Meeting 8: Trends and Advances in Aviation Maintenance Operations

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

Report of Meeting

16 - 17 November 1993

Alexandria, Virginia

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Information Division

Atlanta, Georgia

FOREWORD

The Office of Aviation Medicine views the Human Factors in Aircraft Maintenance and Inspection workshops as an important means to foster two way communication between the FAA and the aviation industry. Further, the workshops ensure that the research goals and findings are aligned with the pragmatic needs of the aviation industry. This workshop is the eighth in the five year history of our research program.

This workshop attracted speakers from the world's leading airlines and suppliers. Personnel from research laboratories, consulting firms, universities, and national associations were also among the speakers. Members of the human factors research team reported on how the research is being implemented in airlines and/or FAA field applications. In all cases the presentations describe how basic scientific principles can be applied to "real world" settings to focus attention on the human as the central and critical part of the maintenance system.

The popularity and success of these workshops must be attributed to active participation from the international aviation community, governments, universities, and the variety of technical personnel who have guided and involved themselves in the research. Once again we acknowledge such participation.

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

EXECUTIVE SUMMARY

This was the eighth meeting in a series on Human Factors in Aviation Maintenance and Inspection sponsored by the Federal Aviation Administration. The purpose of this two-day meeting, held November 16 and 17, 1993, was to discuss changes and advances in aviation maintenance operations.

The meeting was divided into three sections. The first section dealt with changes and advances in air carrier procedures. The presentations covered the following topics:

- Reorganization of British Airways Maintenance Organization
- Application of computer-based training to improve maintenance training efficiency
- Changes in worker relationships by emphasizing teamwork, empowerment and process simplification
- Changes in environmental regulations that affect maintenance operations.

The second section covered technology advances supporting aviation maintenance. The presentations covered the following topics:

- An experiment to investigate the reliability of eddy-current inspection
- A project using the Flight Control Maintenance Diagnostic System (FCMDS) to improve technician diagnosis of system problems
- A pen-based computer demonstration of the Performance Enhancement System (PENS) for Aviation Safety Inspectors
- The project to develop MEDA (Maintenance Error Decision Aid), a "human-centered" methodology to investigate maintenance error
- A workcard design on a portable computer-based system
- Development of an audit program for human factors issues in aircraft inspection
- A study of the effects of work postures in confined areas.

The third section was devoted to advances and issues impacting the maintenance work force and included the following topics:

- Work force procedures and maintenance productivity at Southwest Airlines
- The TWA-IAM/FAA Conformance Committee Procedures program.

INTRODUCTION

In November 1993 the Federal Aviation Administration (FAA) Office of Aviation Medicine (AAM) sponsored the eighth in a series of two-day meetings to discuss human factors issues in aviation maintenance and inspection. The theme for this meeting was "Trends and Advances in Aviation Maintenance Operations." Fourteen presentations were made by personnel from government, research, academia, and industry. The topics ranged from FAA regulatory changes, air carrier procedure changes, technology advances, and other issues affecting the maintenance work force.

The National Plan for Aviation Human Factors was published in 1991. The Plan recognized that attention to the human in the aviation maintenance system is as important to overall safety as human factors attention to air traffic control and flight operations. The Office of Aviation Medicine has mapped its research program to the National Plan recommendations. The research, the workshops, and proceedings like this are an indication of FAA commitment to continued aviation safety through attention to human factors research and development.

These proceedings, in addition to being available in paper form, will be available on the second CD-ROM published by the FAA/AAM later this year. The CD-ROM will also include all previous meetings, progress reports of the FAA/AAM Human Factors in Aviation Maintenance research program, software developed under that research program, Federal Aviation Regulations, and the Airworthiness Inspector's Handbook.

FAA HUMAN FACTORS PROGRAM EMPHASIS

Brooks Goldman
Associate Administrator for Aviation Standards
Federal Aviation Administration

I would like to welcome you this morning to the FAA Meeting on Human Factors Issues in Aircraft Maintenance and Inspection. This meeting is the eighth in this series on human factors in maintenance. It serves to illustrate the FAA's continuing belief in the importance of the human element in the operation of the national air transport industry. My welcome is extended on behalf of our office in Aviation Standards and, in part, on behalf of the Office of Aviation Medicine, which has served as sponsor for all these meetings. The meetings provide a forum for the exchange of ideas and information among those working on the human factors technology base, those in industry who understand the day-to-day problems and are in a position to apply new technologies aimed at improving safety and efficiency, and those of us concerned with regulatory oversight of the U.S. aviation industry. We all benefit from this information exchange.

The theme for today's meeting is *Trends and Advances in Aviation Maintenance Operations.* Usually, with a theme such as this, we might be talking about new diagnostic equipment for examining aircraft structures, the incorporation of new composite materials in aircraft design, new techniques for corrosion proofing, and the like. While these topics might arise today, the focus of this meeting is on the human, and rightly so.

Recognizing the importance of the human in aviation operations is not a new insight. The Wright brothers clearly understood that a pilot was necessary in the first airplane. Likewise, a competent mechanic has always been considered necessary for continuing flight operations. These components represent the human essentials for aviation -- a good flight crew and a good maintenance team. As aviation has developed, we have learned that simply selecting and training a good pilot or a good mechanic may not be enough. Aviation safety requires continuing attention to the human. In flight operations, year after year statistics show that between 50 and 85 percent of all accidents list human error as either the primary or as a contributing cause. This is true of even highly motivated and well-trained flight crews. We must understand that the human is a fallible element in an aviation system and deal with this fact in system design and operation.

A good example of human-oriented problems in flight operations is found in incident reports submitted to NASA's Aviation Safety Reporting System. These reports describe in-flight and on-the-ground incidents that jeopardized safety. In a study of over 12,000 incident reports, more than 73 percent showed evidence of some problem in the transfer of information within the aviation system. The pilot misunderstood ATC instructions; ATC misunderstood the pilot's response; the pilot misread some information display in the cockpit; and so on. Fortunately, there are enough redundancies in aviation systems that most of these errors are detected and corrected before a catastrophe occurs. However, this is not always the case.

If communications represents a problem in flight operations, so can it be a problem in maintenance. Maintenance job cards can be misread; information can be lost during the transfer of responsibilities from one maintenance crew to another as shifts change; diagnostic signals can be misinterpreted; and so on. The human, however well motivated and well trained, requires on-going support in terms of his compatibility with the system in which he is working and in terms of the activities he is called on to accomplish.

The call to arms, in terms of the importance of human factors in aviation maintenance, came, as we all know, with the Aloha incident. Here we had an airplane, judged safe for flight as a routine matter, in which some 18 feet of the cabin structure suddenly was ripped away due to structural failure. Until that time, we operated on the philosophy and assumption that given proper inspection, preventive maintenance, replacement of parts as required, aircraft could be flown to their economic design goal and well beyond. The degree of damage to the Aloha airplane was shocking to everyone and was totally unexpected. Immediately, a number of questions were raised. One was "Should a fixed service life be set for aircraft in the commercial fleet?" Obviously, this is a difficult question to answer and raises any number of engineering and economic issues. One conclusion, however, was made immediately. If we are to combat the safety issues raised in the Aloha incident, the aviation maintenance technician represents our first line of defense. The success of any program to preclude future in-flight incidents comparable to that of Aloha rests with the performance of the aviation maintenance technician.

In order to bring full attention to problems of aging aircraft, an International Conference on Aging Aircraft was held in Washington, DC in June 1988. This conference highlighted the importance of human factors support for aviation maintenance. Dr. Bill Shepherd, who is our host today, noted that "The more we looked at problems in maintenance operations, and particularly those of aging aircraft, the more we saw human factors as some part of the problem."

When we speak of *human factors* in aviation, and particularly in aviation maintenance, we are dealing with a very broad topic. Dr. John Jordan, the Federal Air Surgeon, noted these when he addressed your group last year. The first human factors element affecting the performance of a maintenance technician is his *health.* Here, we refer to much more than whether or not he is sick. Health, again in the broad sense, can be affected by external as well as internal factors. For example, environmental influences such as noise and temperature can affect the momentary health of a worker and in turn his ability to perform his job well.

The second human factors element refers to the performance capability of a technician. Here we were interested primarily in the basic capacities of a worker to perform. Does he have the necessary strength, vision, etc. Of greater importance, however, are the effects of training. What are his performance capabilities after appropriate training for the task?

The next human factors element is one not usually considered in a discussion of human performance in complex systems, yet it is of great importance. Here I refer to any transitory condition which impacts performance. This might be recent or on-going drug use, emotional stress, financial problems, or any other factor that serves to degrade ability to perform. In the Office of Aviation Medicine, we support a number of research activities in which we identify the effects of substance abuse, whether abuse of alcohol or other drugs, on performance. Within the FAA, we also have an industry-wide anti-drug program in effect for all segments of aviation, including aviation maintenance.

The final human factors element to note is, for today's purposes, the most important one. Here I refer to *task demands*. This topic encompasses most of the typical human factors issues one would find in a text on this subject. Man-machine relationships, communication systems, job aids, and all components of the human/system interface are of concern. How does the human function as one part of this man-machine system? How must the system be structured to draw on the best human capabilities and reduce the potential for human error?

Just as we learn more of the complexities of human performance, we also note that aviation itself, and certainly aviation maintenance, is becoming more complex and, in turn, presenting new demands to the maintenance workforce. Procedures and systems for the delivery of maintenance information are changing. Hard copy is rapidly being replaced by electronic delivery systems. Do these changes improve maintenance quality? We do not know as yet. New composite materials are being tested for use in aircraft. These composites appear to have greater strength and lower weight than conventional aluminum plate. They also appear to offer a service life three to five times greater than that of corresponding aluminum structures, with greater resistance to fatigue crack growth after repeated stress loadings. What does this mean for inspection procedures and for repair requirements? Fiber optic harnesses now are being tested in aircraft for the transmission of flight deck maintenance data. While this system should increase transmission capacity, does it impose new maintenance requirements as well? Is the potential for maintenance error changed in either direction?

We might also note that All Nippon Airways recently opened a new hangar at Tokyo's Haneda Airport. This hangar is believed to be the world's largest truss-roofed aircraft hangar and has room for five wide-body transports. The hangar has an automated parts storehouse that can accommodate some 130,000 items. Will this facility, and its automated systems, have a significant affect on the quality of maintenance? Certainly, this facility is further indication of an increasing role for automation in maintenance programs. I suspect we will hear more about the pros and cons of automated maintenance systems in our presentations and discussions today and tomorrow.

Now, in closing, I would like to return again to our theme *Trends and Advances in Aviation Maintenance Operations*. The FAA program **"Human Factors in Aviation Maintenance"** has been in operation now for approximately five years. During this time research has been conducted; meetings have been held; reports have been prepared and distributed to industry. If nothing else, this effort can be justified in terms of the extent to which it has sensitized the aviation maintenance community to the importance of human factors and to the extent to which human factors technology can contribute both to operational efficiency and to the control of error. However, the contributions of this program go far beyond simple increased sensitivity. New human factors maintenance technologies have been developed and new ways of dealing with man-machine interface issues prepared. Some of this work has been done by the FAA and its contractor team. Other work has been done within industry facilities. Together considerable progress has been made. I am most interested in hearing the presentations today to learn of current industry programs and the successes for which we all may take some measure of credit.

This meeting should be a pleasant one as we review recent accomplishments. It should also be stimulating as we consider the challenges that lie ahead in a growing and increasingly complex maintenance industry. I wish you a very productive and successful meeting. Thank you.

FAA REGULATORY OVERSIGHT AND UPDATE

Leslie K. Vipond
Aviation Safety Inspector
Federal Aviation Administration

I began my career as a young engineer working on missile design. We had an airframe life in those days of approximately one minute. You were not happy unless the payload and the missile blew up. Now that I have aged a few years, we are looking at preserving airframes into the fourth decade. In fact, we would like to end up in terms of safety in the boneyard tucked away down at Davis Monthan, or someplace like that. My career at this point is to be dedicated to preserving those airframes and to regulate the people that work with them.

We in the FAA have two ongoing regulatory activities that relate to maintenance technicians in Parts 65 and 147. Part 147 relates to maintenance training and the certificated schools where people come for their primary training. The training in the schools last for approximately two years. Part 65 regulates the maintenance technician himself or herself. Where are we right now? I have to tell you that Part 65 on the maintenance technician is moving far faster than we expected. It seems like every time we have a meeting, we make new advances in the notice of proposed rulemaking.

Approximately five years ago, we began a project to change the rules for aviation maintenance technicians schools. The process resulted in a final rule in 1992 (midyear) in which we upgraded nondestructive inspection for composites and turbine engines; in fact, avionics or electronics were also upgraded. One of the problems we found was that the 200 schools we have are pretty much stuck at 1900 hours of training, primarily because there was an implicit limit of two years of training. One of the problems we had with the school curriculum being confined to two years was that we could not upgrade our standards for the technicians. The industry's needs have moved beyond what can be done in the limit of 1900 hours; this limitation is slightly outdated. We started an Advanced Standards Initiative (ASI) last year. The ASI would involve training and certification, thus encouraging technician schools to develop new curricula.

We already have four or five schools that are quite interested in helping us create this Advanced

Standard program, and we are creating Centers of Excellence for Technician Training. These centers would train technicians to advanced standards. A task force is currently working with industry to determine the length of ASI training. We believe that it will be between 500 and 700 hours, but we do not want to nail that number down until industry gives us a reasonable figure. We are also finding it best, in terms of regulatory activities, to keep the curriculum flexible. In order to ensure that the curriculum remains flexible, we may try a different type of certification for the training provider. In other words, we may look more closely at the training provider, rather than trying to adhere to a rigorous curriculum, to provide flexibility in the curriculum yet regulate it through the training provider.

We have an Aviation Rulemaking Advisory Committee (ARAC) that has met a number of times. This is an FAA-industry working group that is helping us with the Advanced Standard Technician (AST). The primary difference in this program is that the person gaining the advanced knowledge would pay for it himself, as opposed to the current process where the airline trains an individual after graduation. Our bottom-line about both programs is that maintenance errors must be reduced.

There are many possible benefits to industry (**Table 1**). We believe that the advanced curriculum will lead to an immediate reduction in maintenance errors and a corresponding increase in the operation's efficiency. The operator can then focus internal training on type and difference; that is certainly not the case today. A big portion of operator's training time is currently devoted to things like basic electronics training.

Table I Industry Benefits

- Existing qualified technicians will be grandfathered
- Some advanced training costs shifted to technicians
- Reduction in training programs at operators
- Operator training can focus on aircraft type and company procedure training
- Reduction in maintenance errors

The Professional Aviation Maintenance Association (PAMA) is solidly behind this proposal. They do believe that their members should pay for this training themselves. We believe that an ASI technician will be significantly more valuable to the employer and hence the certification is more valuable to the technician (**Table 2**).

Table II Technician Benefits

- Existing qualified technicians will be grandfathered
- ASI technicians will be more employable
- ASI training will be an extension of basic school
- ASI technicians will work at a higher standard
- ASI technicians will be more valuable to employer

Table 2

Figure 1 shows the current training structure. If you take the horizontal axis as time to train a technician and the vertical axis as the depth of training, you see that the primary training for an aviation maintenance technician (AMT) is general airframe and power plant courses that last for approximately 1900 hours. When apprentice AMTs come out post- certification, they are trained by industry. Currently, they are trained in type training, processes, and company culture. This training is quite costly to the industry.

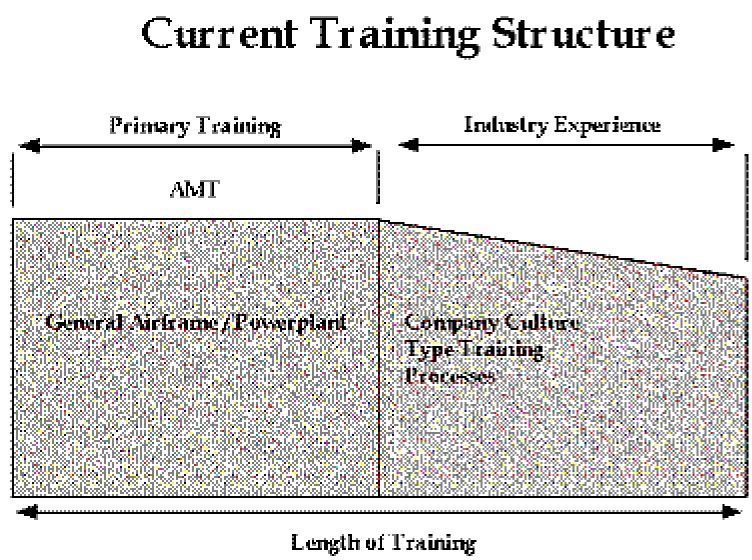


Figure 1

Figure 2 is the essential part of our proposal. What we are saying is that when the postgraduate student comes out and if he or she were working in the air transportation industry, the student should take the Advance Standard Initiative, providing his or her own training. You can see that the advanced training is to the same depth as the primary training. At some unspecified point in the advanced training (we do not yet know how many hours that would be), the student would have avionics, electronics, nondestructive inspection, composite training, and some pieces of type and culture. Industry would then provide the remainder, to the right, which is, again, primarily type and difference training on the aircraft in an airline's fleet.

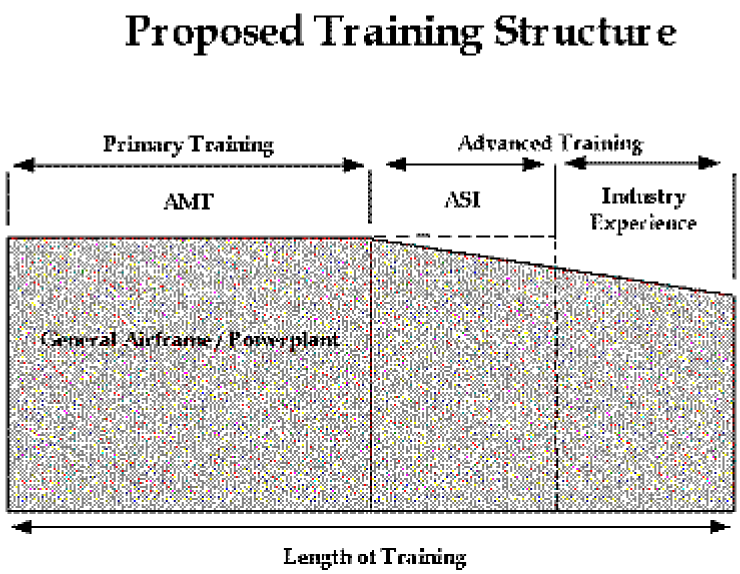


Figure 2

Figure 3 shows what we think the regulatory structure will look like. The structure continues to evolve, as we have had a number of meetings, and the proposal is evolving rather rapidly. Currently, in the portion to the left, a student becomes an AMT by going to a Part 147 school, by having a certain amount of experience in the industry, or by a combination of 147 school and experience. AMTs are eligible after three years for inspection authorization, giving them certain privileges primarily on light aircraft. However, it also extends to some transport operators for certain types of work. Our proposal is that advanced ASI status would be grandfathered initially for AMTs working in the field. After the grandfather phase is over, ASI status would require advanced schooling. Upon successful completion, they would be an AMT ASI and have the privilege of working for the airline industry, primarily in return to service of Part 25 aircraft.

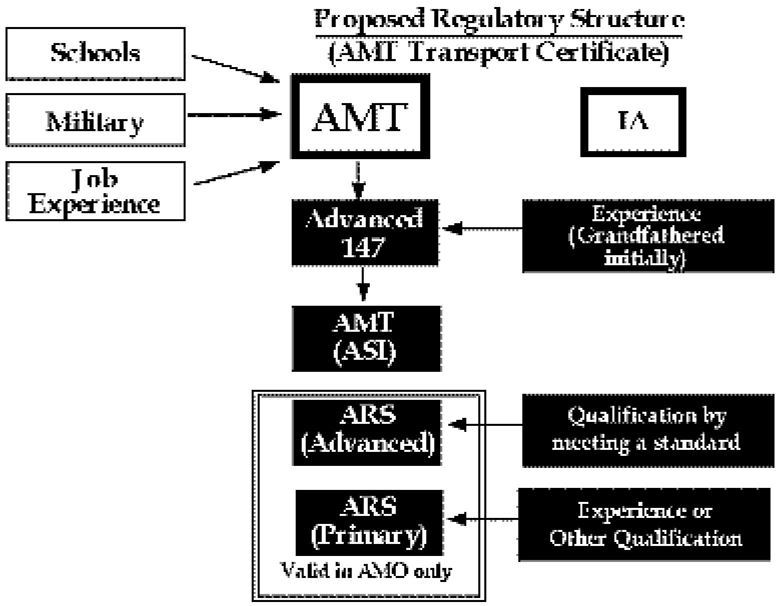


Figure 3

At the bottom of **Figure 3** is special portion of the proposal I have not discussed; it relates to advanced standards for specialists. As an AMT is a generalist, there is also another program for the specialist, primarily for AMTs working on nondestructive inspection, avionics, electronics, composite repair, and other specialties. The proposal is that a primary ARS (aviation repair specialist) can become an advanced ARS through experience only and with some limited training. We are now going to specify qualifications as standards for particular types of specialties. The details have yet to be worked out. We are working with industry to identify which specialties need a higher qualification and which types of training would be appropriate. You see that this is marked valid in AMO only. That means in an approved maintenance organization only, which would be an airline shop; you cannot go out there and work on your own. Only an approved maintenance organization can exercise those privileges.

IMPROVEMENTS THROUGH REORGANIZATION OF BRITISH AIRWAYS MAINTENANCE

Michael Skinner
Maintenance Training Manager
British Airways

British Airways has been undergoing a reorganization of its entire Engineering Department in order to improve safety and efficiency. **Figure 1** gives you an idea of the size of various different departments within British Airways. Total company has about 48,000 staff. Engineering and Property is a not a very large section of that. You can see that a large part of the cost of an airline tickets goes to Marketing and Operations. Still, without those people, we would not sell very many seats. Most airlines are probably similar to **Figure 1** in composition. I am not going to comments on salaries earned in the various departments. If you happen to notice, the flight crew is at the bottom. That is only for purposes of this slide. Their salaries are not at the bottom.

