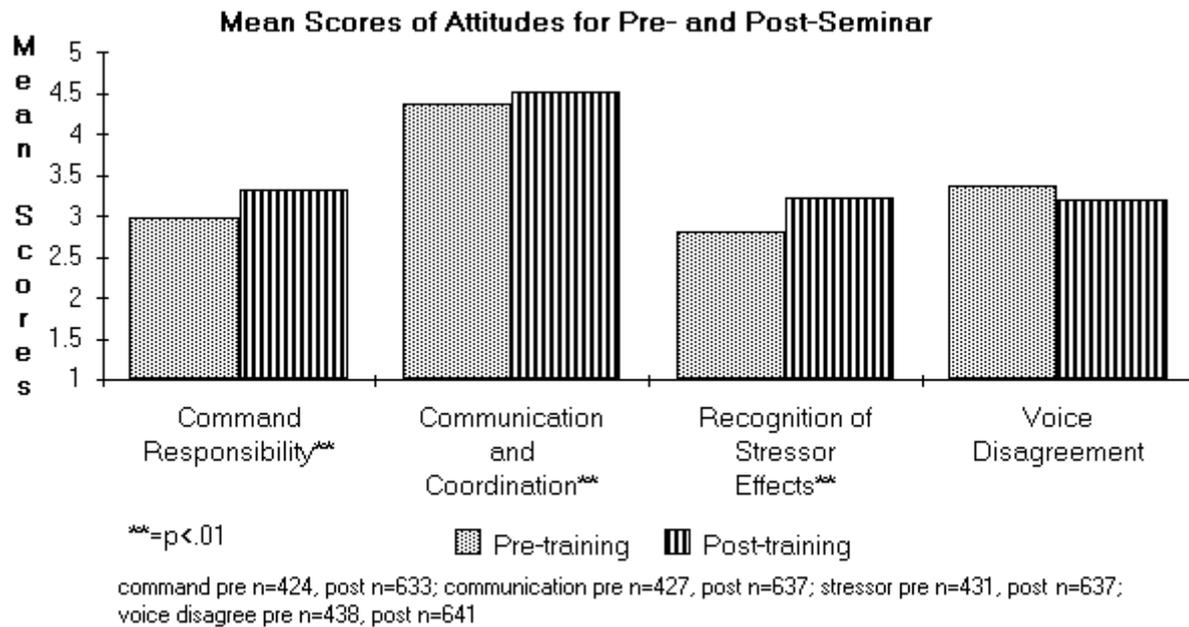


n=215, two months; n=186, six months; n=64, twelve months

**Figure 2 Reported Use of Training**

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

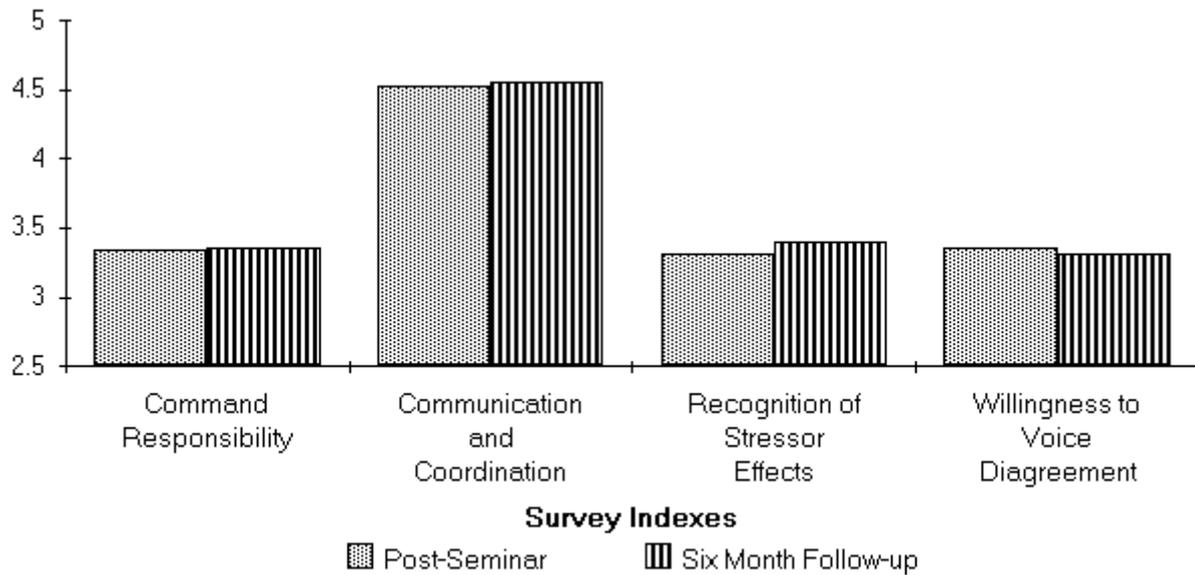
the four attitude scales derived from the questionnaire. All four of these attitude scales are expected to measure ideas and beliefs taught in the CCC training. From left to right the scales are "Sharing Command Responsibility," "Communication and Coordination are Useful," "Stress Affects the Quality 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>Work Classification</b>	<b>Number</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.

<b>Frequency of Use</b>	<b>Number of Replies</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.

<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>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>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.

**Table 7** Preference for Physical Structure  
of a Human Factors Guide

<u>Alternatives</u>	<u>Number</u>
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.

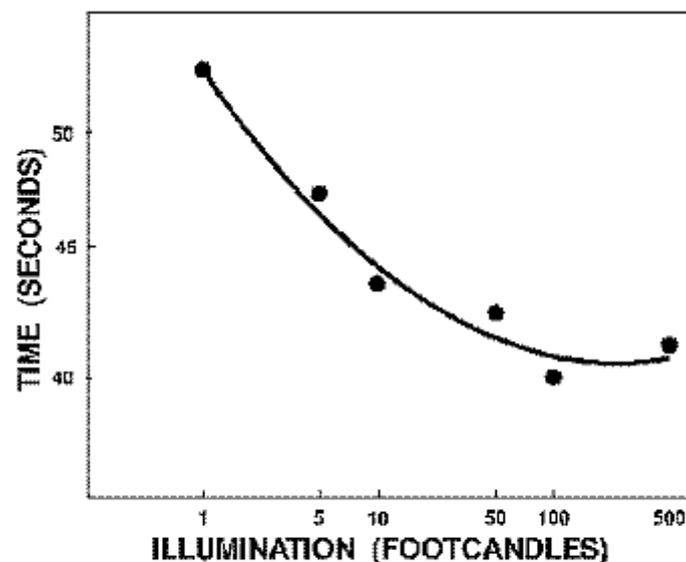
### 3.0 SAMPLE SECTION OF A HUMAN FACTORS GUIDE

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](#).

<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.

<b>To Control Direct Glare</b>	<b>To Control Indirect Glare</b>
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>Measured (Footcandles)</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>Recommended (Footcandles)</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.

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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 & Caucus 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

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