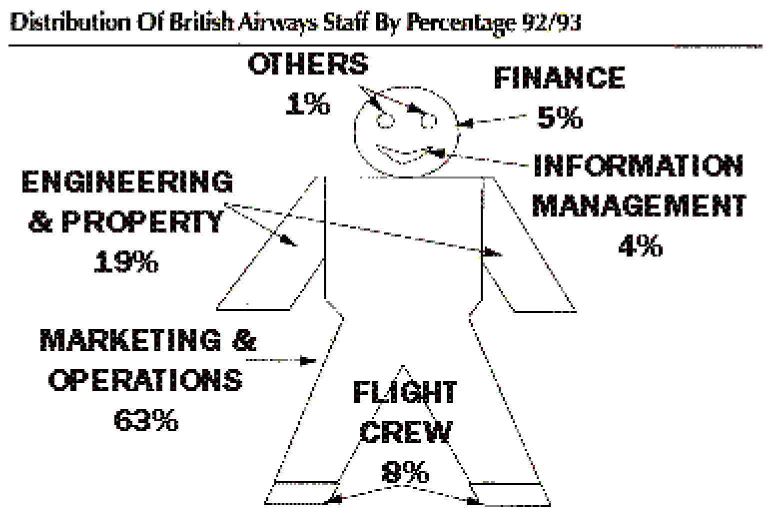


Figure 1

Although engineering is a small part of British Airways, it is the arms and has probably led the way with cost savings within the company. We have done a lot of work in reducing costs and have had a lot of new initiatives. One thing I would like to talk about today is a new initiative to restructure the entire Engineering Department.

Engineering has about 8,700 people. **Figure 2** shows the breakdown. Operational Aircraft is the largest segment, for obvious reasons. Heavy Maintenance includes all the main work done in the hangars. MMCO is our component overhaul side. It was considerably larger until we sold the engine overhaul division to finance an acquisition. As you probably know, we have money invested in all sorts of companies: US Air, QANTAS, and one or two other.

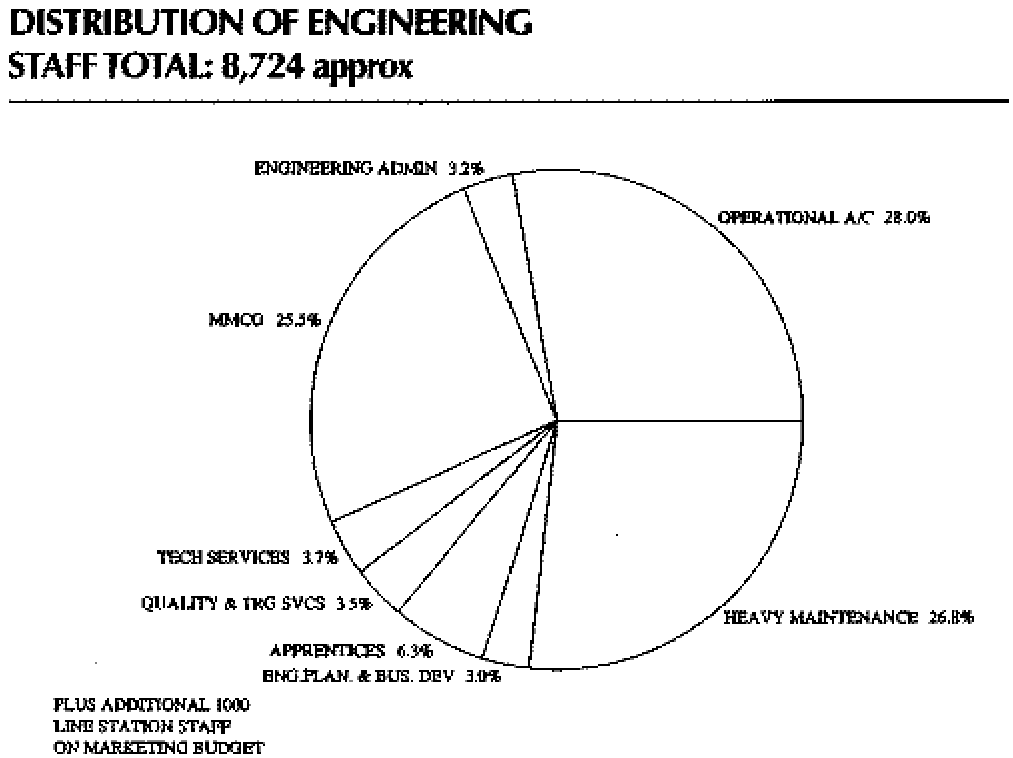


Figure 2

I work in Quality and Training Services, a very small part of Engineering. I run a training school with some 25 instructors, not very large when you consider that my target population is about 8,700.

Figure 3 breaks down where our 8,700 engineers and support people live. The two biggest areas, again, are Heavy Maintenance and Operational Aircraft. That is what I am mainly going to deal with. The figure dates back to November 1992, and the figures do not truly reflect the breakdown of people at that time, but was an estimate. Included in that estimate are LAEs, technicians, and aircraft mechanics.

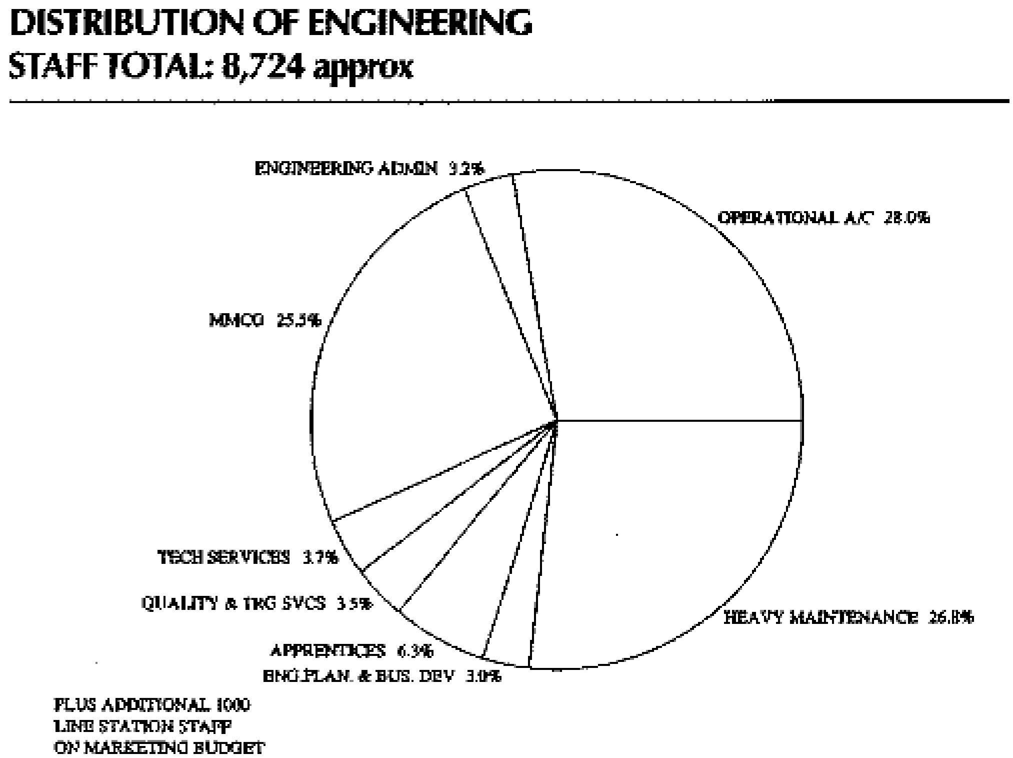


Figure 3

The number of people who work directly on aircraft is about 4,800 (**Table 1**). If we break this into two 50% chunks, 50% of those people are managers, foremen, supervisors, and CLTs (Certifying Lead Tradesmen). A CLT is a licensed engineer with exactly the same qualifications as a supervisor, but not holding a supervisory post. The 50% of tradesmen are skilled, but do not hold licenses and, therefore, do not receive services from my department. One of our concerns is that we have a massive work force and we only teach 50% of them real detail on the full CRS (Certificate of Release to Service) cover. These are the guys that sign out aircraft. The tradesmen work on aircraft, but they do not have a certificate of release, which means that they cannot sign an airplane out.

Table 1 Engineering Manpower 1992

<u>Engineering Manpower 1992</u>

- 4800 Direct Labor on A/C

<u>Breakdown:</u>
- 50% Managers/Foremen/Supervisors/CLTs
- 50% Tradesmen

Now, we are missing quite an opportunity. One of the things we wanted to do is eliminate supervisors, so part of our restructuring has changed a lot of ways we work. **Table 2** outlines one way we have approached it.

Table 2 Engineering Manpower 1993

Engineering Manpower 1993

- 4200 Direct Labor on A/C

  Breakdown:
  - 700 Support - Managers / Dock Control / Planning
  - 3500 LAE/Technician/Mechanic
    20% LAE (Licensed A/C Engineer)
    40% Technician
    40% Mechanic

You will notice that the numbers have come down a little. That is not a result of our getting rid of people, but a result of natural waste. One thing we do not want to do in British Airways is to make people redundant. We create gaps in the lines to bring more work in because we do not want to get rid of people. We have a large investment in people; we spend lots of money training them. The last thing we want to do is to give them away. There are plenty of people out there who want to take them, like Virgin and one or two others.

We now have about 700 people in what we call support. Managers were always there for dock control and planning. Dock control was the function of a foreman before, and planning was the function locked away in an ivory tower somewhere. We never had planners on the hangar floor. What we have now is planners on the hangar floor that are part of the dock control system. They do part of the job that the supervisor used to do, so these 3,500 people, the hands-on people, do the job they are paid to do. They are not involved in progress chasing, running for the bit, looking at this/that bit, or running away to stores. We have a separate group of people under dock control to do that.

Our aim is to be at those levels in five years: 20% LAE's (Licensed Aircraft Engineers) instead of what we currently have; 50% of our stock licensed. It is a big training burden to train 50% of your staff for full CRS. Our goal is to have 20% licensed aircraft engineers. I do not use the word *supervisor* because it is a swear word at British Airways, but that is the type of role an LAE performs, a person who does the diagnostics and troubleshooting on the airplane. An LAE leads a team to repair an airplane.

Dealing with the 40% of technicians is a new beast for us. The technician is not new; the function is new. This person will have a limited CRS, without necessarily being a license holder, in other words without holding a full CAA license without type rating (LWTR). In five years' time, that is what our breakdown will look like.

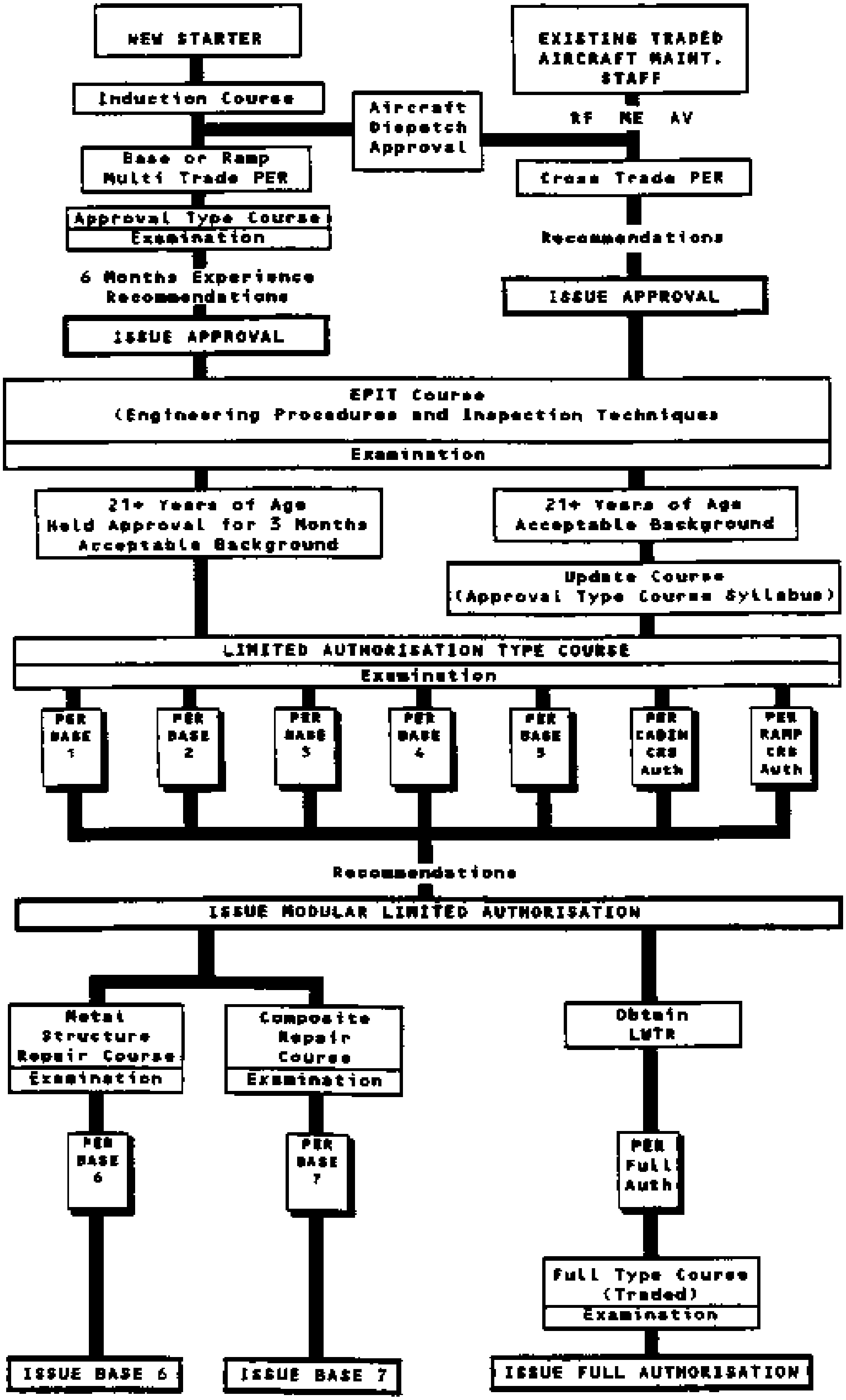
Our training school has a throughput of 240 students a day under this new system. When I was training 50% of the work force, I had about 140 students a day in training school. Since this has gone up to about 240, one of the natural questions, "How many more instructors will we have for the extra workload?" The answer is none. Now that does not mean that my instructors are underworked. In fact, any of them will tell you that they are very much overworked. So basically, I have about a 100% increase in throughput for the department with no increase in staff. There is no magic formula as to how I have done it. I did what most of you would probably have done; basically, I asked for more staff. I was told, "Sorry, you can't have more staff."

I went and talked to the customer. I went and talked to the boss of Operational Maintenance and to the boss of Heavy Maintenance. I said, "We need to do something to train your people. In time, this new structure will drive down the demand for full CRS training, but in the meantime we have an operation to keep going and my customer out there still needs his licensed engineers." The only way I could solve the problem was to be loaned some staff; this is how I got a 100% increase in staff. It is great because I do not have to pay them. I just manage what they do. I am responsible for what they do, so what they do is produce work for me.

It has other benefits. Not only does it give me the ability to meet this increase through labor, but it breaks down some gaps that were there before; it builds bridges out of gaps. I have always had a problem with paying engineers more than instructors. Through a bit of restructuring, not only in the training department, but in the whole of technical services of British Airways we created something called *technical management*. My instructors now are classed as a technical management group. They do not necessarily manage employees, but this gives me the ability to pay them a bit more, to bridge the gap between them and the mechanics on the airplanes.

So, now I bring in this increased work force, give them basic instructional technique training, sit down with my instructors to develop courseware, and have a great big catchall area of potential instructors. I have already recruited two of them to my permanent work force, so it has done me a favor, as well.

Figure 4 is a flowchart of the restructuring process. It looks a bit like a map of the London underground; so, to make it easier to understand, I will divide it into three parts.



NEW STARTER
Induction Course
Aircraft Dispatch Approval
Base or Ramp Multi Trade PER
Approval Type Course
Examination
6 Months Experience
Recommendations
ISSUE APPROVAL
EXISTING TRADED AIRCRAFT MAINT. STAFF
RF ME AV
Cross Trade PER
Recommendations
ISSUE APPROVAL
EPIT Course
(Engineering Procedures and Inspection Techniques
Examination
21+ Years of Age
Held Approval for 3 Months
Acceptable Background
21+ Years of Age
Acceptable Background
Update Course
(Approval Type Course Syllabus)
LIMITED AUTHORISATION TYPE COURSE
Examination
PER BASE 1
PER BASE 2
PER BASE 3
PER BASE 4
PER BASE 5
PER CABIN CRS Auth
PER RAMP CRS Auth
Recommendations
ISSUE MODULAR LIMITED AUTHORISATION
Metal Structure Repair Course
Examination
Composite Repair Course
Examination
Obtain LWTR
PER BASE 6
PER BASE 7
PER Full Auth
Full Type Course (Traded)
Examination
ISSUE BASE 6
ISSUE BASE 7
ISSUE FULL AUTHORISATION

Figure 4 Restructuring Flowchart

As I already said, we will not benefit from this system for five years. People coming in from the top (the two lines shown in **Figure 5**) are skilled mechanics, tradesmen, engineers, call them what you will. These are not people coming into the company off the street. They all have the necessary experience and background to be an aircraft maintenance technician. There is another line for existing people in the company. We have negotiated this agreement with the trade unions and have got their total agreement. We have talked it through the CAA and have a year's trial period to see if it works OK and has no negative effects on aircraft safety. What we have agreed on is that every tradesman technician currently in the company has the opportunity to achieve technician.

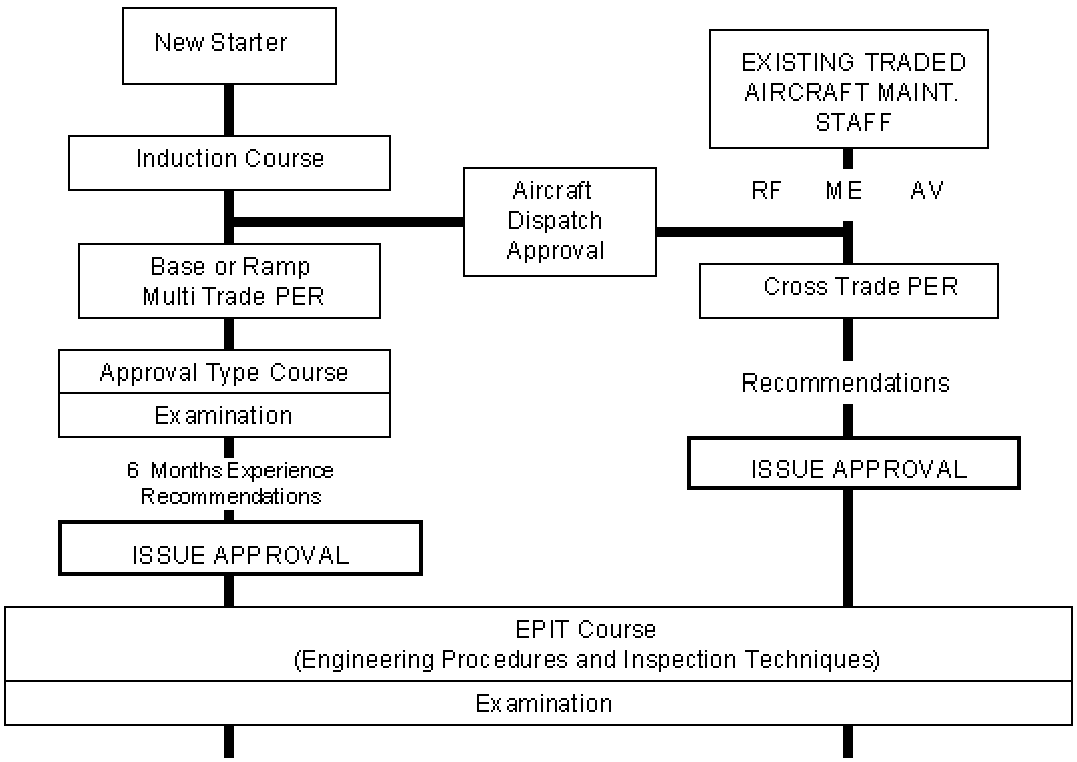


Figure 5 Restructuring Flowchart Part 1

What I have not mentioned is perhaps one of the most significant changes. Our license structure is a little different than what you have here in the US with the FAA. We have mechanical tradesmen, Airframe and Powerplant, and avionics instruments: electronics, radio, etc. Our CAA licenses dictate that technicians who sign out aircraft are either licensed in the mechanical or the avionics arena. What we have done is to produce a limited authorized person who can do limited tasks across all trade boundaries. A technician will come in here and will do some cross-trade training, organized by his or her manager, refurbishing mechanical and avionics. They already have skills in other trades because they have worked with those people for awhile. They will learn from that basic experience, work in a different trade, and build up what we call a PER, that is a Personal Experience Record. It is a record of tasks they have performed it is monitored by our senior people. This is a very closely monitored process. Once they have worked across those trades, completed their cross- training PER, and have their supervisor's recommendation, they will get an approval.

The approval does not enable the person to clear any aircraft paperwork. It means an individual can do tasks and identifies that he or she has done the job. The release to service comes later. Everybody who works on an aircraft has completed basic skill training and has learned the company's procedures. They know how to inspect an aircraft because it is laid down in a manual, but we felt we were missing something. So, we have run every single mechanic and engineer in the company through this engineering procedures and inspection techniques program, to refresh and update their skills.

When a new starter comes into the company whether from another airline, from an apprentice program, from the military, or from wherever, they get an induction course into what British Airlines is and how it works. They start to build a multi-trade PER. These people work either in heavy maintenance, which is base, or line maintenance, which is ramp. They start to build up their experience record. They then have an approval type course, which is not my responsibility. I am responsible for authorization training, not approval training.

The people I have in line who are doing this limited authorization training will, in time, pick up and run the approval course. Then, when the person has built up the PER, has done some approval training, has the necessary experience, and has the assessor's recommendation, he or she will be approved.

Figure 6 shows basic requirements of age, having held the approval and having been accepted. It goes on both sides. The update course is built into an authorization type course run in our training school. However, this is not the only training that the engineers have to get this limited authorization. What we try to do is to present a common core course that runs across base maintenance and operational aircraft. This is followed by hands-on training which is then recorded in the various PERs.

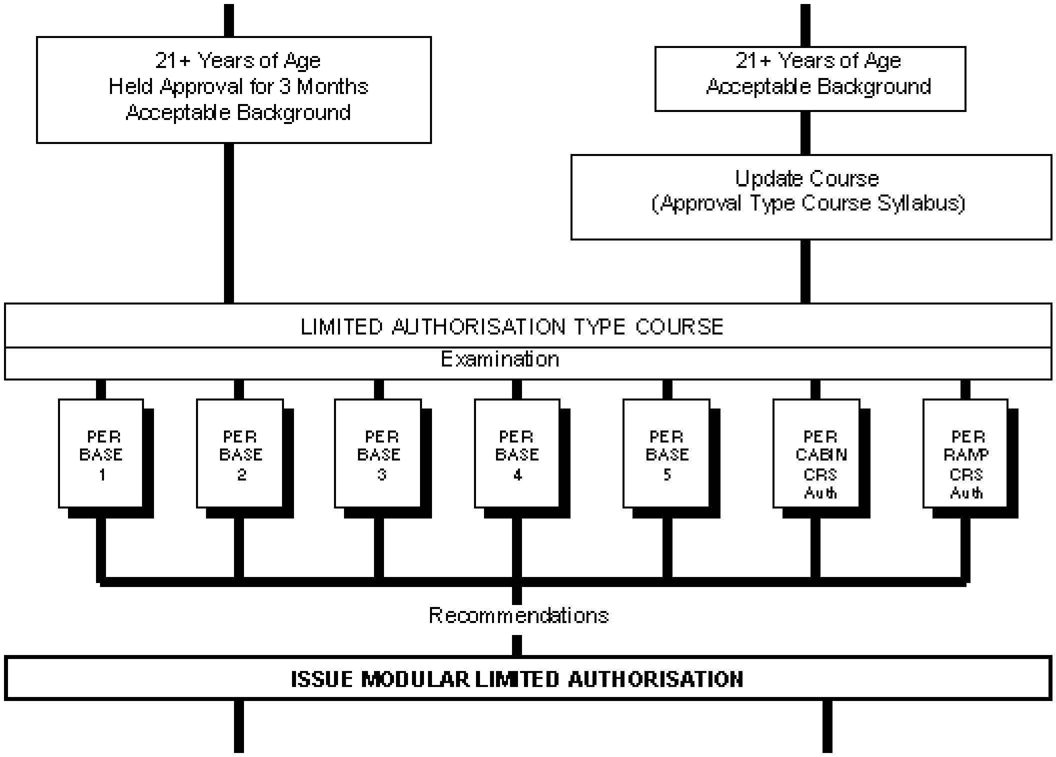


Figure 6 Restructuring Flowchart Part 2

Generally speaking, this course is aircraft type oriented and is basically a three-week full- trade familiarization. It covers the systems, how the airplane works from all trade areas. After they have completed that course, they go away and build their PER. I will go into what the one, two, three, four and five are in a moment. Basically, one, two, three, and four are purely base maintenance. Five is an oddball, what we call a service check and cabin and ramp CRSs. It would take far too long to cover the whole lot, but I will touch on what we do in the base area. When the engineer, mechanic, tradesman, or technician has completed the three-week course and the PER, had it all suitably stamped by a quality approved assessor, they are then issued the modular limited authorization.

There are two more modules in **Figure 7**. I will go into a little more detail in a moment. From this point on, there are a whole bunch of people who are multi-trade covered. For somebody to have a full certificate of release to service an airplane, he or she must comply with CAA regulations; they must be licensed and trained in accordance with CAA regulations.

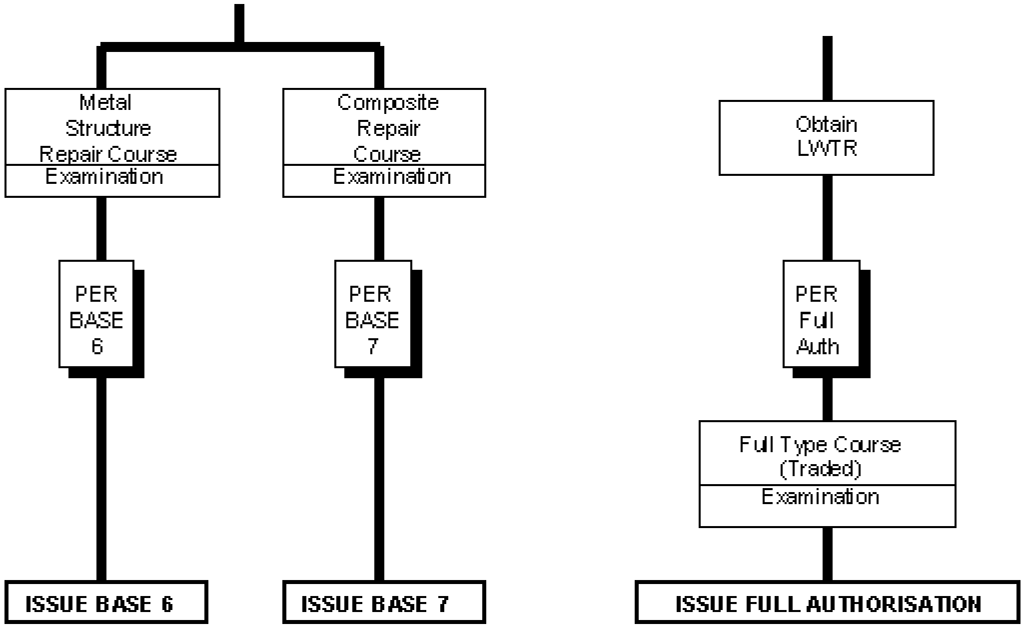


Figure 7 Restructuring Flowchart Part 3

We now have people who have limited authorization, and I will go into what we can do with that in a moment. Those people can go on and get full license without type rating, receive a full aircraft type course, and end up restricted by trade as to what they can do. Even so, the person probably is better all-round qualified, having broadened his or her skill base across all trade categories.

What are the modules (**Table 3**)? This really is all for heavy maintenance: it is how those different areas are broken down. I do not want to spend too much time on this; I want to spend more time on the one for Base. Basically, they break the airplane down into areas, and a technician can have limited approval on various areas. Numbers six and seven are extensions given to somebody who holds numbers one, two, three, and four. Number 6 is for structural repair--metal; number 7, structural repair--composite. They are both specialist training courses. Numbers one and two stay in our skill center, which trains apprentices and gives basic training to all the engineers in British Airways.

Table 3 Modules

	Modules
1.	Engine / Pylon / APU
2.	Wings / Empennage / Ldg Gear
3.	Ext Fuse / Equip Bays / Cargo
4.	Cabin / Flt Deck
5.	Service Check
6.	Str Repair (Metal)
7.	Str Repair (Composite)

A person with ramp maintenance authorization is one of our front-line people. These people are working on our airplanes that come in sick and, hopefully, go out fixed. Sending out a licensed engineer to an airplane that basically just needs gas pumped in, the tires kicked, and a quick look around is an expensive way to operate. We want to give the people with limited authorization the ability to go out to a clean airplane, that is, an airplane coming in with no significant defects. When a plane is inbound and the pilot calls in to say that it has no significant defects and is good for a turnaround, we do not need to send a licensed engineer. We can instead send someone with limited authorization to go out and do a PDI (Pre Departure Inspection) on ramp 1. That is basically a turnaround check, involving a lot of extra work like looking at bits and pieces of the airplane, kicking tires, checking wires, looking at the wheels, and looking at the brakes. If an airplane has significant defects, we have to send out a licensed engineer.

We have picked or identified 21 items that really are not that important because they are liable to change, and you will notice that we have included the engine starter. When we used to operate airplanes like Tridents, we used to change starters like they were going out of business. We do not change many starters now. Anyway, we identified 21 items these people could have limited authorization on (**Table 4**). They can identify a brake unit that needs changing and change it, certify it, and send the airplane on its way. I must stress that this is a trial. We are about nine months into the trial, and everything was negotiated and agreed with CAA. They are looking at us and what we're doing; they want to make sure that it has no significant safety effects on the British Airways' operation.

Table 4 Ramp Maintenance Authorized Tasks

Ramp Maintenance Auth Tasks

- PDI / Ramp 1
- Defect Rectification and Component Changes:

1.	WHEEL CHANGES	11.	HE IGN PLUG (LESS FNC)
2.	BRAKE CHANGES	12.	INT DOORS & PLACARDS
3.	EMG EQUIP (LTD)	13.	CABIN FURNISHING REPAIRS
4.	OVENS / BEV MKR	14.	ENG OIL FILT CHK (LESS L/CHK)
5.	LIGHT FILAMENTS	15.	STATIC WICKS
6.	W/WIPER BLADES	16.	CREW H/SETS
7.	SEAT REPAIRS	17.	BATTERIES MAIN & APU
8.	COWLS & QA PANELS	18.	ENG ST VLV (LESS FNC)
9.	TOILET PUMP / FILTER	19.	ENG IGN BOX (LESS FNC)
10.	STARTER (LESS FNC)	20.	IDG RESET (LESS FNC)
		21.	IFE SYSTEM

That is basically what a person with ramp maintenance authorization does. When you consider that this person is not necessarily a fully licensed engineer, that gives you some idea of where we are saving in the cost of the person, not in the individual's skill and qualification. We feel we have trained the individual to meet the task's requirements.

Table 5 gives you an idea of the size of the task. We started less than a year ago, although we had talked about it for a long time before we started. By the end of October 1993, we had trained 1,146 technicians. It takes a little longer for those technicians to get their PER work done, to get it all stamped up, and then to obtain approval by getting it authorized. As of the end of October, we only have 131. We need many more to make the system work properly.

Table 5 Total Trained & Authorized to Date

- Trained - 1146 to end Oct 1993
- Authorized - 131 to end Oct 1993
- Target to train by end Mar 1994 - 2614

Our target is to train 2,600 people by March 1994 and we should achieve that. Basically, that is a brief overview of the approach British Airways has taken to deskill the task. It is very important to realize that we are giving people a limited authorization and an opportunity for training and hands-on experience in that task.

APPLICATION OF COMPUTER-BASED TRAINING FOR IMPROVED MAINTENANCE TRAINING EFFICIENCY

Dieter Reichow
General Manager, Technical Training
Lufthansa Airlines

It is an honor for me to be here to speak about improving some aspects of maintenance training by applying computer-based training. Let me begin by stating a few facts. We all know that today the air transport industry is facing a major crisis. Since the demand for available seat miles is less than the supply, aircraft are being deactivated. Since airlines are losing money, airline workers are being laid off. Here in the U.S., airlines are operating under Chapter 11 or are going bankrupt. So, this obviously would not seem to be the right time to brood about new training concepts.

However, you may be interested to note that *crisis* is derived from ancient Greek and originally had two seemingly different meanings. The familiar meaning points to an unstable, dangerous situation; the second, strangely enough, points to a chance or opportunity. In the case of the air transport industry, the chance should be viewed in terms of consequences of the pressure on airlines to become more efficient. The issue is so serious that airlines which do not become more efficient will not survive. The chance the current crisis offers is for airlines to use the excess human resources many of them have these days to realize their current strategic goals and to be better prepared for the future. Well- prepared, efficient airlines can meet their future earning goals with their marketing, reservations systems, service systems, and so forth. Efficiency also positively affects costs.

Figure 1 shows the typical cost distribution of a typical airline. Incidentally, the figures are from Boeing. These figures are from Boeing's current market data, and they use them every year. There are only a few costs we can influence. Costs like those for fuel and landing fees cannot be greatly influenced by an airline. However, the 11.5% of total costs for maintenance can be positively influenced. Given that the overall operational profit margin of an airline over the last two decades or so is typically 2%, you can imagine how much we can improve profits by reducing maintenance costs.

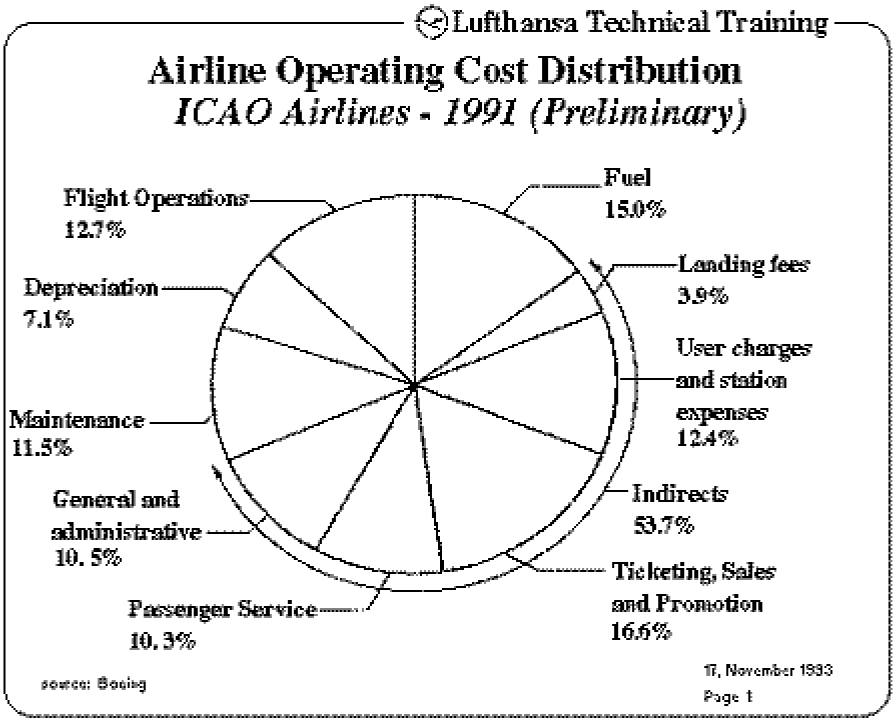


Figure 1

We should also continuously assess the present situation and anticipate future developments. One parameter we are interested in, obviously, is our future capacity requirement (**Figure 2**). These figures, again, are from Boeing's current market outlook. Notice that the almost-catastrophic crisis, or at least the crisis that was a catastrophe for a few airlines, shows as only a small dip in the capacity requirement. Even though we as an industry are certainly facing difficult times, there is no doubt whatsoever that the capacity requirement will reach levels much more dramatic than many people realize.

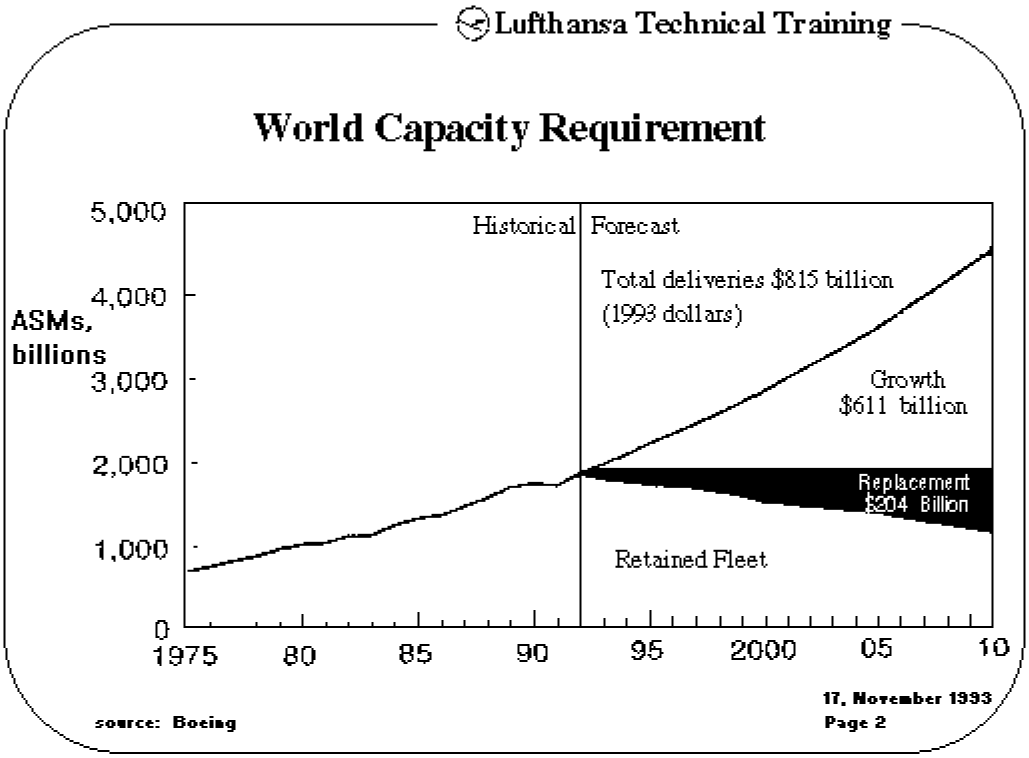


Figure 2

Next, consider U.S. airlines operating profit margins (**Figure 3**). The gray areas represent recessions when profits are, of course, unstable. The average profit margin is 2%, but there are major noise factors leading to losses during recessions. The industry either has just been through or is still in a recession now. Boeing is expecting a profit margin between 4% and 6% after 1995. Boeing has been undertaking this study for about 20 years, and they have been very successful in anticipating the future. After all, they are number one in the aircraft industry. While we can somewhat rely on their numbers, we also have to realize profitability is certainly not guaranteed for airlines because Boeing thinks the good times will return when airlines can charge passengers at pleasure in order to cover their costs and provide some profit margin. In any case, money will certainly not be falling from the sky. Rather, the only airlines to survive are the most efficient in providing air transport service.

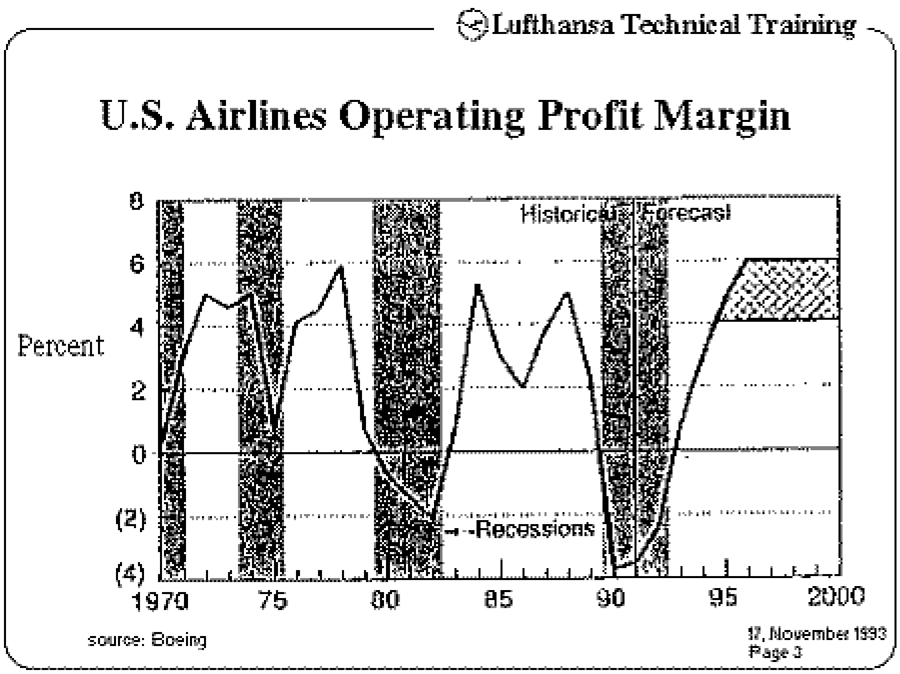


Figure 3

As an example of this increased efficiency, the Boeing study simply assumes a 3.9% per year decline in maintenance costs. Maintenance clearly has to become more efficient to meet the challenges of tomorrow's air transport environment. How can we enhance maintenance efficiency (**Table 1**)? One way certainly is to purchase maintenance-friendly aircraft. There has been a lot of progress in this direction, and today's aircraft are much more maintenance- friendly. We are not going to talk about this today. Once an aircraft is in operation, of course, the task is to optimize the maintenance schedule, maintenance organization, and work structures. We heard a bit about this from the last speaker. I would like to address a third issue: qualifying maintenance staff exactly to the required competence. Before we do that, we should realize a few facts and conditions that, in my opinion, sum up the problem statement (**Table 2**).

Table 1 Ways to Enhance Maintenance Efficiency

- Design/Purchase Maintenance-friendly Aircraft
- Optimize Maintenance Schedule, Maintenance Organization, Work Structures
- Qualify Maintenance Staff exactly to Required Competence

Table 2 Facts to Sum up the Problem

- Aircraft technology increasingly complex
- Maintenance training volume steadily increasing
- Yet: Training results increasingly questionable
- Benefits of aircraft technology advances not fully realized in maintenance
- Presently: Qualified maintenance personnel decreasing/migrating to other professions
- After 1995: Over-proportionally increasing demand for AMTs

First, everyone knows that aircraft technology is becoming increasingly complex and will continue to become even more complex. The amount of training maintenance requires is concurrently increasing steadily, or at least the volume has been steadily increasing. The problem we now have is that training results are increasingly questionable. While an AMT may have passed an examination, we are not really sure that he or she is really competent to locate a fault when seeing only its symptom. We also wonder if an AMT is competent to use the aircraft documentation or the troubleshooting manual. In short, we have questions as to whether the AMT is actually fully trained for his or her tasks. I certainly doubt that he or she is.

The benefits of technological advances in aircraft are not fully realized in maintenance. Many training and maintenance structures do not fully benefit from the fact that we have fault- tolerant aircraft capable of surviving multiple faults without having to be repaired. The CMC (Central Maintenance Computer) or CFDS (Central Fault Display System), if you will the troubleshooting computers, are not fully utilized as the prime tool for many concepts. Also, maintenance personnel are migrating into other professions simply because they are being laid off. However, the Boeing study and the Blue Ribbon report, mentioned earlier today, predict an increasing demand for AMTs after 1995. Now, I am not saying we were not prepared to produce competent AMT's in the past; and I am also not saying that we can throw away anything that we have learned about training. I am saying that we are going to have a problem tomorrow if we do not anticipate future demands and challenges today.

We cannot simply continue to address training the way we have in the past. Today, we have to embark into developing and implementing more efficient training strategies (**Table 3**). This effort is twofold. First, we have to produce the required number of competent AMT's after 1995; second, we have to synchronize AMTs' skills with technology changes efficiently. Therefore, we have to ask ourselves what are we doing wrong (**Table 4**) and identify what will we have to do to be better in the future. This process is not confined to Lufthansa, to European, or to U. S. airlines. It is a typical challenge, I would say, for the entire world.

Table 3 The Challenge

To embark into more efficient Training Strategies:

- To produce the required numbers of competent AMTs after 1995
- To efficiently synchronize AMTs' skills with technology changes

Table 4 What are We Doing Wrong?

- Apprentice Training based on yesterday's technology
- Skill deficiencies only partially compensated by lengthy Type Rating Courses
- Hopeless attempts to mediate increasingly complex technology by increasing training volume

Yet: AMTs are not sufficiently prepared for their task
Yet: Aircraft safety essentials sometimes falling a victim to aircraft complexity

Apprentice training for AMTs is typically based on yesterday's technology. I think that the Blue Ribbon Panel pointed out that while some five or so AMT schools were updating their training, they still rely upon yesterday's technologies such as prop airplanes, avionics, and software. These AMTs will have skill deficiencies once they enter airline operations, and these deficiencies are only partially compensated by lengthy type rating courses. Eventually, airlines get caught in what are essentially hopeless attempts to mediate increasingly complex technology with increased training volume.

We have to realize that with a typical modern aircraft there are some 20,000 signals being processed, transmitted and received. It is completely hopeless to attempt to explain everything. The trainers, at least those designing the curriculum, basically try to include what is probably necessary to know and also include what has to be addressed in order at least to address an airplane's most important features. The result, at least at Lufthansa, is that a modern aircraft such as a 747-400 has a thirteen weeks' type rating course, which is too much. An average of 10% of our mechanics are constantly in training, which is also too much. The problem is compounded by the fact that, as I indicated above, AMTs are not fully prepared when they join an airline's operations.

Even more marginal, to say the least, aircraft safety essentials sometimes fall victim to an aircraft's complexity. In the mess of all the various functions and signals, in the middle of all the thousand of things that seem to be somewhat important, essentials suddenly get lost. Let me give you an example. A mechanic has typically been trained to and fro, forwards and backwards on the autopilot. He or she also knows all the logics and subroutines one finds in a computer nowadays (to me, by the way, that knowledge is a complete nuisance). However, suddenly it happens, in fact it happened in my airline, that there was a squawk and the dual autopilot disconnected below 100 feet. There are so many squawks on autopilots, so much nuisance, that the mechanic did not understand, "Hey, this is something else. It has a different dimension.

There must never be an autopilot disconnect below 100 feet. A dual-land operation on an autopilot is not supposed to do that." Consequently, this problem was treated like many other squawks; it popped up to somebody who thought, "Hey, we have a problem here. This autopilot has a design deficiency." This is a typical example of why the aircraft essentials are important; it is not so critical to have all the functions in memory.

What can we do to solve our training problem (**Table 5**)? Mechanics certainly need more profound jet aircraft fundamentals training, as for example that provided by the TRO/DLH CBT project on JAMF (Jet Aircraft Maintenance Fundamentals). This project arose from our conviction to meet future AMT requirements in both quantity and quality. Mechanics need a profound base of know-how about modern jet aircraft. When a mechanic is familiar with the generic systems of a modern aircraft, the peculiarities of a specific aircraft type are not so problematic. Task-oriented type rating training, such as the new DLH concept on type rating discussed later, can then be extremely efficient.

Table 5 The Solution

- Profound Jet Aircraft Fundamentals Training
  Example: TRO/DLH CBT-Project on "JAMF" (Jet Aircraft Maintenance Fundamentals)
- Task Oriented Type Rating Training
  Example: New DLH Training Concept on Type Rating

Let me enlarge a bit on JAMF, a project we are working on as a part of our fundamentals training and CBT project (**Table 6**). We are working with TRO (TRO Learning, Inc.) on this project. Although it costs a lot, we believe this is our best way to create a platform to work with in the future.

Table 6 JAMF Project

The Target Population

- A&P apprentices
- Skilled workers of appropriate technical trades, like car mechanics, to be re-trained to A&P mechanics in large jet aircraft maintenance
- A&P licensed mechanics with no experience in latest generation large jet aircraft maintenance

The Concept

- Task/procedure-based instead of system-based approach to determine the training contents
- Up-to-date aircraft technology (747-400/A320 generation)
- Edutainment
- Computer-based training (CBT, 100 hours of courseware); Classroom training; On the job training (OJT)
- Latest CBT technology, video overlay

JAMF's target population is primarily A&P apprentices from schools and colleges who have little experience in any trade. Also, we are targeting skilled workers in appropriate technical trades like auto mechanics who can be retrained as A&P mechanics in large jet aircraft maintenance. Licensed mechanics without experience working on modern jet aircraft are also included.

JAMF uses a task/procedure-based approach, not a system-based approach, to determine training contents. I will get back to this later. JAMF uses up-to-date aircraft technology, i.e. the 747-400 and the A320 as the generic aircraft. We included at least long-range, short- range, two-engine, four-engine, and the current generation. One thing we find very important is the edutainment value we insert in the program. In other words, a mechanic must be thrilled to go through this training. A mechanic should never say, "Thank God it's Friday"; we want him or her to say, "What a pity the day is over."

JAMF includes some computer-based training, using essentially the latest CBT technology with the video overlay. In other words, there is one screen containing the CBT and video. Of course, we also have both classroom training and on-the-job training, depending upon the lesson's content.

The major, and probably the most important, part of JAMF is the process of identifying the current training needs. Let me briefly describe it. In the top left of **Figure 4**, there is the terminal task listing. What we do is to go through all the job cards for the 747-400 and the A320 and also analyze the target population, e.g. what knowledge do our students have and what knowledge do we have to give them. These elements together comprise the Task Procedure Analysis: this is the point where we select and generalize so-called concepts. A *concept* is an idea, comprehension, or conception in aircraft technology that is not commonly known from daily life. The concepts are then sorted into a concept hierarchy from superordinant to subordinant. For example, a superordinant concept would be electrical power system; a subordinant, the DC power system, emergency plus battery. The concept hierarchy ensures that concepts are complete, that no important concept is missing simply because it did not appear on a job card for at least one aircraft.

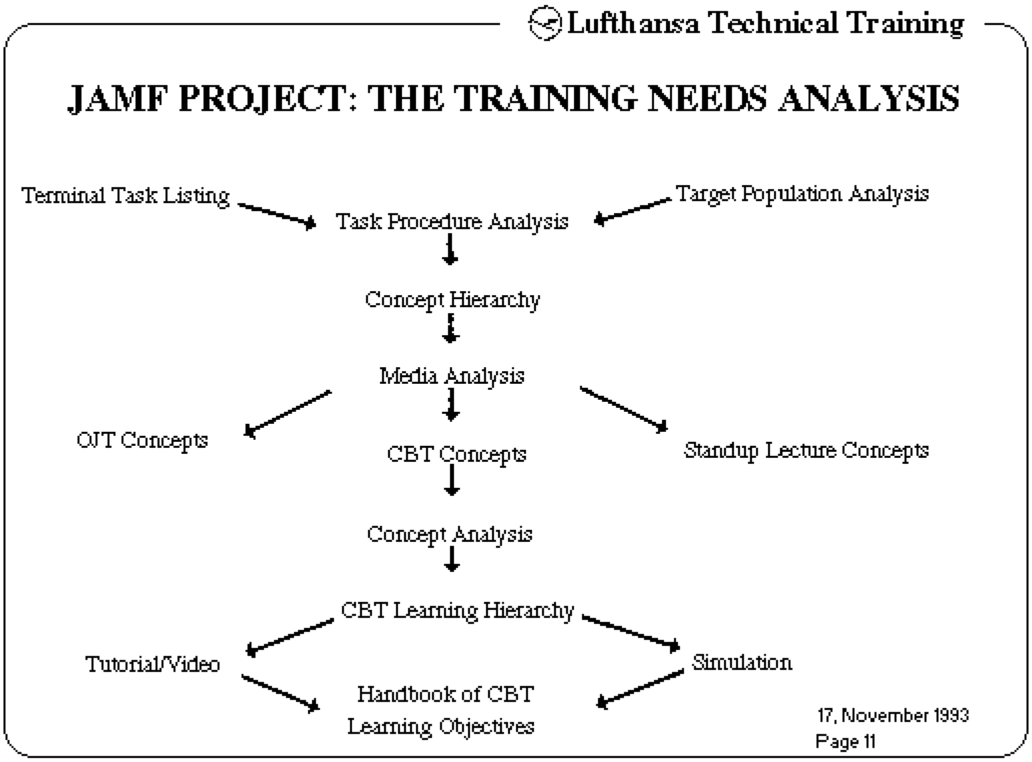


Figure 4

Concepts are then sorted as to which kind of training method or media is appropriate. The best approach for training may be on-the-job, CBT, or a standup lecture. For the project with T.R.O., we are picking out and making a concept analysis only for the CBT concepts. We are trying to determine the concept's peculiarity, its purpose, why it is necessary, and how it is best accomplished.

The next step is to define the learning sequence in the CBT learning hierarchy. Of course, this consists of tutorials and videos, being more-or-less an explanation for the student, and the simulation, being an exercise. Eventually, we chunk everything together. We allocate time and eventually create lessons from these elements. The result is a handbook of learning objectives.

The course menu is straightforward. As shown in **Figure 5**, there are unit menus containing tutorials and simulations. There is a glossary which the student can always access to find out the specific meaning of a word or abbreviation. There are questionnaires at the end of each section, and there is a final mastery test. Now, I would like to elaborate on a few aspects on this project.

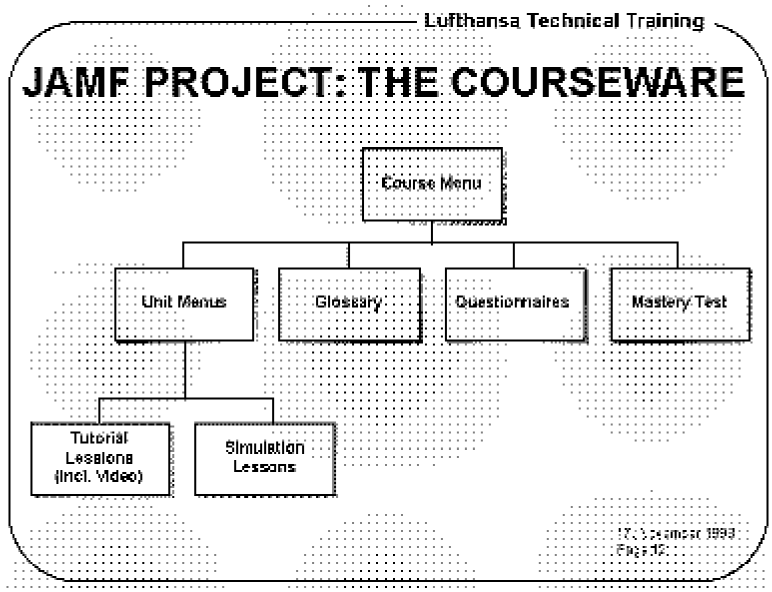


Figure 5

As I mentioned, not all training objectives are best met with CBT. Standup lectures are and will continue to be necessary. Certainly, on-the-job training is always necessary; things like a torque on a bolt cannot really be trained because an AMT has to feel it. CBT is best used for system-simulation arrangements. This is the major advantage and strength of CBT. In order for the student to master certain systems, system operation, and troubleshooting certain things, in other words for the student to learn by doing, CBT is also for tutorials designed to meet these objectives. We intend to have students use CBT without a trainer being present, but this is only possible and acceptable when designers take a systematic approach. In other words, we have to use a lot of manpower to arrive at a CBT lesson that provides a good tutorial that is acceptable to the student. Tutorials cannot be made on the basis of substituting standup lecture point-by-point and claiming that you now have a CBT tutorial. This has been done in the past quite often, leading, in my opinion, to unacceptable, catastrophic results.

As I said, type rating is training in fundamentals. I would now like to talk a little about the courses we have for type rating. CBT in this case is applied to simulation models. Since students actively use simulation modules, they appear to be very valuable. However, if they are done right, tutorials turn out to be too expensive. Therefore, we had to change our thinking about training for the type ratings concepts.

Our incentive for the new DLH concept on type rating courses was that we wanted to benefit from maintenance fundamentals training and avoid tedious repetitions (**Table 7**). For example, an hydraulic actuator was again and again explained in each type rating course. This ridiculous nuisance was necessary simply because it was not included in fundamental training. We now use task-oriented training to avoid training complex and unnecessary ballast such as the autopilot interlock chains.

Table 7 Incentives for New DLH Concept on Type Rating

- Benefit from profound Maintenance Fundamentals Training - Avoid tedious repetitions
- Task Oriented to avoid training complex, unnecessary ballast
- To make use of modern jet aircraft maintenance tools
- To maximize mechanics' competence on their jobs
- To maximize safety and economical benefit of training - using most efficient training methods and media

We also want our mechanics to use all the available maintenance tools. Our goals are to maximize mechanics' on-the-job competence to do the work they are required to do, to train them to use EDP (Electronic Data Processing) terminals, to train them to use aircraft documentation, and for them to learn to do those tasks they have not been trained on earlier. Eventually, to maximize the safety and the economic benefits of training, we do not want 10% of our mechanics in training.

I would like to briefly address subject-oriented as opposed to task-oriented training (**Figure 6**). In the past, we in the airline industry have utilized subject-oriented training. In other words, we have explained the aircraft, more or less in the hope that the mechanic would be able to handle the aircraft and perform necessary tasks once he or she understood all the functions. As you can see in the figure, of all potential training objectives, the results subject-oriented training achieves (vertical ellipse) are not the same as desired training objectives (horizontal ellipse). Subject-oriented training includes areas in which desired training objectives are achieved, but there are also desired training objectives that are not achieved. Subject-oriented training also achieves undesired training objectives, typically those things never exercised in the field. These are the things that people vaguely remember having heard five years ago. Desired training objectives are not things students learn only for an examination and never use again. Subject-oriented training leads to both "not achieved" and "not desired" training results. We are now trying to structure training so that desired and achieved training objectives are identical.

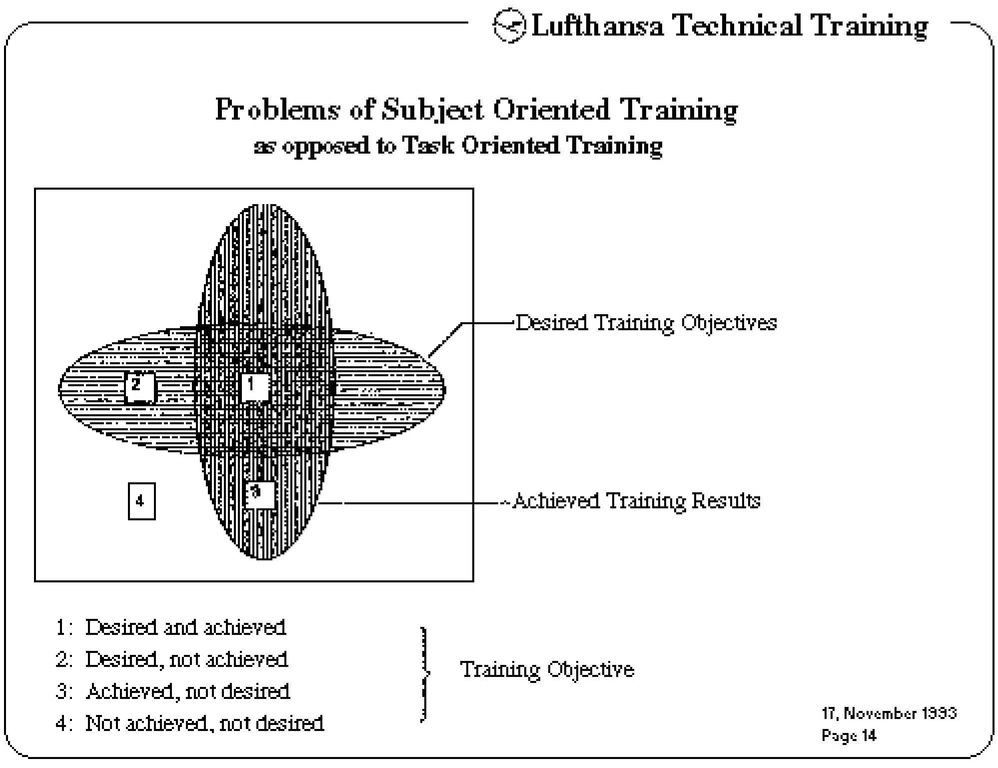


Figure 6

The training preparation sequence (**Table 8**) for the new DLH concept on type rating begins with the task analysis, i.e. with taking all job cards and identifying the qualification level (skills) a mechanic must have to perform the task. For example, a job card could contains the necessary steps for activating the APU. The next step is the training objective analysis, e.g. to identify what a student needs to activate the APU. Next, the trainer has to determine training steps and pick the most efficient training method and aid for each training step. The end result is a curriculum definition.

Table 8 Training Preparation Sequence for New DLH Concept on Type Rating

- Task Analysis
  for specific aircraft type
- Training Objective Analysis
  depending on qualification level required
- Determination of Training Steps
- Selection of most efficient training Method and Aid for each Training Step
- Curriculum Definition

Some training methods and aids are summarized in **Table 9**. Although CBT plays a major role in our training, we certainly do not use it exclusively. We continue to have standup lectures for tutorials, as well as instructor-led CBT's for tutorials. This is very nice, by the way. It provides more or less a moving overhead foil that can help students visualize signal flows and switchings. We have student-paced CBT mainly for exercises. We also use a full flight simulator, although we unfortunately do not have a maintenance simulator. Since a full flight simulator is so expensive to use, we employ it for circumstances such as engine run-up training. This allows us to avoid having an aircraft standing outside and having to train outside.

Table 9 Training Methods and Aids for New DLH Concept on Type Rating

▪ Stand-up Lesson	(e.g. Tutorial)
▪ Instructor-led CBT	(e.g. Tutorial)
▪ Student-paced CBT	(e.g. Exercise)
▪ Full Flight Simulator	(e.g. Engine Run-up)
▪ Team Exercises	(e.g. Troubleshooting with A/C DOC)
▪ Video	(e.g. Location)
▪ On-the-Job	(e.g. Removal/Installation)

We also use team exercises. For example, we might have four students sit together and train troubleshooting. The students would have access to the aircraft documentation. We also use video for location training, and of course we have on-the-job training like taking the students to an aircraft and performing tasks such as removal/installation. We try to mix method and media; we think this is necessary in order to keep the students awake. Quite frankly, thirteen weeks in the classroom from morning to afternoon can be quite tedious.

I would like to conclude my presentation with a few messages to the U.S. as well as the European airline industry. We must find ways to be efficient and part of that is to bring our technicians to the necessary competence and to ensure unimpaired flight safety as a result. Since our salaries in the Western world are magnitudes higher than in other countries, we cannot afford to have students sit in a classroom and fight against falling asleep. We also cannot afford to keep an aircraft on the ground because our AMTs are not competent to release it for service. We must make the maximum benefit of our human resources to secure our place in the world's leading aviation industry countries.

AIRCRAFT MAINTENANCE PRODUCTION AND INSPECTION: TEAM WORK + EMPOWERMENT + PROCESS SIMPLIFICATION = QUALITY

Robert Scoble
General Manager of Inspection
United Airlines, San Francisco

What I would like to do is to change our focus a little. So far this morning, the audience has heard about training technicians, mechanics, and inspectors. What I want to present will be familiar to those of you who have gone through TQM-type issues. At United we are learning to think in terms of TQM (Total Quality Management) philosophies and if some of my words sound like buzzwords, I apologize. They are new for us.

What I want to talk about is a management training and learning program that is underway at United. Over the past several years the industry invested considerable time focusing on human factors issues. We have looked closely at the environment: heating, lighting, and issues affecting how an individual works and his or her ability to get at the aircraft and feel safe and comfortable. Another factor that is also critical is an individual's attitude. I am going to focus on attitude today.

Since assuming my position as General Manager of Inspection, I had noticed an increase in friction in our work force over the last several years. My interpretation of the causes of this friction are summarized in **Table 1**. I suspect that everyone recognizes that the aircraft fleets have aged, although newer aircraft are entering operations. The older aircraft certainly have impacted inspectors and mechanics, and how they approach their work. We have seen increases in inspection requirements, Airworthiness Directives, and inspection programs. The newest requirement we are struggling with is the corrosion inspection program. These increased requirements produce additional work for inspectors. Most of these result in increased work cycle times and worker requirements. Another event we have seen at United is a significant increase in the size of the work force. We have newer, younger mechanics and newer, younger inspectors. To give a little perspective, eight or nine years ago, it required twelve to fourteen years seniority as a mechanic to become an Inspector. Today, an inspector can achieve a position with less than five years mechanic seniority. These elements combine to produce lower levels of experience and skill.

Table 1 Observations

- Aircraft Age
- Increased Inspection Requirement (AD's, NDT, Corrosion Program, etc.)
- Increased Manpower Cycle Times
- New/Younger Work Force and Less Dependant on Management
- Reduced Experience and Skill
- Increased Conflict/Tension
  - Lead Mechanics and Inspectors
  - Foremen
  - Mechanics

Routine employee meetings often carried a tone of tension between mechanics and inspectors. Through these meetings and interviews we found that many of the mechanics had a low regard for the aircraft inspector. They criticized the inspector for his perceived lack of skill and his unwillingness to work with mechanics. The mechanics believed the inspector had no "ownership" with the maintenance process. As a result, similar meetings were held with the inspectors. The inspectors were presented with the same questions. The inspectors responded with the same comments about the mechanics and lead mechanics. While conflict is not a new phenomenon in aircraft maintenance ,what I was beginning to see was unique and possibly the beginning of a potential problem.

We began with an aggressive approach to what was going on and to look for opportunities for improvement. The opportunities are summarized as the Process Review in **Table 2**. Four years ago, the Maintenance Division began to move towards TQM. Those of you who have been through TQM know that there is a definite focus on inspection. The idea is to eliminate inspectors and produce quality the first time. As you might imagine in an aircraft maintenance environment this added pressure to the work environment. However, we came through that period and validated the Value-Added role of inspectors. For example, the inspection approach of the past was to insure quality workmanship with inspection. Today, we use the inspector for his ability to evaluate the in-service condition of aircraft structure and when necessary provide a second look or "second set of eyes" for critical installations or system operation. In our environment we are dealing with a maintenance program that requires the skills of detection to identify the defects needing repair. Our inspectors focus these skills on preliminary or shakedown type inspections.

Table 2 Process Review

- Top-Down Directed Implementation of Total Quality Management Philosophies (Best Maintenance)
- Ongoing Process (We have Today's Answers and Tomorrow's Questions)
- Reviewed Organizational Structure of Separation
- Discussions with Lead Mechanics, Inspectors, Foremen, Managers
- Review of Existing Processes (Ongoing)
  Work Relationships between Production-Inspection
  - Separated Maintenance Organizations
  - Job Descriptions/Work Rules
  - FAR Required Separation "121.371" of Production-Inspection
  - Departmental Policies
  - Personalities: Control Types
  - Routine and Non-Routine Work Process
  - Department Goals
    -- Preliminary Inspection Performance
- Reviewed Non-Routine Document Process
  - Developed a Flow Chart of Steps Followed by each Non-Routine
- Experimented with Preliminary Inspection

We are now going through TQM training and TQM roll down to our foremen, and then on down through our inspectors and mechanics. This training is giving us is a new approach for evaluating our business processes and work relationships.

I am going to share some ongoing analysis that we are doing as a result of being critical of our business processes and worker relationships. I have to say that I think I have answers for what is going on today in our process. As we review problems and develop solutions, we discover that there is often an additional answer or another problem (opportunity). The process seems to snowball in terms of looking for new avenues and new approaches to solve problems on the floor. In aircraft inspection we undertook a rather critical organizational review. For those of you who may not know it, within our environment aircraft maintenance and inspection are in a sense two different organizations. I manage the inspection organization, and under the management philosophy taken from the FARs there had been an effort to keep inspectors separated from maintenance. We are finding that this structure creates a very complex work environment that produces turmoil. As I said earlier, we held discussions with our leads and inspectors. We also talked with our foremen. We found many of the work relationships among the foreman were similar to the leads and inspectors. What was apparent throughout all of the discussions was that everyone wanted the work to be done right.

Next, in our aircraft inspection, we began a review of the processes that operated between inspection and production. We focused that review on the relationships between production and inspection. We looked first at the separation of the organizations to understand and determine how valid it is and how it works. We looked at job descriptions and work rules, many of which we found are defined by the FARs, our IAM contract and by the way management has interpreted those definitions over the years.

We took a look at the FAR requirement of separation, §121.371, and at our departmental policies. We evaluated many of the regulations and definitions, placing our emphasis on simplicity. What we typically found was that we had interpreted rigidly and with a much greater requirement of separation than actually exists. When we looked at the people in our process, we discovered that many of our staff have control type personalities, frequently taking control and directing the individual organizations very rigidly. This adds to the friction between inspection and production when they are two separate organizations. The first corrective action we undertook was to reduce the conflict within the management group.

The inspection section managers were released to participate in planning and staffing meetings with the production units. The Inspection Department retained responsibility for the inspection process, overrule decisions and the individual evaluations and job performance issues of the inspection management team. This simple change began the process of combining the inspection and production elements back into aircraft maintenance.

Routine and Non-Routine Work Processes

The next process to be reviewed was the method of communicating non-routine maintenance. The inspection managers developed a process flow chart to trace the movements of the non-routine document and the way we identify non-routine work. Much of this process is a problem when you have a separated maintenance organization. We historically worked hard at keeping the inspector and the mechanic away from each other. Over the years we took the philosophy of separation in support of the FAR requirement and carried it into a separation of talent and skill that created a sense of conflict. When we developed the flow chart and made a presentation of our non-routine work process, it quickly became referred to as the great Easter egg hunt. The process works this way: an aircraft inspector would be assigned to accomplish a preliminary inspection of the aircraft, and he would report defects on single sheets of paper (non-routines). He would then turn the paper over to the planning center. The document would go to a lead mechanic, and the lead mechanic, under our system, will determine the corrective action to fix the defect.

The lead retraces the inspectors steps to locate the defect, spending time searching, identifying it, and determining what corrective action is necessary. The lead then processes the non-routine simply by saying what to do; it could be anything from simply changing a tire or brake to accomplishing a major structural repair. The lead's work then would go back to the planning center and then finally to a mechanic. The mechanic comes in as the third player in this process and must locate the defect again, figure out what to do, obtain all the documentation, obtain all the tooling and then probably would have to find the lead mechanic for additional information. This process requires a protracted period of time. Finally, after the mechanic does in fact get the defect corrected, the inspector, who has been kept out of the process is now brought back to evaluate the correctness of the repair. Because we have variable staffing and manpower to keep the work flow and work force somewhat steady, this is probably not the same inspector who wrote up the defect initially.

Now a fourth person is in the picture who does not have the advantage of ever having seen the defect. This final inspector has to determine if this is the defect area and repaired or a brand new part that was replaced. One can picture a repair that has obviously been repaired, but it is not quite so easy when a component has been completely replaced and the inspector can only assume that the work accomplished and the non-routine match up. So this is what has come to be called our great Easter egg hunt, the non-routine process.

Conflicting department goals are another process we have. Even though we kept telling ourselves that inspection and production plan and organize their work and their operations very much the same, they were separate departments with different goals. Together we did not understand the impact of some of the goals that we had, and we still do not understand them all. I think what I will show you shortly is a little of what we saw in the way of how our goals affect each other.

We reviewed the non-routine process that I have described and then we began to experiment with our preliminary inspection (**Table 3**). This is the issue of goals that I just talked about. For example, we had a time line to complete the aircraft maintenance visit in the hangar and to return the aircraft back to service. It is a business practice. We do not want an aircraft sitting in the hangar for a long time. It certainly does not generate any revenue during maintenance, so the idea is to get the inspection done, to identify all the defects, repair the defects in the shortest amount of time, and release the aircraft. We thought, and some of us still think, that the preliminary inspection is the critical path for completing the aircraft. The method used by inspection to accomplish this is to increase the staff and complete the inspection as fast as possible. We experimented just a bit to see what would happen if we altered the preliminary schedule. In one event, we increased the inspection staff to speed up the preliminary to get it done faster. The aircraft visit was completed in the same amount of hanger time. Next, we went back and reduced the preliminary staffing allowing the preliminary to drag on, while keeping a focus on the planned aircraft release date. The aircraft was released to service in the same amount of time.

Table 3 The Experiment

- Clearly Defined the Mission of Aircraft Maintenance:
  "Maintain Aircraft Better than Anyone Else"
- Defined Aircraft Maintenance as a Combined Inspection-Production Activity
- Assigned Inspection Management to Attend the Production Organization Meetings
- Selected Work Centers (Dock 4-SFO B737 HMV and Bay 1,3OAK B747 & DC 10 BCP)
- Created Lead/Inspector Teams
- Fixed Versus Variable Assignment of Inspectors
- Redefined Preliminary
  - Find Most Significant Defects Early
  - Routine Preliminary Accomplished within First 1/3 of Aircraft Visit
- Mechanic Given Expectation of Personal Responsibility for Quality

We now questioned whether or not there was any real validity to rushing through the preliminary. We knew we had conflict growing between inspectors and lead mechanics. We also knew that we had a complex non-routine system.

Now that we had several theories about our processes, the next step was to lay out an experiment. Within our organization I began to refer to the operation as aircraft maintenance, combining inspection and production activities. We are trying to get our people away from talking to each other in terms of inspection and production but simply to talk as aircraft maintenance professionals. Within my own management staff, I directed the inspection managers to attend and participate with production management so that they are, in a real sense, in direct communication with their counterparts. We also traded foremen between the inspection and production organizations.

Working with our heavy maintenance managers, we selected several work centers for the experiment. The first, Dock 4, accomplishes 737 HMV's in San Francisco. This dock was selected because of its consistent work type and because the dock is often used to provide manpower to other work centers. We thought that the 737 HMV was an ideal choice for the experiment since the mechanics have the same desire to complete the aircraft on time as everybody else. But they always feel that they are impeded because they become a manpower pool for the wide body fleet. In Oakland, the DC-10 and the 747 heavy checks were selected. In Oakland the work is performed in Bay 1 and Bay 3.

The next step was to create focus groups (TEAMS). This is a little different from the way we would have had it in the past, which was with variable staffing and isolated inspectors. We created lead/inspector teams that would remain with the aircraft through the entire visit, working together and developing their plans together. The inspector was also expected to remain in the work area, providing help and coaching the mechanics while repairs were in progress. The lead/inspector teams were assigned for the duration of the aircraft visit and responsible for all the work accomplished in specific zones of the aircraft. Instead of the inspectors accomplishing a rush-type preliminary with 15-20 inspectors on the aircraft at a time, we reduced the staffing to five inspectors. We allowed them to stay there for the full length of the visit rather than staying for a couple of days, during the preliminary, and then going to another dock, leaving just one or two inspectors to finish up. The fixed and variable assignment offers some interesting opportunities that we did not anticipate.

In addition to the pace of the preliminary we asked the team to locate and identify the significant defects early. Over the years, we have learned that our leads and inspectors that have worked with an aircraft know what to expect to be wrong before the aircraft arrives. They know what they can anticipate in the way of heavy work. We asked them, rather than to spend their time on the rigors of a focused preliminary, use your experience and identify the defects that have a high probability of occurring. We wanted those reported early to gain the greatest possible lead time for repair. We wanted to complete the preliminary within the first 1/3 of the aircraft visit to keep pace with the expected aircraft release date. In the past, we would have said that we wanted the preliminary done in the first 12 shifts. The experiment was set up to reduce the pressure of schedule on the preliminary. We said it was appropriate to take the preliminary out to 18 or 21 shifts and not to worry about it as long as the major defects were found early. Then, go back through all the standard work patterns to ensure that the preliminary inspection requirements were accomplished.

The last thing we did was to tell the mechanics that they are responsible for quality. Over the years, United's focus on inspection has grown so that today at the Maintenance Base we have 100% inspection Buy Back of every task accomplished by a mechanic. The inspector is asked to accept too much responsibility and the mechanic is willing to transfer his responsibility to the inspector. It is not unusual to hear a mechanic say, "If the inspector buys it, it must be O.K." Statements like this from the mechanic cause the inspector to lose his confidence in the mechanic and become far too critical of the work performed (remember the conflict I mentioned). This also defeats the second set of eyes concept since the mechanic is essentially transferring his responsibility to the inspector. The mechanic has ceased to be the first element in the Quality Control Process. This is why we went back to the mechanics and reinforced that quality is their responsibility.

Table 4 lists some of our expectations. The process simplification is certainly the non-routine. We are still working to simplify that process. However, teaming the inspectors with the lead mechanics on the dock certainly does reduce some of the hand-off and the communications breakdowns resulting from having separated and variable staffing. Having the leads and inspectors working together as a team reduces some of the communications breakdowns and misunderstandings they were having. We believe that we are seeing an increase in their knowledge of each other's responsibility and, as a result, an increase in the respect they have for each other. Lately, we are seeing a significant reduction in conflict. To better explain that, I conducted several focus meetings with various groups of mechanics, leads and inspectors that were working on the docks. One of the things that I used to finish my presentation was that a year ago we were seeing conflict and frustration between inspectors and leads. One of the leads rebutted my comment with "We don't have any conflicts." He then went through a long litany of how they work together, how they discuss their problems, and solve problems without involving management. I thought that was pretty good. I kept quiet, sat back, and said, "Great, I think we're heading in the right direction." Because the leads were saying something completely different the year before.

Table 4 Expectations

- Process Simplification
  - Non-routine Document Process
  - Simplified Communications between Lead and Inspector
  - Increased Knowledge of Each Other's Responsibility
  - Reduced Conflict Caused by Separation
- Empowerment
  - Decisions Being Made Jointly with Leads/Inspectors
  - Reduced Management Control of the Process
- Information Access
  - Inspector is Available for Consultation with Mechanics/Leads
  - Eliminates "After-the-Fact" Decisions by the Inspector
- People Development
  - Inspector can Train and Coach Mechanics
  - New Inspectors have Opportunity to Learn from Experienced Leads/Mechanics
- Future Focus
  - Continue Moving the Inspector into the Process

We continue to struggle with empowerment. We are not certain where we are going with empowerment, but we are trying to move some decision-making down to leads, inspectors, and mechanics. We had forgotten that our mechanics are trained, qualified and licensed. What we find when we look at our processes with simplification and empowerment in mind is that we have built considerable control into our system and reduced the authority and responsibility of the mechanic. Generally, we have some rule that a foreman must be involved and make the decision. We are now trying to push decisions down to lead mechanics and to allow them to use their authority and training and getting management out of micromanaging the process.

Information access is another issue with us, as well as probably everywhere else. In this case, I am referring to the information between the inspector and the lead. Keeping the inspector on the dock allows for close communication. A lead having a problem with a write-up knows who wrote it enabling him to get quick resolution. The mechanic can do the same.

We also are interested in developing our people. We find that the inspector, who receives considerable training, has an opportunity to train and coach the newer mechanics, providing them with the guidance they need to achieve. We focused on providing classroom opportunities where we present the same material over and over again. An individual needs someone to reinforce that learning, somebody to troubleshoot with, somebody to bounce ideas off. We had success with these ideas in our **NDT** operation when inspectors were teamed together. Now, we are trying to move it into the general maintenance community, having the inspector and the lead who have the training start to roll it down to the mechanic. Keeping the crew and team together allows training and learning to occur.

We saw the same thing happen with the new inspectors. Where we have new inspectors who are allowed to work with the senior inspector, they have a much higher confidence level and become independent much faster. After we looked at the separation of leads and inspectors and saw the conflict, we knew that mutual learning between leads and inspectors was not occurring. In the areas where we experimented by putting the inspector on a team permanently, communication significantly increased and we could see the mutual training and learning beginning.

In terms of where we are going to go with these ideas, I like the idea of putting the inspector in the process so much that we are continuing to do that. We see the inspector and the lead as the leaders in the hangar. They have the expertise; they have the experience. We are seeing that they also can provide leadership if we let them.

Table 5 offers a quick summary of what was observed.

Table 5 Results

Dock 4:

- Minor Increase in Cycle Time for Preliminary Inspection
- Increased Number of Non-Routines
- Reduced Number of Post-Visit Test Flights
- Slight Improvement in Aircraft MSR over Previous HMVs

Bay 3:

- First Aircraft to be Released Ahead of Schedule
- Significantly Improved Relationships among Inspectors, Leads, and Mechanics

General

- All Personnel Expressed Satisfaction with the Process
- Provided Increased Time for Lead Mechanics to Lead Work Force and Direct Aircraft Operations
- Significantly Reduced Conflicts between Leads-Inspectors
- Leads become Supportive of Inspectors

In Dock 4, the first item is a minor increase in the cycle time for the preliminary inspection. I was initially anticipating a preliminary goal as half the length of the aircraft visit; what we saw was an increase of only three or four shifts, not a significant change. However, we did see something that causes some anxiety: a significant number of non-routine documents were generated. We did four aircraft in Dock 4 and each aircraft increased over the previous one in terms of non-routine. The last aircraft completed with over 3,900 non-routine documents; typically, we would anticipate 2,500-2,800 non-routines.

On the positive side, we also saw a reduced number of post-visit test flights. Those of you who are familiar with our operation know that our aircraft coming out of heavy check receive a full flight test by our engineering flight test crew. For the last 737 that Dock 4 returned to service, the aircraft flew a single test flight with only one non-routine for a coffeemaker, of all things. We have a significant payback because it is rather expensive to do a test flight and then bring an aircraft back for additional work.

We are tracking the four aircraft through their operational cycle, and we are seeing a slight improvement in the airplanes' operating performance. In this case, I am referring to the MSR. For those of you familiar with the mechanical schedule reliability, those four airplanes seem to be slightly better than aircraft previously released from Dock 4 in terms of delays and cancellations. In Bay 3, the aircraft released in Oakland was one of the first that was released ahead of schedule. The first airplane on which we put the inspectors and leads together as a team was also the first aircraft that released to service ahead of schedule.

We have seen a significant improvement in relationships among inspectors, leads, mechanics and management. The reduction in turmoil is improving the cycle and the process considerably;

certainly, it adds to our training and to the understanding each has of their responsibilities and their roles.

These are some of the comments I heard when we debriefed our people on how they saw this process. I think everyone basically expressed satisfaction with the process. The leads liked having the same inspector to work with through the entire visit. One of the features that came from the change in the preliminary was more freedom for the lead mechanic. A diligent inspector rushing to complete the preliminary can inundate the lead with paperwork. Keep in mind that in our process the inspector is not allowed to tell maintenance how to fix the airplane, he works in that other organization. An inspector is only allowed to say what is wrong. Maintenance wants to determine how to fix it, and that is the lead mechanic's role. At the same time, a lead is also directing people, directing the work on the airplane, and trying to keep the entire process going during its early stages in the hangar. We found that by stretching out the preliminary, leads were not inundated with paperwork, and, as a result, the lead did not need to create more lead mechanics to do the work. When we debriefed the lead as to what they had been doing in the past, we found that they were upgrading mechanics to be lead mechanics during the preliminary so they could keep up with the work and, at the same time, keep all the paperwork flowing. We gained rather significantly here.

I have talked a lot about the conflicts between leads and inspectors. In summary, what we are observing is that much of this conflict is caused by processes. When the groups work as TEAMS they are capable of reducing the conflict caused by complex processes. I believe what we are seeing is that the way we manage is impacting our work force with rules and requirements that set the stage for conflicts. The leads and inspectors in these experiments became supportive of each other in the hangars, and were overall very pleased with what they were doing. These are a few of the changes we made to evaluate our processes. We by no means have them fully implemented in San Francisco or Oakland, we still have not convinced our personnel that leads and inspectors are talented and can be expected to do good quality work in a cost effective manner. But, we are moving in a direction that will empower the technicians to use their skills to produce a QUALITY PRODUCT at the LEAST COST.

In March of 1994 we are opening up United's Maintenance Center in Indianapolis. All of what I have discussed here will be implemented directly into the Indianapolis operation. The lead and inspector will be on the same team, the inspector will also determine corrective action and many routine checks or inspections will be delegated to the mechanic to find and fix. Thank You.

ENVIRONMENTAL REQUIREMENTS OF MAINTENANCE ORGANIZATIONS

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Aircraft Maintenance Technicians, Repair Stations and Aircraft Operators are all faced with an ever- expanding number of environmental laws and regulations. These new requirements can be expensive and require many hours of your time. Several examples in the United States are hazardous waste under RCRA (Resource Conservation and Recovery Act) and hazardous substances under CERCLA (Comprehensive Environmental Response, Compensation and Liability Act), the Safe Drinking Water Act, the Clean Water Act, and the Clean Air Act.

In 1990, the U.S. Environmental Protection Agency began implementing the many amendments to the Clean Air Act. Some of the new amendments have changed the way maintenance is performed and have increased the cost of doing business. Of the many chemicals used in the maintenance of aircraft and system components, a number of these materials and processes are critical to the quality, performance, and reliability of an aircraft over its life cycle. We must develop new ways to maintain the aging aircraft fleet in order to address environmental concerns.

The ozone protection provisions of the Clean Air Act require State Implementation Plans to place controls on the use of solvents, coatings, and paints. In 1993, these new requirements will stop the production of methyl chloroform, commonly used as a chemical degreaser, and restrict chromium processes. Several chemicals such as CFC-113 and methyl chloroform (1,1,1 trichloroethane) will be eliminated by specific deadlines mandated internationally. Development, qualification, and acceptance is well underway for alternative materials and processes that meet specific performance requirements and are cost-effective.

Solvents with a chlorinated formulas are being identified as either ozone depleters or toxic air pollutants. Until recently, Aircraft Maintenance Technicians had to rely on chlorinated hydrocarbons, petroleum naphthas, and CFC-113 to remove grease, oil, flux, and dirt. However, political pressures to eliminate these chemicals is mounting. They deplete stratospheric ozone and are restricted by the Montreal Protocol and the U.S. Clean Air Act. Also, many are suspected carcinogens posing health risks to employees.

Alternatives now on the market use citrus or terpene bases. Some alternative cleaners meet Air Force Specification MIL-C-25769-E. These include citrus-based products that act as a combined solvent and emulsifier system that does not cause corrosion; they are degreasers as well as cleaners. The products are nonflammable, non-toxic, and non-corrosive. Characteristics to look for include the following: biodegradability, water solubility, 100% fireproof, neutralizer for acids, emulsifier, rust retarder, oxidation renewer, multi-purpose concentrate, and economical.

Another option for cleaners are terpene-based cleaning agents that do the same job that chlorinated solvents (like 1,1,1-trichloroethane) and petrochemical solvents have done traditionally. These terpene- based cleaners meet the SAE ARP 1755A standard for use on all alloys. They are safe, non-toxic and biodegradable.

Ozone depletion and global warming are valid and growing concerns throughout the world. Replacement of ozone-depleting chemicals and chromium processes are just two applications that will require new alternatives. CFC-113 is currently used for cleaning printed circuit boards, for surface cleaning during aircraft assembly, and as a coolant and lubricant for many maintenance operations. Also restricted is methyl chloroform (1,1,1-trichloroethane) which is used for degreasing and as a carrier solvent for a variety of coatings and adhesives.

Another complex problem is eliminating the use of chromium and its compounds. Chromium has been used for many years in a number of surface finishing processes, coatings, and sealants due to its favorable corrosion protection characteristics. On the other hand, there is now an opportunity for new alternative coatings and paints to find a ready market.

In order to find a replacement for methylene chloride chemical stripping systems, there have been studies using dry media, dry ice and sodium bicarbonate, and flashlamps. They all have to be evaluated with these criteria: the cost of paint stripping, the labor and facility costs, and the possibility of causing fatiguing of the airframe, as well as causing additional corrosion problems.

We have to find alternatives to eliminate the safety and environmental headaches associated with chemical strip operations. The flashlamp system prevents the generation of large amounts of hazardous waste. The flashlamp is an Xenon arc lamp used directly on the coating. Depainted surfaces are ready for paint application after a simple water washing and solvent wipe. The coating will absorb light and carbonize without going through the melt phase. This is just one example of how new technology provides alternatives to using hazardous chemicals.

We, as Aircraft Maintenance Technicians, have several ways to comply with the law. We can practice waste minimization, source reduction, and recycling. *Waste minimization* means the reduction of waste generated or subsequently treated, stored, or disposed. Waste minimization includes source reduction of the quantity of hazardous waste or its toxicity while minimizing present and future threats to health and the environment.

An example of waste minimization is the substitution of cleaners for MEK, methyl ethyl ketone, which was identified as hazardous in November 1980. Do not dump these substances down the drain in the hanger. The Clean Water Amendments of 1987 mandates three classes of penalties, criminal, court- imposed, and administrative civil, that apply to certain municipal and industrial storm water discharges. The penalties are as follows:

Criminal Penalties (Penalties doubled for second conviction.)

- Negligent Violations - Person shall be punished by a fine of not less than $2,500 nor more than $25,000 per day of violation or by imprisonment for not more than one year, or by both.
- Knowing Violations - Person shall be punished by a fine of not less than $5,000 nor more than $50,000 per day of violation or by imprisonment for not more than three years, or both.
- Knowing Endangerment Violations - Person subject to a fine of not more than $250,000 or imprisonment of not more than 15 years, or both. A person which is an organization (meaning a legal entity, other than a government) shall, upon conviction, be subject to a fine of not more than $1 million.

Court-Imposed Civil Penalties - Courts may impose civil penalties of $25,000 per day for each violation. In determining civil penalties, the court shall consider the seriousness of the violation, economic benefit (if any) resulting from the violation, any history of such violations, any good- faith efforts, and the economic impact of the penalty on the violator.

Administrative Civil Penalties - The 1987 law gave the EPA new authority to administer administrative civil penalties (judicial review allowed) and fines may range from $25,000 to $125,000, depending on the type of enforcement action the EPA decides to pursue.

Source reduction is a second option. This approach means reduction of hazardous waste usually within a process. Source reduction measures involve process modifications, material substitutions, improvements in material purity, housekeeping and management practices, increases in the efficiency of machinery, and recycling within a process. Source reduction implies any action that reduces the amount of waste exiting a process.

Recycling is the use or reuse of waste as an effective substitute for a commercial product, or as an ingredient or additional material in a process. Recycling implies use, reuse, or reclamation of a waste after it has been generated. One example of a recycled material is used oil.

We all hope that we manage our resources wisely, provide for sustainable development, and improve the quality of life for all people. Reducing potentially toxic emissions into the air, water, and land is fundamental to this growing worldwide concern for our planet and its future.

HUMAN FACTORS EFFECTS IN THE FAA EDDY-CURRENT INSPECTION RELIABILITY EXPERIMENT

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Introduction

High-frequency eddy current inspections are an integral part of routine maintenance checks and of directed checks for surface fatigue in aircraft fuselage skins. To investigate the reliability being achieved in high-frequency inspections in airplane maintenance facilities, an experiment using simulated lap splice joints was designed at the FAA's Aging Aircraft NDI Validation Center. The design and implementation of the experiment was sponsored by the Federal Aviation Administration Technical Center in Atlantic City, New Jersey.

The goal of the experiment was to quantify the reliability of inspections as they are routinely performed in aircraft maintenance facilities. The participants were asked to perform the inspections using their own equipment and procedures. The experiment was generally located in work areas where this type of inspection would occur, thereby subjecting the inspectors to the same environment, distractions, etc.

The experiment was taken to nine (9) maintenance facilities from March 1993 to August 1993. At each of the facilities, four (4) inspectors (or inspector teams) inspected 924 rivet sites contained in the simulation. One of the inspectors (or one of the teams) repeated the inspection, thereby permitting for repeat inspection variation to be characterized. All inspections were observed and detection data gathered by a team of monitors. One of the monitors was a human factors specialist and the other was an NDI (nondestructive inspection) specialist.

The 924 rivet sites contained 184 cracks of known and well characterized length. All of the cracks were fabricated through load cycle fatigue in aircraft skin material. Details of the fabrication are given in Reference [1]. The cracks varied in length from 14 mils to close to one inch. Most of the cracks were in the neighborhood of 100 mils. This is the size of crack specified in Boeing procedures to set-up eddy current inspection equipment.

Subjective ratings on a three-point scale were obtained from the inspectors. This was done so a relative operating characteristic (ROC) analysis could be performed to supplement probability of detection (POD) curve fitting. Here, we restrict attention to the data that include all calls made by the inspector, regardless of the subjective rating. For most inspectors, even the most lax criteria level did not include an excessive amount of false calls.

Some of the flawed rivet sites had cracks from the right side, some from the left side, and some had cracks from both sides. In marking the rivet sites containing cracks, we asked the inspectors to indicate where the crack was with respect to the rivet head. It became clear that many of the inspectors did not have the ability or the experience in pin-pointing and marking crack locations. The most common result was that only one of the cracks would be indicated at those rivet sites containing two cracks. We decided that it unduly penalized the inspector to consider the unmarked crack at a doubly cracked rivet as having been missed. In the data presented, a cracked rivet is characterized by the length of the longest crack. The effect of having two cracks is studied as a factor in the regression analysis presented in Reference [2].

Experimental and Observed Factors

Various controlled factors were incorporated into the experimental design. These factors include: off-angle flaws, painted versus bare inspection surfaces, accessibility or ease associated with the inspection task, and specimen type. Details of the experimental design, including a discussion of these and other factors are given in Reference [1].

In addition to the controlled data factors that were included in the experimental design, there are a number of identified factors that were uncontrolled, but for which information was gathered. Factors included in this case were those that, in the past, have been shown to have effects on general inspector performance. For convenience in talking about these factors we have divided them into two broad categories: Environmental and Personnel factors. The Personnel factors category has been further subdivided into Physical and Psychological factors.

The measures that were examined in this section of the research were general measures of *performance*, rather than probability of detection. POD is important to safety, but does not tell the whole story. For example, improvement of factors that improved speed of inspections without lowering accuracy would result in lower inspection costs. Human factors in procedures that led to smaller cracks being detected at adequate POD levels could also lower inspection costs by allowing more aircraft flight cycles between inspections. These sorts of results can improve overall safety by increasing the resources that can be devoted to other safety issues.

Selection Of Observational Factors

Environmental Factors. The following environmental factors were selected for measurement or recording for their effects on inspection performance shown in other research **and** for the feasibility of measuring or consistently judging them. The selected factors were:

- Housekeeping
- Temperature
- Humidity
- Lighting
- Noise levels
- Behavioral Climate
- Tool condition and availability
- Instrument and probe type
- Instrument calibration characteristics (setting)
- Procedures used
- Scanning techniques
- Changes in environmental conditions

Personnel Factors. There are a very large number of personnel factors that have been found to be more or less relevant to inspection types of tasks in previous research. We broke them into two categories: Physical and Psychological. Physical factors are more easily measured, judged, or reported (e.g., age or gender). Psychological factors are less easily measured, judged, or reported (e.g., attitude).

It should be understood that the inspectors were regular employees of aircraft maintenance facilities. The parent organizations volunteered the time of these inspectors without any recompense. In fact, due to confidentiality requirements of the research, these facilities could not even find out how well their people did. The fact that so many organizations volunteered the time and space at their own cost is a tribute to the dedication of these organizations to safety and improvement of the entire industry. The inspectors were nominally volunteers - although we know that most of them were simply assigned to the experiment in much the same way that they would be assigned to any other job.

Physical factors that were selected to be recorded were:

- Observed general physical condition
- Postures used during test
- Age
- Gender
- Previous amount of sleep
- Time on duty
- Prior activities
- Reported physical condition
- Reported fatigue level (beginning)
- Reported fatigue level (ending)

There were more psychological factors proposed overall, since the research literature is quite full of factors that have some effect upon performance (although some of those effects are quite subtle). However, it was not feasible to give these volunteers a full battery of psychological tests, so the factors were limited to those that could be obtained through self- report or that could be easily observed. In the design, however, some of these factors were obtained from both self-report and observation and, in some cases, several measures that get at the same factor were built into the system.

The *Psychological factors* that were selected to be recorded were:

- Attentiveness
- Work patterns
- Attitude toward job
- Instrument-specific training
- Type of training
- Lap-joint experience
- Perceived management attitude
- Reported attitude toward experiment
- Reported mental condition (e.g., irritability, efficiency, depression, mental condition)
- Observed attitude
- Education level
- General experience level
- Recency of instrument-specific training
- Instrument-specific experience
- Lap-joint experience recency
- Perceived realism of test
- Reported attitude during test

Results

In presenting the results we will first discuss general observations on the controlled factors, followed by some discussion of the uncontrolled factors in the experiment. Detailed analysis of the data will be presented in Reference [2].

Controlled Factors and Inspection Data Results

Table 1 presents a summary of inspection results, where the total number of finds are given in several categories along with the false call rate. The categories presented are the cracks with lengths less than 50 mils (still under the countersunk rivet head), cracks with lengths between 50 and 100 mils, and cracks that exceed 100 mils in length. The 100 mils criterion was chosen because Boeing procedures call for setting up the inspection equipment using standards with 100 mil cracks.

Table 1 Number of Crack Detections and False Calls by Inspection within Facilities. The "R" inspections are the repeat inspections.

Inspector	<50 mils	50 to 100 mils	>100 mils	Total # False calls	Inspector	<50 mils	50 to 100 mils	>100 mils	Total # False calls
A1	0	42	97	22	F1	2	52	96	9
A1R	0	39	98	0	F2	0	24	79	2
A2	0	48	98	0	F3	0	54	97	0
A3	0	47	97	0	F4	2	53	97	3
A4	0	48	95	3	F4R	0	53	98	13
B1	1	50	98	1	G1	0	13	78	5
B2	2	56	93	1	G1R	0	13	81	4
B3	0	42	97	2	G2	0	28	98	6
B4	0	38	98	0	G3	1	5	73	10
B4R	1	48	95	0	G4	6	29	89	59
C1	0	41	98	2	H1	0	41	94	17
C2	0	49	97	1	H2	0	36	93	0
C3	1	56	96	6	H2R	0	42	96	0
C4	0	22	84	1	H3	0	28	91	3
C4R	0	26	93	0	H4	1	35	90	24
D1	0	34	97	3	J1	0	22	95	1
D2	0	35	96	6	J1R	0	38	98	11
D2R	1	41	96	3	J2	1	29	87	25
D3	2	45	98	29	J3	0	42	98	3
D4	4	45	98	84	J4	1	41	96	0
E1	0	35	97	2					
E2	1	32	93	3					
E2R	1	30	94	6					
E3	0	39	96	2					
E4	2	34	97	53					
#	22	64	98	598		22	64	98	598

Table 2 gives a summary of the inspection results by Facility. Also given in **Table 2** is the condition of the surface inspection at the facility. An analysis of variance (Anova) table for the number of detects in the 50 to 100 mil range is given in **Figure 1**. The Anova table summarizes the data for testing whether the facility-to-facility variation is significant when compared to the within facility (inspection -to-inspection) variation. The facility variation is significant but an examination of **Table 2** indicates that the major reason for facility-to- facility differences could be attributed to facility G.

Table 2 Number of Detections and False calls by Facility

Facility	<50 mils	50 to 100 mils	>100 mils	Total # False	surface condition
A	0	224	485	25	bare
B	4	234	481	4	paint
C	1	194	468	10	bare
D	7	200	485	125	bare
E	4	170	477	66	paint
F	4	236	467	27	bare
G	7	88	419	84	paint
H	1	182	464	44	paint
J	2	172	474	40	paint
# possible	110	320	490	2990	

Figure 1 Analysis of Variance Table for Facility Effect

Source of Variation	*Sum of Squares*	*df*	*MS*	*F*	
Facility	2512.89	8	314.11	3.51	(p=.007)
Inspections	2415.	27	89.44		
Total	4927.89	35			

Figure 1

From **Table 2** it is seen that the top five facilities, with respect to 50 to 100 mil detections, includes the four facilities where the inspections were performed on bare surfaces. A t-test comparing the overall means (for the 50 to 100 mil detections) of the inspections done on bare surfaces compared to those done on painted surfaces shows statistical significance (bare mean=42.7, painted mean=33.8, p=.005).

Uncontrolled Factors

Although the list of observed and measured factors is quite long, very few of them had demonstrable effects in this research. As is often the case when factors are not controlled, some of these factors may influence inspection results, but their effects are muted or confused by interactions with other factors. For example, factors within a facility, such as attitude and experience, could have strong effects that override other facility specific effects, such as poor lighting or the discomfort of high heat and humidity.

An additional difficulty in trying to analyze the effects of human factors on performance comes from the fact that some of the facilities use 2-person teams for eddy-current inspection. Thus, there is only one performance measure for two people. How can we tell which person's characteristics are affecting the score? The answer, of course, is that we can't. However, it did appear to the monitors that the poorest person in the team dragged the team down - rather than the best person pulling the team up (weak link phenomenon). Further research would be required to determine whether this impression is valid. If it is, the implication is that the best and most effective performance is actually obtained by inspectors working solo. The cost implications of such a finding are plain. It was clear that the two inspectors did not act as independent checks on each other in performing the inspections.

Only those factors that seemed to have real effects on performance (speed, accuracy, etc.) will be discussed here. All of the factors that were examined will be discussed more fully in the final report of this project (Reference [2]).

Instrumentation Factors. The three factors of "Instrument and Probe Type", " Instrument Calibration Characteristics", and "Procedures Used" are directly related to instruments and instrument use within the facilities. In general, these factors were consistent within a given facility.

Eddy current inspection equipment ran the gamut from very old Magnaflux ED-520s and Forester 2.8s to New Zetec MIZ-22s and Nortec 19s (and one Rohmann B1 with a rotating probe). The monitors acquired the impression that the older instruments were less sensitive for detecting cracks than the newer styles of impedance plane instruments (See Hagemaier [3]).

There were several different kinds of standards blocks used for setting up the inspection equipment. Blocks specific to the lap splice being inspected and called out in Boeing procedures were the most common. However, two facilities used "universal" eddy current standards (different at each) and setup the inspection equipment in ways other than specified in Boeing **NDT** procedures. One facility was near the top in overall performance, while the other was the worst in overall performance.

The monitors also observed variations in *interpretation* of calibration procedures. For example, many inspectors calibrated impedance-plane instruments to have a very tall, narrow loop or a very short, flat loop - rather than the symmetrical loop called for in the procedures. Similarly, some inspectors calibrated needle-deflection instruments to small deflections for lift-off and large deflections for cracks (typically full-scale) - rather than deflection in one direction for lift-off and in the opposite direction for cracks.

Inspectors who did not know how to set up optimal impedance plane settings (90% separation of x and y axes) or optimal meter balance (liftoff in one direction and crack indications in the other) handicapped themselves by making the interpretation of readings harder.

Lighting. The inspectors were able to overcome the lack of good lighting, in many cases by using flashlights to see the rivet heads. Although lighting is not nearly so important when inspecting with EC instruments as when visually inspecting, lighting seems to affect the speed of inspection. Simply put, the cost of better lighting (portable units, etc.) could be quickly repaid in faster inspections of the same accuracy.

Personnel Physical Factors.

Although physical factors have been shown to be important in manufacturing and visual inspection, they did not seem to have large effects in this research. Quality, rather than speed, of decision-making seems most important in the use of inspection instruments. Of course, fatigue slows all functioning so that performance suffered for the few inspectors that we had who were working past 8-hours in that day.

Age. There was some consistency of age within facilities. That is, a given facility tended to have all, or mostly all, younger inspectors or all older inspectors. Thus, the possible effect of age becomes hard to separate from other facility specific characteristics. Although not statistically significant, indications are that the younger inspectors tended to perform better overall than older inspectors. The impression of the monitors was that some differences were attributable to improved training methods that have come into use in the last few years, benefiting younger, but not older, inspectors. In addition, as was once told to the first author by an old Chief Warrant Officer in a military maintenance setting, "Lots of these old-timers just know a lot of things that ain't so."

In general, the solution to older inspectors "knowing a lot that ain't so" is not so simple as just requiring refresher training. Methods must be found to encourage old-timers to adopt more effective methods and newer equipment. In other words, there is a difficult problem of getting older inspectors to *accept* rather than just *undergo* fresh training.

Previous amount of sleep/fatigue. One inspector had worked an eight-hour shift before starting the experiment, several others told us of personal and/or family problems that had kept them from good nights of sleep before coming to the experiment. Most of the midnight shift inspectors reported being somewhat tired. These inspectors probably did not work to their own potential, but the differences among inspectors were so great that it is hard to tell how much better they would have done if they had had more sleep.

Psychological Factors

Essentially all of the inspectors were attentive to the job, had reasonably good attitudes toward their work and had good work patterns. That is, all the inspectors that we observed using eddy-current equipment were there to do a good job. For this reason, many of the psychological factors did not have importance because all inspectors rated "good" on the scales.

"Behavioral Climate" and "Perceived Management Attitude" did vary quite a bit between facilities, but we found that the inspectors overcame a lot of those difficulties through personal and professional pride in their work. Factors of housekeeping, resource allocation, and morale - that have been seen to affect performance among less skilled and dedicated workers - seemed to be overcome by the inspectors that we observed.

Work Patterns. All inspectors worked diligently at the experimental task. Many of the inspectors stated that they would have taken more breaks and rest periods on a regular inspection job that was not a test. In fact, some of the inspectors who took more breaks tended to be more accurate than those who worked straight through without looking up. This finding is consistent with prior research on inspection tasks. Inspection work requires many short breaks to maintain performance.

Type of Training. Other factors being equal, the school-trained inspector participating in the experiment was most accurate and performed the inspection in a timely manner. Inspectors who had taken good quality local classroom training (typically ASNT Level III instructed) on their instruments also did well. On-Job Training, even formalized on-job training, did not seem to produce the quality of inspectors that formal classroom training produced. It must be noted, however, that training in the theory of eddy-current instrumentation was not nearly so useful as training on the proper calibration and use of a specific instrument.

Specific Experience. Overall experience in **NDT** inspection appeared to be less important than experience with the particular instrument being used. In some cases, the inspectors had been well-trained on other instruments and spent the time and effort to familiarize themselves with the available instrument(s). In other cases, the inspectors were not familiar with new or upgraded instruments, which seemed to hamper their performance.

Summary and Conclusions

The goal of the Eddy Current Inspection Reliability Experiment was to quantify how reliably inspections can be carried out in aircraft maintenance facilities. Factors that might affect the reliability and that could be controlled were designed into the experiment. One of these factors, inspection surface condition, was shown to be significant using categorical detection data. The full quantification of the design factor effects will appear in a final report [2].

Data were also collected on various uncontrolled factors related to the inspectors and the inspection environment. Variations in many of these factors were observed and have been briefly described. Facility correlations and the particular mix of the observed factors, does not allow for statistical significance to be demonstrated for the effect of the uncontrolled factors. However, suggested influences of some of the factors are consistent with published research and have been briefly discussed.

The facilities who supported this research and the inspectors who participated were helpful in every way and seemed to want the program to succeed. The inspectors felt that the mock- up of lap joint inspections were a fair representation of the job and that, if anything, they would do a little better on the mock-ups than on the real thing. The mock-up was more uniform and regular than aircraft that have seen a lot of cycles of service. The inspectors were obviously doing their best to perform well on what they considered a "test". Nonetheless, we feel confident that this research reflects the general level of inspection quality that is found in the American Air Carrier Industry today.

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DUAL-USE TECHNOLOGY: APPLICATIONS OF FLIGHT CONTROL MAINTENANCE DIAGNOSTIC SYSTEM TECHNOLOGY IN THE COMMERCIAL ENVIRONMENT

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Abstract

First, this paper will discuss the problem that we were trying to solve with the flight control maintenance diagnostic system. Then we will present the results that one can actually achieve using this sort of system. We will present the technology elements that go into achieving that kind of result, and discuss the difference between what one would like to achieve and what is achievable. We give some views concerning what factors influence the technology transfer which so critically affects the attainable level of achievement. Finally, we will discuss the actual transfer that we've been able to achieve.

Problem Statement

The Flight Control Maintenance Diagnostic System program began in 1985. It is an effort for the Air Force Flight Dynamics Laboratory. We began this program working on the flight control system on an F-16A. At that point the flight control systems were analog. Even in the more simple analog system, there was a relatively high retest OK rate. On the flight line, a maintenance technician would remove a Line Replaceable Unit (LRU), more informally referred to as a "box". The technician would sent it back to the intermediate shop, they would run it through their automated test equipment, and about 40% of the time they were unable to find anything wrong with the LRU. The LRU would then be tagged as OK. That process is termed a Re-test OK or RTOK. What our analysis of repair records found is that the flight control system is substantially worse than other systems on the aircraft with regards to the RTOK problem. The high RTOK rate is still found as recently as 1990-91, as shown in **Figure 1**.

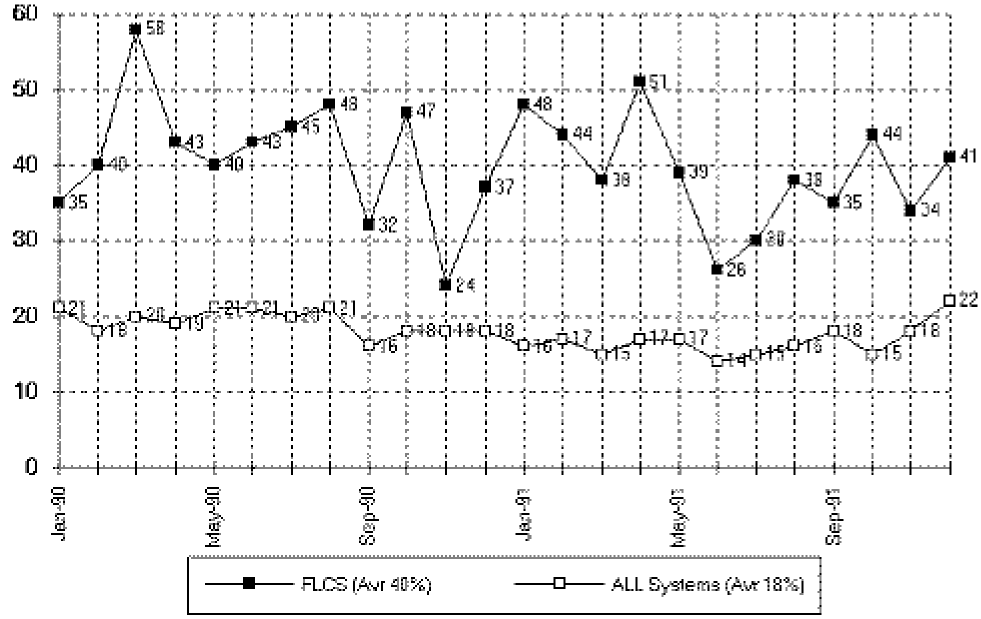


Figure 1 F-16C RTOK Rates

There are a lot of reasons that the retest OK rate is that high. One of the causes of that high RTOK rate, in our opinion, is the requirement for the maintenance technician to traverse the diagnostic information and tech orders as they are currently structured. If one looks at the tech data that exists for an F-16, it nearly fills an 8' x 10' room--floor to ceiling--it's pretty impressive mass of data. For a technician to diagnose and repair a given problem on the aircraft, the technician must access the fault isolation guides and job guides and the wiring diagrams; he's got about six books. By the time he's done getting all the information that he would actually need to repair a particular fault on an aircraft to isolate the repair, he's probably got about eight books and has only about ten place holders (fingers), which doesn't work well.

The other factor that one tends to find even given this massive amount of technical information is that if one tries to diagnose a particular problem using this technical information, one doesn't always find the answer. The reason for that is intrinsic to the nature of the paper documentation. To maintain a reasonable volume, (even a small roomful of information), one must draw the line somewhere for what failure cases one will consider and document. The structure of the fault isolation guides is a tree. one begins with a fault tree, which covers all of the considered cases. A set of symptoms defines a starting point on a tree and subsequent actions allows one to make decisions that will follow one branch or another. At some point, though, one "falls off the bottom" of the tree. This happens when the problem that the technician is diagnosing is considered so rare that it is not handled in the technical information.

In other cases, the technical information may contain errors. In a recent field test, we injected a number of failures into the flight control system by means of a breakout box, and then tried to track them down using the technical information. About 70% of the time the current fault isolation manuals will not diagnose the right failure.

Field Test

The obvious question then is, "Given a different approach, how good a job can one do?" In order to provide an initial answer to that question, we performed a field test at Luke Air Force Base looking at the following elements. First, we wanted to make sure that we could interface with the bus on the aircraft -- a 1553 bus. We wanted to extract some flight control system signature data--what it looks like when there's a particular class of faults. We want to use a fault isolation manual to see how well technicians perform with a given type of fault, test the FCMDS approach, enhance that approach based on what technicians reported back to us, then go through a more extensive comparison test.

Validation

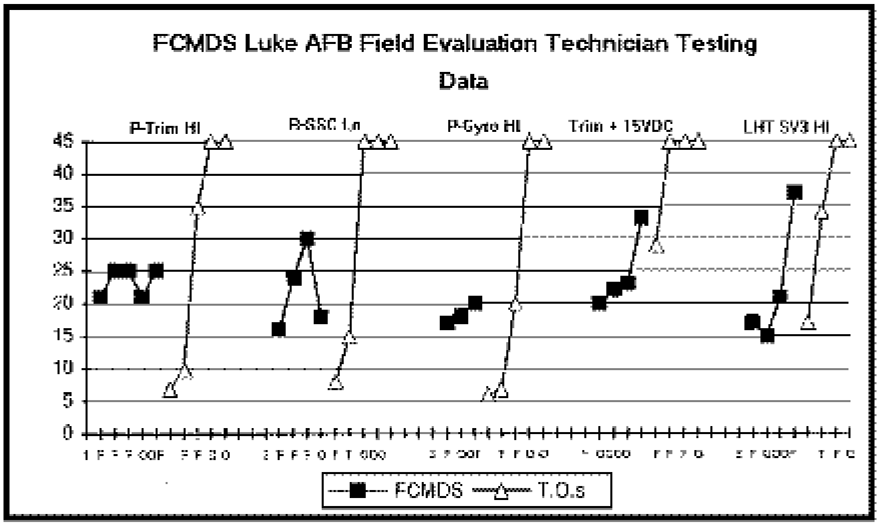
In the FCMDS system we take the representations of the procedures found in the Air Force technical orders and reauthor them so we have an electronic format of the same data. Thus, the information presented has, in most cases, the same content. The underlying reasoning process, presentation and aiding capabilities have been altered substantially, however.

When one changes the content or presentation of technical data one must validate that one has not made any adverse, substantive changes (i.e., negatively affecting safety or correctness) to that technical information. For our program, since we were testing in a constrained maintenance environment, this validation consisted of review of the procedures with a General Dynamics Flight Controls expert, Terry Hay, and an Air Force Engineering Technical Support (AFETS) engineer, Dave Lafferty. Though not a part of our original field test plan, while we were at Luke Air Force Base for the field test, actually we assisted the maintenance staff with a number of diagnostic problems that were troublesome.

Technician Evaluation

Evaluation Design. The primary purpose, of course, was to perform a set of technician evaluations. The technician evaluations that were conducted as follows: we gave the technician the FCMDS unit, a ruggedized portable computer, and gave him a twenty to thirty minute training session. Essentially, we had the technician work through a diagnostic problem using our system. This example problem was not one of the ones that was in the test set. Then we injected a failure into the flight control system using breakout boxes, junction boxes which fit between connectors in wire harnesses to allow easy access to the signals traveling in the wire harnesses. We would then tell the technician what he would have seen as the results of a pilot debrief. When a pilot returns from a flight and reports a problem (squawks), he provides a set of Master Fault List (MFL) codes, which indicate the nature of the problem and symptoms he experienced in a standardized format. We provided the technician with this set of MFL codes, and observed what the technician does using their "standard technical procedure" and then the

FCMDS box, using a balanced experimental design. The results of the testing are summarized in **Figure 2**.



F = Flight Controls Technician

O = Non-Flight Controls Technician

Figure 2

It is notable that there are a lot of test cases in which the time was forty-five minutes. The reason for this improbable result is that if a technician was not approaching a solution (for example, the technician was examining the wrong branch of the flight control system) after forty-five minutes of running the test, we would terminate that trial. The intent of the time limit was to not frustrate the technician unnecessarily. Typically when a technician who's not experienced in the flight control domain runs into a problem that he can't solve, the technician will find the chief and the chief will help him work through the problem. Since in this field test one of the factors we wanted to assess was the extent to which FCMDS could help an inexperienced technician approach an expert's performance, we required that the technician diagnose the problem working alone.

The evaluation data compares a technician's Standard Troubleshooting Methodology (STM) performance to his performance using FCMDS, for two technician skill levels: 1) flight controls experienced and 2) flight controls novice (which includes junior technicians and technicians with avionics experience. Many of the more flight-controls experienced technicians didn't use the tech orders at all, thus it would be inaccurate to term the non- FCMDS sessions "TO use". For some of the cases flights control technicians were able to isolate the problems very quickly. The diagnosis time across test cases suggests that there is a range of difficulty, with case #1 the easiest, and #5 the most difficult. One sees that these cases were a little bit more difficult.

Figure 3 shows a technician trying to use the technical manuals. He has five places marked in the manual, so that he can maintain his place while flipping back and forth between pages. Since he's using his other hand to command BIT, that leaves him with one hand too few to flip through the data. **Figure 4** shows the technician using the FCMDS unit.

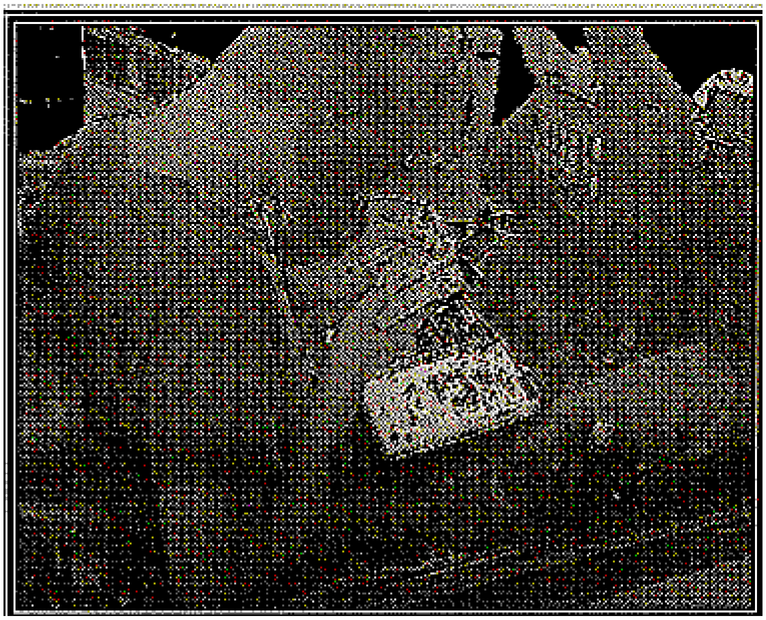


Figure 3 Technician using STM

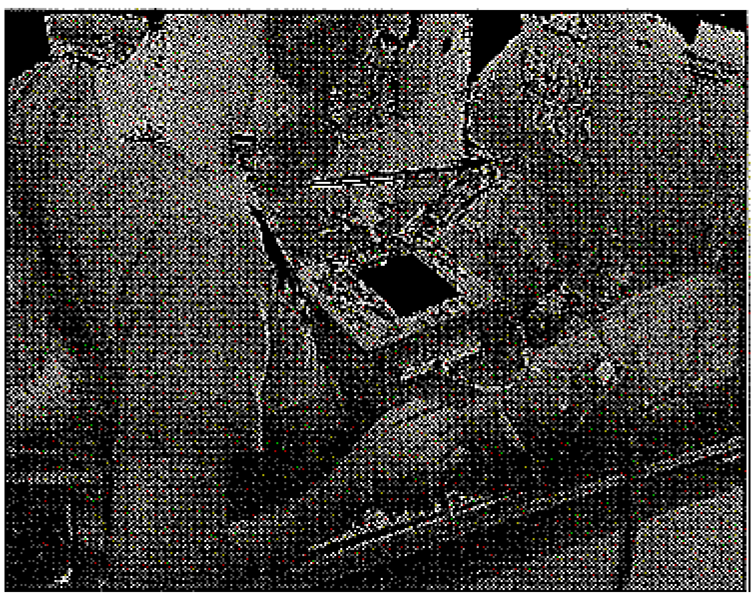


Figure 4 Technician using FCMDS

Evaluation Results. The performance of flights controls experts is quite reasonable for this task; they correctly isolate the problem in eleven of fourteen trials. Unfortunately, non-flight control technicians were only able to isolate the problem in one of nine trials. In all, the technicians were able to find the problem in twelve of twenty-three trials using the STM. Isolation time shows a similar pattern. The flights controls experts averaged twenty-three minutes;

non-flight-control technicians were very close to the forty-five minutes limit (there was one technician who isolated the problem in less than the forty-five minutes allotment).

When using the FCMDS unit, all technicians were able to isolate the problem in a more uniform and reduced amount of time. That average time, in fact, matched the performance of the flight controls experts.

The final factor that we consider notable in the evaluation results is a comparison of false pull rate between the STM and FCMDS conditions. A false pull, in our evaluation scenario, is the removal of a **LRU** which is not faulty. In our case, since we knew the symptoms and faults a priori, that is the same as saying the LRU was not indicted by the symptoms. False pulls are the result of a troubleshooting technique for which the denigrating term is "swaptronics". In this technique, LRUs are removed and replaced to assess their correct function. While this may be a fast means of assessing correct operation, it is expensive. Once a technician removes the LRU, it has to go back through the system to be checked out and recertified before it can go back on an airplane. That has severe implications in terms of the spares requirement, what the Air Force has to maintain in back stock. The expert technicians had eleven false pulls, and there were twelve among the non-flight-controls technicians. There were no false pulls with the FCMDS unit.

Payoff

If the performance improvement that was seen in the field test evaluations were indicative of the benefits which would be realized across organizational maintenance units, a quick calculation shows the savings would amount to over 2200 hours per month for the F-16 flight controls alone. This calculation uses conservative estimates for reduced false pulls, and diagnostic time reduction. It does not take into account other savings which are consequences of the reduced false pull rate, for example the reduction in Avionics Intermediate Shop (AIS) testing, or the reduction in prime system spares, assuming an 80% reduction in false pulls, and a 25% reduction in diagnostic time.

Technology Elements

Technology elements are the concepts and techniques which taken together, form the basis for the FCMDS system, and provide a means to achieve the sort of performance improvement we have presented here. We will discuss several of these technology elements in turn.

Diagnostic Reasoning: The Fault Tree

Diagnostic reasoning using current Technical Orders (TOs) uses a fault tree. Each node in the tree corresponds to a certain state of information. Information collected at a node leads the technician to examine a branch of the tree. Leaf nodes correspond to an identified fault, or to a group of fault cases considered rare enough to not be worth expanding. This grouping of rare fault cases serves to constrain the set of TOs to a manageable size, with the undesirable effect that further diagnosis is the responsibility of the technician. Such groupings are commonly associated with the instruction, "Refer to schematic". The fault tree represented in current TOs is static, or predetermined. As failures of one type or another are found to be more common, changing the fault tree to reflect that change in probability of occurrence requires a major re-write of the TOs, something which is rarely undertaken.

In contrast, FCMDS is able to generate the next level of the fault tree dynamically. The FCMDS unit maintains the state of the diagnostic session, i.e. the information collected thus far. Given this information, FCMDS can determine a set of suspect components which could be responsible for the observed symptoms. FCMDS then scans all available tests to determine the test which (at this point in the diagnostic session) would provide the most information for the lowest cost. In a sense, then, FCMDS dynamically selects the best node to hook to the tree, attaches it, and suggests that test to the technician. The technician can override the recommendation and attach another test (node) at the current location. In order to assess the significance of the test which is then run by the technician, FCMDS uses a model of the flight control system to interpret a passed or failed test.

The System Model

The model of the system that FCMDS maintains is simply a representation of the functional dependencies in the system. Each Line Replaceable Unit (LRU) is decomposed into its functional elements, or sub-LRUs. FCMDS connects the inputs and outputs of these functional units (and LRUs) to determine the functional dependencies.

Our system covers 74 LRUs which comprise some 4,300 functional elements and about 12,000 signals. The model is used to interpret the outcome of diagnostic tests by associating a functional path through the model with a test. When the test fails, some element on that functional path is asserted to be failed, though it is unknown which specific element is indicted. Another test is selected which exercises some, but not all, of that functional path, and the overlap is either doubly indicted (if the test fails) or cleared (if the test passes). When all of the multiply indicted functional sub-paths lie in the same **LRU** or wire, the bad system element has been found.

Test Selection

At any given point in the diagnostic session there are a number of potential suspects. What FCMDS is designed to do is reduce the size of that set to one suspect. FCMDS examines the set of suspects and signals that those suspects use. For each available test, FCMDS determines whether the test examines any of the suspect signals. If so, the test is deemed applicable under the current circumstances. If not, the test is eliminated from consideration.

The test to recommend is selected from this applicable set by performing a (simple) cost- benefit analysis. Essentially, it is desirable to conduct a binary search, eliminating as close to half the suspects as the set of applicable tests will allow at each step in the diagnostic session. We have experimented with complex schemes which take into account the number of people required, the test duration, and how easy it is to conduct the test, based on the current state of the aircraft (e.g., is a panel removed which makes a particular test much easier). FCMDS must maintain a knowledge of the aircraft state to be able to instruct the maintenance technician what "clean up" actions remain at the end of a diagnostic session. The more complex information theoretic analyses are not used in the current system, since they are found to have little benefit over a simpler test prioritization scheme.

Technician Aiding

In addition to tracking the state of the system for maintenance clean up, we provide other forms of aiding to the technician. The aiding is structured so that the technician can call up help at any point, but is not presented gratuitously for the more advanced technicians that do not require assistance. This aiding can take the form of additional instructions (i.e., sub- procedures which comprise a single step in a parent procedure), graphics which locate references within a procedure (e.g., the location of the BIT switch on a panel, and the location of the panel in the cockpit), or schematics which explain a signal flow path.

Wiring

One of the features that is incredibly popular in the FCMDS system is the wiring display window. An example of the wiring display window is shown as **Figure 5**. The technical information in commercial or military manuals that supports wiring diagnosis is tabular data. It is quite challenging to use this tabular data to trace a wire path through the aircraft. At one point, Paul Bursch, our lead field test engineer, was tracing a wire path. He took twenty minutes to track through a particular wire path. At the end of that period of time, he found out he was on the wrong wire. He had made an error in tracking through the effectivity codes.

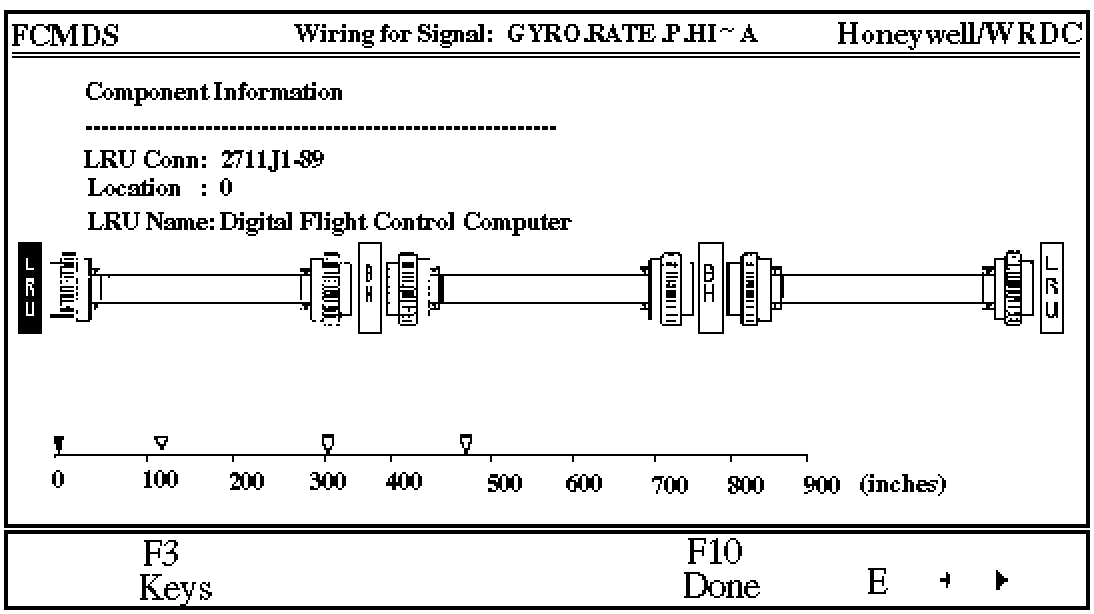


Figure 5 Wiring Display Window

Our system accesses a wiring database to generate a graphic representation of any wire path in the system in less than twenty seconds. Using the arrow keys, one can flow through the wire path from connector to wire to connector. In each case one will gain information about what pin and connector the signal of interest is on, so the correspondence to observable physical characteristics is maintained.

FCMDS also provides a time domain reflectometer (TDR) trace for the wire path. Essentially if the technician pings the wire, a TDR trace shows the places that the technician would expect to see returns. Typical reasons for returns are places where the wire path went through a bulkhead or through a connector. If the technician sees a return at any other location, that is an anomalous condition that needs to be investigated.

Constraints on Technology Transfer

We have field tested the FCMDS unit and, under a constrained scenario where we ran five test cases, we've proven the worth of the system. The technology we developed under the FCMDS program is somewhere beyond a laboratory system, but short of a production product. Why, if this technology is useful, does it not immediately get implemented? One phrase which comes to mind is, "a square peg in a round hole."

Actually, the situation, while of that nature, is far more complex. FCMDS is a packaged solution. In order to support that packaged solution, there are requirements on the infrastructure, such as the authoring of technical data, the capture of the model, and so forth. Most organizations, including the Air Force, are understandably reluctant to undergo such large changes with the consequent disorganization that results. What happens instead is that selected pieces of the solution, or, as we have termed them, "technology elements" will be adopted and applied. We have seen this happen in a variety of domains. In the commercial airline domain, the diagnostic approach used for FCMDS was modified and forms the basis for the Boeing 777 Central Maintenance Computer (CMC). Other elements of FCMDS, such as the technician aiding approach, were not used due to the difficulty of modifying the way that technical data is authored and distributed today.

The decisions as to whether or not a particular technology element will be a part of the solution for a new application domain are of course driven by projected costs and benefits. For the Boeing 777 CMC, some diagnostic system had to be built. We asserted that maintaining the data for the diagnostic system is more easily done when the data has the same structure as the system. Our functional model has that form, so that if one makes design changes in a particular **LRU**, one has to change only the model for that LRU.

Other problems that are typically faced when trying to introduce this technology into a new application domain are concerns over the external visibility into an LRUs performance. When one builds a flight-critical/safety-critical kind of system, one typically wants to build a "wall" of sorts around the equipment. One wants no other systems to interfere with what the system is doing. From the diagnostic perspective, this is an undesirable state of affairs, because the diagnostic system wants to know everything that is going on inside the safety- critical system.

There is a tension between having good subsystem boundaries, and being able to provide meaningful information on system health which improves the performance of the system as a whole.

In spite of these limitations, and others like them, we have now successfully applied these concepts to factory test, **LRU** diagnostics, commercial avionics suites, military flight controls, and space avionics. Certain elements will also be incorporated into the F-16 Integrated Maintenance Information System (IMIS) project now underway.

DESIGN, IMPLEMENTATION AND EVALUATION OF A PERFORMANCE ENHANCEMENT SYSTEM FOR AVIATION SAFETY INSPECTORS

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1.0 Introduction

The **P**erformance **En**hancement **S**ystem (PENS) is an electronic job aid designed for Aviation Safety Inspectors (ASIs). The system was in design and development for nearly 9 months before the first substantive pilot evaluation began. At the date this paper is being written PENS is in evaluation in all nine FAA regions, from Fairbanks, Alaska, to San Juan, Puerto Rico.

This paper describes the PENS development and implementation process. It also considers the question - how much "human factors scientific discussion" is necessary when involving users in system design.

1.1 A Human Factors Approach to Design of PENS

Previous publications from the Aviation Medicine Human Factors in Aviation Maintenance research programs have defined human factors and have emphasized the focus on the human as the central part of a technical system (**FAA/AAM & GSC, 1993**; Johnson & Shepherd, 1993). The human is affected by such factors as personnel selection, training, job design, and environmental issues, as examples. The design of tools, procedures, and information can also have a significant impact on human performance. PENS falls under these topics.

The involvement of users in early stages of system specification and design is important. It ensures that the system in development, both hardware and software, is compatible with the needs, expectations, and capabilities of the potential user. Thorough front-end studies, including job/task analyses and cognitive task analyses, can help determine and/or validate user requirements. Rapid prototyping is another development technique that ensures successful product design (Sewell & Johnson, 1990). The "bottom line" of good design is that the final product enhances human performance and affects overall system efficiency and effectiveness

(Johnson, 1993).

Terms like cognitive task analyses and rapid prototyping are from the lexicon of the scientist. The human factors scientist, however, should not burden users with such terms. Instead, the user must be guided to express reasonable system requirements by discussing the tasks of the job, the information requirements, the working environment, and other such job characteristics. The various system prototypes, in software or in hardware mockups, permit users to modify specifications as their perception of the product becomes mature.

Human Factors (HF) personnel must work diligently to not impose their process and language on their customers. The HF personnel must merely communicate that a systematic process shall be used to arrive at optimal design and that the user is at the central focus of the process. This approach was used for PENS design, development, and implementation (Layton and Johnson, 1993). The results have been positive.

User "buy-in" to the PENS concept has been a vital reason that the project is succeeding so well. At a recent FAA meeting on training and automation a senior FAA manager described the PENS project as "a revolutionary FAA approach whereby the project is first studying user requirements before selecting and installing hardware systems". While not necessarily revolutionary this approach is certainly aligned with a human-centered approach to system development. The remainder of this paper describes PENS (Section 2) and then discusses the evaluation design (Section 3) and preliminary observations. Finally, in Section 4, the future of PENS and other applications of mobile computing are discussed.

2.0 PENS - How does it work?

The Flight Standards Service within the Federal Aviation Administration (FAA) employs over 2,500 Aviation Safety Inspectors (ASIs). The ASIs serve as the inspection team for the FAA. Aviation Safety Inspectors perform a variety of tasks, including inspecting aircraft and equipment, reviewing manuals and records, certificating pilots, and evaluating training programs. The PENs project is developing job performance aids to support ASIs in their activities. The initial target of PENS is an ASI performing an airworthiness (safety) ramp inspection. (A ramp inspection consists of inspecting an aircraft, while it is at the gate, prior to a scheduled departure.) PENS is an electronic performance support system (Gery, 1991; Layton, 1993) that consists of two components: a "smart" data collection system and an on- line documentation system. PENS capitalizes on recent advances in pen computer technology.

2.1 Data Collection

As is typical with regulatory activities, there are several forms that must be completed while performing an ASI task. Currently, these paper forms require that some of the same information be recorded on each form. After completing the forms, the ASI either types the data into a local computer database or he/she submits the forms to a data entry clerk. There are several drawbacks to such an approach. First, redundant recording of data on multiple forms takes time that could be devoted to more productive activities. Second, the two-step process of recording data on paper and then entering the data into a computer is inefficient. Furthermore, one is either paying an inspector to perform a data entry task for which he/she is over-qualified, or one is paying for a staff of data entry clerks. Finally, a data-entry clerk may make transcription errors (due to misreading the inspector's handwriting) or errors due to incomplete knowledge and understanding of the inspector's activities. Such errors mean that the database is an unreliable source of information. ASIs complete an average of 400,000 copies of the Program Tracking and Reporting Subsystem (PTRS) form annually. In 1993 1000 PTRS entries into the national database had the date 1903, rather than 1993.

Pen computer technology can be easily applied to such tasks to minimize the number of steps required to collect data and assimilate it into the database. Pen computers use handwriting recognition software and a pen stylus for input, rather then a keyboard. The operator writes on the screen and the handwriting recognition software translates the written characters to typed characters. The pen stylus also acts as a pointing device, much like a mouse. When combined with graphical user interfaces, such as Microsoft Windows for Pen Computing or PenPoint, the pen stylus and handwriting recognition software hold the promise of making computers easier to use than traditional desktop computers. A comparison of typical desktop and pen computers is shown in **Figure 1**.

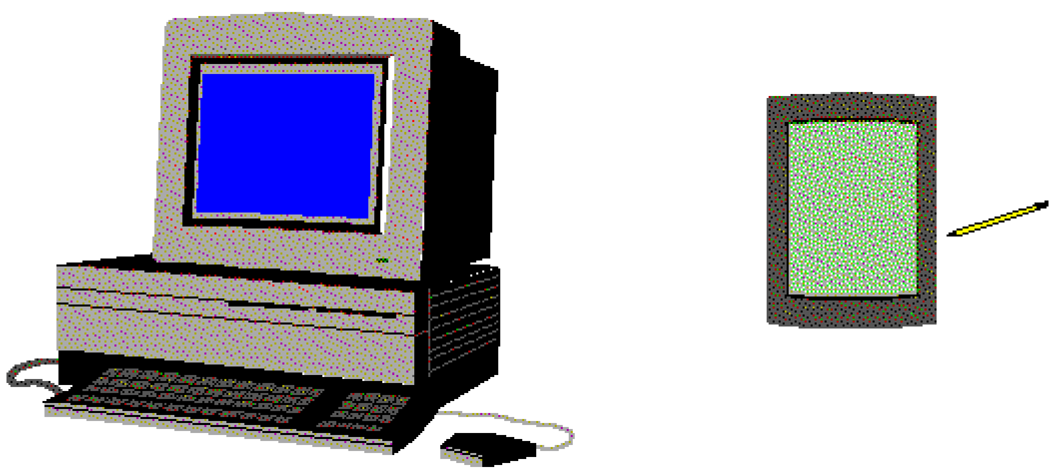


Figure 1 Comparison of Desktop and Pen Computers

PENS capitalizes on the relationships between inspection data and the constraints built into the PTRS form to prevent errors. For instance, some form fields cannot be used for certain activities; the forms are sensitive to the activity being performed so that restricted fields are not available for data entry. As shown in the PENS version of the PTRS form in **Figure 2**, if the inspector selects "Boeing" as the aircraft "Make", only Boeing models appear for selection in the "Model" field. Furthermore, PENS is tied into a database of aviation operator information so that only data options appropriate to that operator are available for entry. For example, if Mythical Airways owns only Boeing 757 and 767 aircraft, the inspector will have only those options to choose from when identifying the type of plane under inspection.

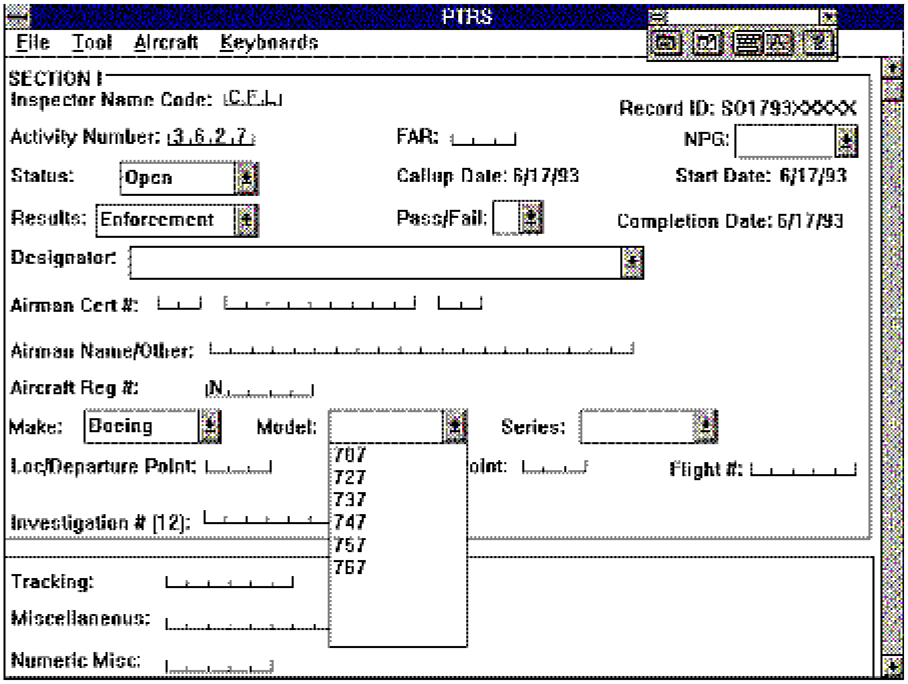


Figure 2 PTRS Form

Concerning the current data collection limitations identified above, forms can be linked together so that an entry in one form propagates to the other forms, thus eliminating redundant data entries. Furthermore, the data can be collected so that they are ready for direct uploading into the database. The inspector will return to the office at the end of the day, connect the pen computer to the office computer network, and start a utility that transfers all of her/his field-collected data to the local database. This method of collecting data obviates the need for data entry clerks and it eliminates data transcription errors.

2.2 On-line Documentation

The second major contribution of PENS is an on-line documentation system. Whereas ASIs currently must carry two briefcases full of books (including Federal Aviation Regulation, ASI Handbooks, and other regulatory documents), the necessary documents can be stored on the hard disk of the pen computer or on a CD-ROM (compact disc, read-only memory). Not only is the computer media more lightweight and compact, it also facilitates quick retrieval of specific information. For instance, an ASI can perform a Boolean search of the regulations for the word "corrosion" to answer a question on reporting aircraft defects. PENS then indicates all of the instances of the word corrosion, as shown in **Figure 3**. The ASI can then ask PENS to retrieve the relevant documents and display the pages that discuss the term. **Figure 4** shows an example page with "corrosion" highlighted.

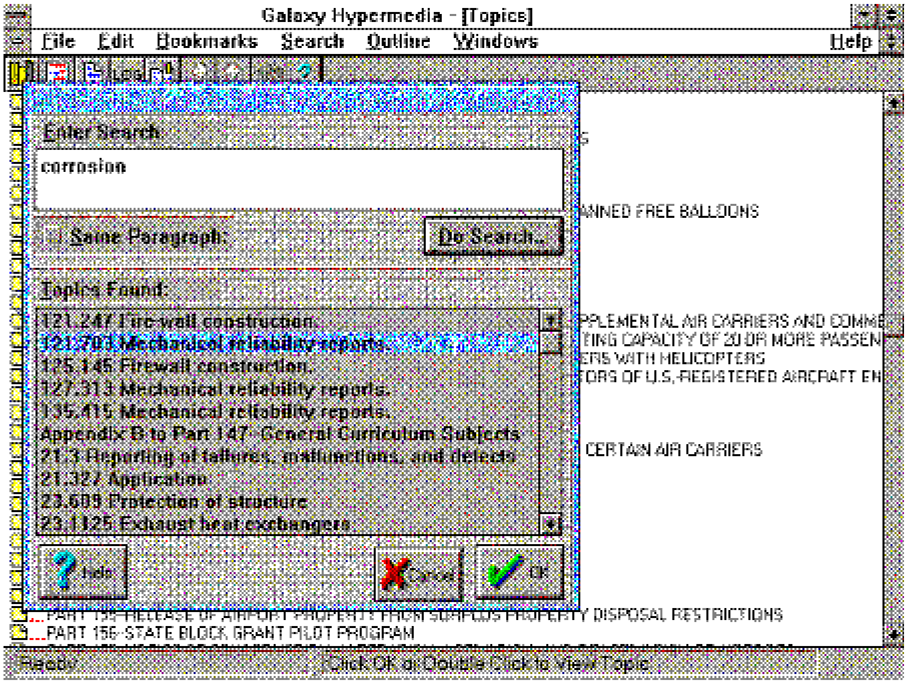
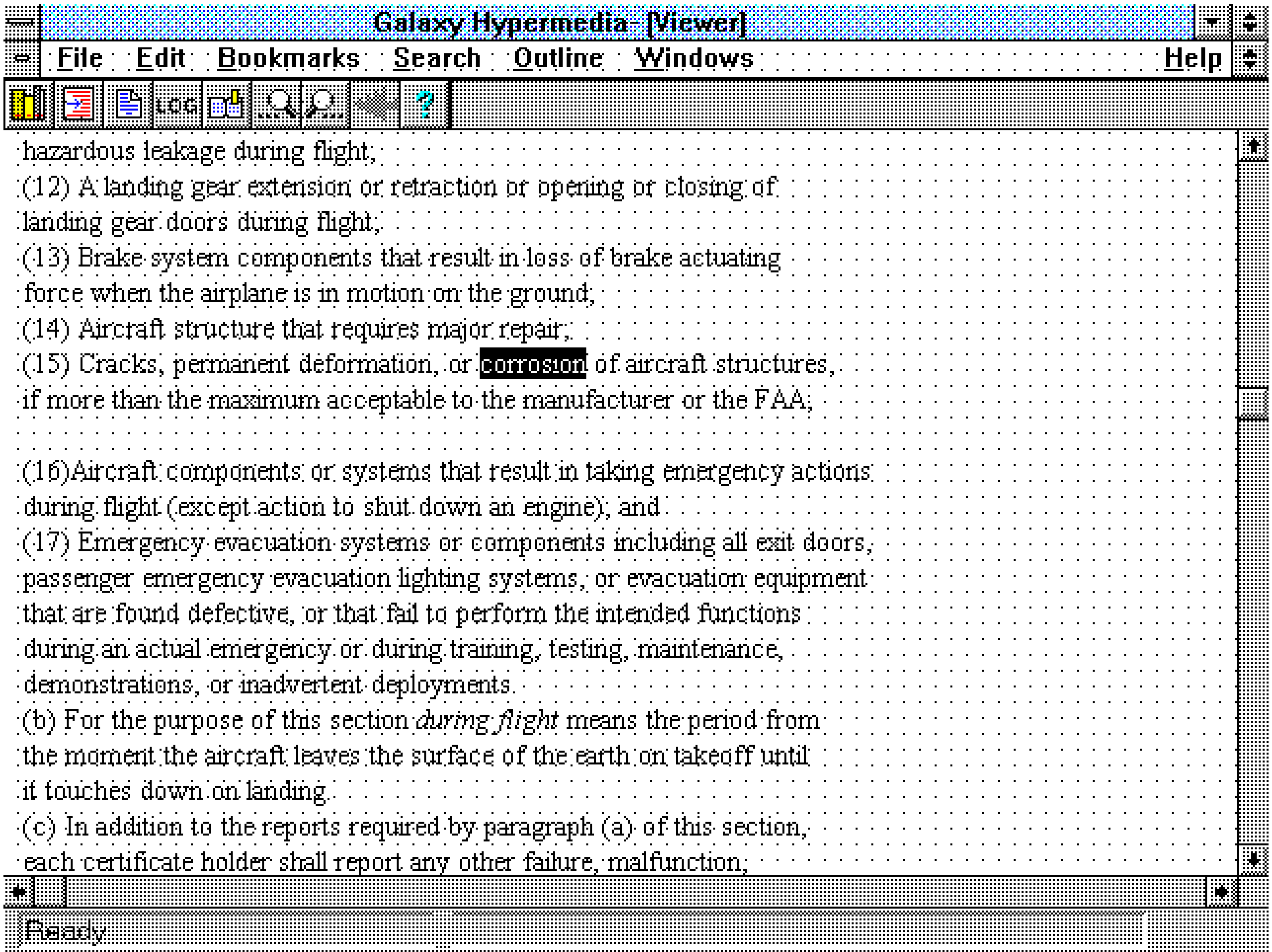


Figure 3 Search results for the word "corrosion" in the FARs



hazardous leakage during flight;
(12) A landing gear extension or retraction or opening or closing of landing gear doors during flight;
(13) Brake system components that result in loss of brake actuating force when the airplane is in motion on the ground;
(14) Aircraft structure that requires major repair;
(15) Cracks, permanent deformation, or corrosion of aircraft structures, if more than the maximum acceptable to the manufacturer or the FAA;

(16)Aircraft components or systems that result in taking emergency actions during flight (except action to shut down an engine); and
(17) Emergency evacuation systems or components including all exit doors, passenger emergency evacuation lighting systems, or evacuation equipment that are found defective, or that fail to perform the intended functions during an actual emergency or during training, testing, maintenance, demonstrations, or inadvertent deployments.
(b) For the purpose of this section *during flight* means the period from the moment the aircraft leaves the surface of the earth on takeoff until it touches down on landing.
(c) In addition to the reports required by paragraph (a) of this section, each certificate holder shall report any other failure, malfunction,

Figure 4 Text of FAR that discuses corrosion

The books are not only bulky and inefficient, they are also frequently out-of-date. One complaint made by inspectors is that they will tell an air carrier that it is not in compliance with the regulations, only to be shown a more recent edition of those regulations. That is, sometimes the air carriers get the most recent editions of the regulations before the inspectors get them. This problem can be dealt with by distributing updated documents through the FAA's computer network. For instance, a person in Washington, DC could edit a document and send the new version to the FAA's main frame computer in Plano, Texas. When the Flight Standards offices connect to the main frame to upload field-collected data, they can also download the new documents. Likewise, when the pen computers are connected to the office network to transfer data to the database, they can receive the new versions of documents. Thus, a new edition of a document could literally be electronically published one day and in the inspector's hands the next.

2.3 Increased Capabilities

A benefit of providing computer-based inspection tools is that it opens the door to other means of assisting inspectors. For example, data propagation need not be restricted to a set of forms. An on-line inspection checklist, shown in **Figure 5**, focuses the inspector's activities and her/his interaction with the computer; by completing the checklist, many parts of the forms are automatically completed. Furthermore, stock letters can be completed and printed based on information in the forms. Similarly, reports can be automatically generated based on inspection outcomes. A scheduling component will remind the inspector to follow up on inspections that identified problems.

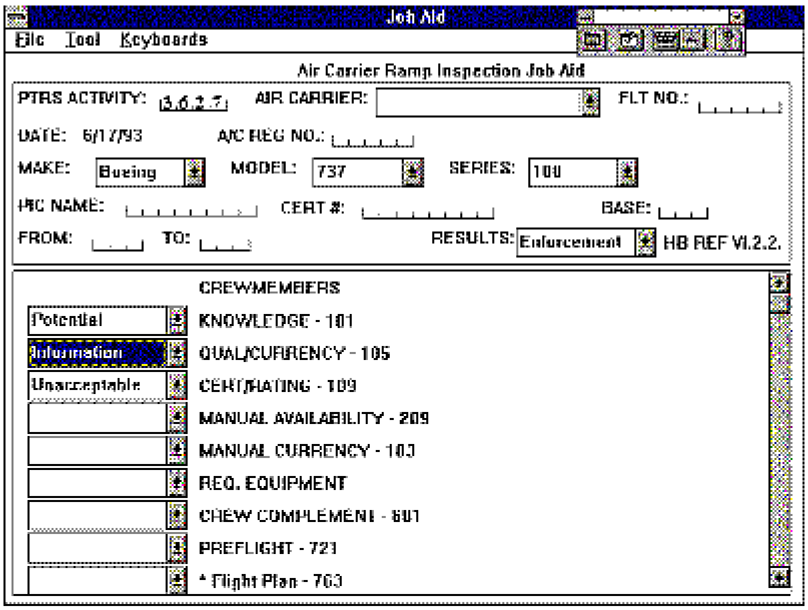


Figure 5 On-line inspection checklist

When documenting an inspection, ASIs currently must record their findings verbally. However, because many inspections are conducted by visually inspecting an aircraft, sketching is a more natural method for recording the results of such an inspection. Thus, if an inspector found a leaking seal on the wing of an aircraft, the inspector could annotate a line art drawing of that aircraft on the computer. This graphic is then stored along with the completed inspection form. **Figure 6** depicts one such annotated graphic.

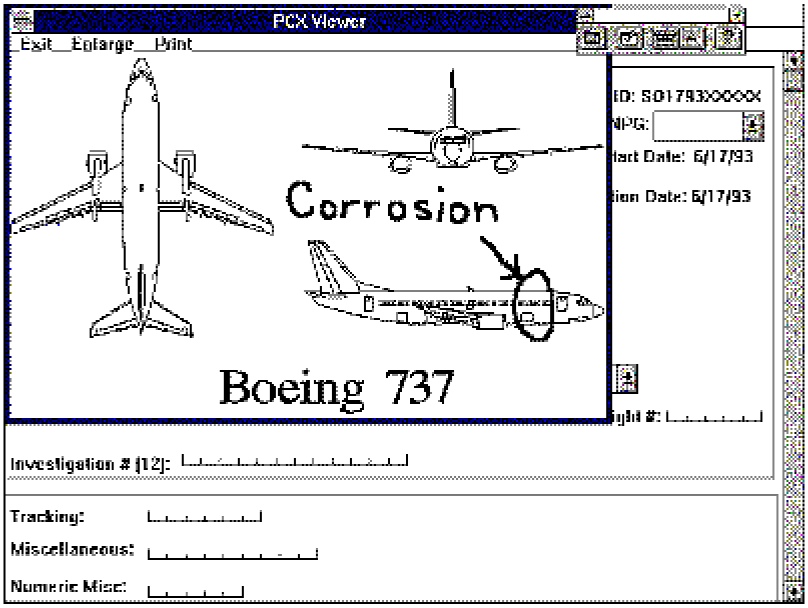


Figure 6 Annotated aircraft drawing

Finally, the data collection system is linked to the on-line documentation system so that the inspector has immediate access to all applicable regulations and handbook chapters. For instance, upon identifying the type of plane under inspection on the form, the inspector is notified of all of the Airworthiness Directives (specific regulatory documents) that apply to that aircraft. These documents are then called up on the on-line system for ready reference.

3.0 The Evaluation

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

During Winter 1993/Spring 1994 the PENs team is conducting a widespread field evaluation of both the prototype PENS software tools and various hardware platforms. A goal is to find out very early in the development process whether inspectors find pen computer technology an appropriate approach to alleviating some of their workload. In order for PENS to succeed, it is critical that the inspectors "buy in" to the project and take ownership of it. Inspector buy-in and ownership mean that the inspectors will know that their input is critical for development of the tools. In turn, they will be motivated to use the tools and improve them. Therefore, many aspects of the field evaluation are geared toward the goals of inspector buy- in and ownership. PENS is being fielded in all nine FAA regions, as shown in **Figure 7**, so that each region will participate. Inspector comments are actively solicited to ensure that the tools meet the inspectors' needs.

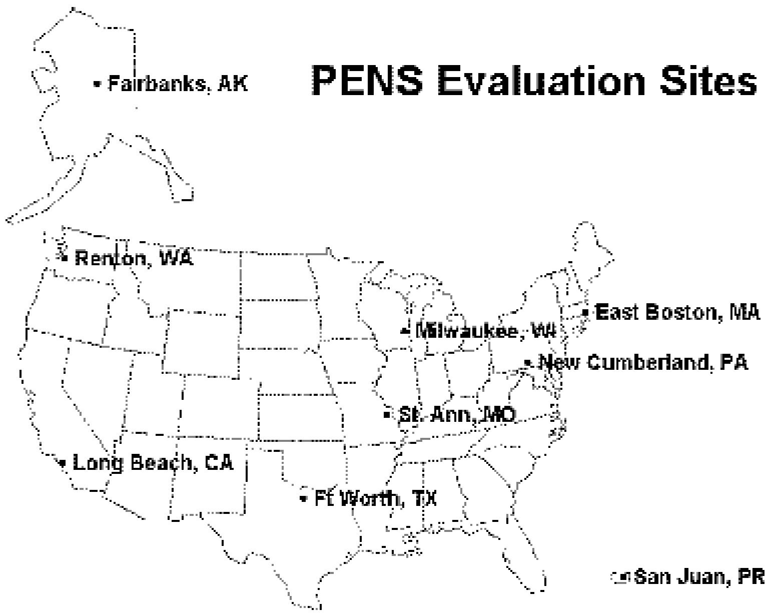


Figure 7 PENS Evaluation Sites

Four different computers are being fielded. Three of those computers are pen computers, while the fourth computer is a standard notebook. Each of the computers was selected based on a specific feature that distinguished it from the others so that we could allow the inspectors to assess the tradeoffs between the various designs. For example, the notebook computer was chosen so that we could answer the question of whether pen capability was really necessary. Other features included weight, attached vs. separate keyboard, and processor speed. A review of pen computers is reported elsewhere (**FAA/AAM & GSC, 1993**).

Four inspectors in each office are performing the evaluation. Each inspector uses a computer for a week and then rotates to a different computer. At the end of each week, the inspector evaluates the computer and at the end of four weeks, he/she evaluates all four computers and the PENS software. The rotation order is counterbalanced to eliminate order effects.

Rarely is a field evaluation of this magnitude performed. It represents a significant opportunity to obtain usability and preference data on computer platforms in a controlled study, while at the same time involving a large number of real domain practitioners in the evaluation and development of tools to support them. The report documenting the results of the study is of interest to not only computer manufacturers, but also to the human factors community at large.

4.0 The Future

The authors believe that mobile computing shall become as common as the desk top personal computer. Hardware is evolving rapidly to provide greater display resolution, faster processor speed, increased storage and memory, lighter weight, improved communication capability, longer battery life, and other features that ensure wide-range useability.

Software development is critical in order for mobile computing to rapidly reach its full potential. Software must evolve with the hardware. Software systems must provide an "information rich" environment for the mobile computing platform. Such an environment must be able, at a minimum, to offer the following: 1) large amounts of data translated to specific user needs; 2) training matched to the job at hand; 3) decision support tools, and; 4) a suite of software tools matched to users needs. Each of these capabilities is described below.

4.1 Data/Information

Mobile computing platforms must provide users with all information necessary for field decision making. For an aviation maintenance technician this information might include, for example, aircraft historical data, logbooks, maintenance manuals, illustrated parts catalogs, wiring diagrams, fault isolation manuals, and other airline-specific information. Inspectors might access additional information, including FAA Inspectors' Handbooks, Federal Aviation Regulations, and Airworthiness Directives. Such information must be easy to access and search. Critical related information must be connected ("linked") together so that users can easily navigate through a variety of information sources. New technology software for mobile computing must go beyond a digital microfiche system to intelligent information.

4.2 Training

Mobile computing must provide users with efficiencies resulting in lower costs. Reduction in classroom training has an immediate cost reduction impact. Economies are achieved through reduction in travel, time of the job, replacement personnel, training facility, and instructor salaries. Mobile computing platforms can be used to provide computer-based training on-the-job when it is needed. The term "just-in-time training" applies to the delivery of training only when it is needed. At such times workers are highly motivated to learn in order to complete a job requirement. Such training minimizes the impact of a worker forgetting critical knowledge and skill where there has been a long time lapse since formal training. Future mobile computing will be able to use powerful communications capabilities to remotely access multimedia training that is either provided by the user's employer or by a training contractor.

4.3 Decision Aides

Mobile computing software must be able to assist field decision making. Such software must capitalize on the extensive research and development with user modeling and expert systems. Software must be able to help the mobile computing user to select, access, and assimilate the massive information sources and analytic tools that can be immediately available. The software must be able to observe the user and then make inferences regarding best information sources. The computer shall become an active participant in the job tasks of the mobile computing user.

4.4 Suite of Tools

The mobile computing platform software environment must be versatile. It must provide a wide variety of tools. Successful Mobile Computers will not be designed for, or limited to, single tasks. Communications, word processing, data collection/retrieval, data analyses, and training development/delivery are but a few of the multi-purpose capabilities that shall be provided by mobile computing software environments.

4.5 Easy to Use

This paper began with a discussion of human factors and the design process necessary to ensure successful application of the FAA Performance Enhancement System. The same systems approach must be used to design any mobile computing software. The software must be compatible with users' expectations and capabilities. The powerful information technologies must be integrated so that the user can understand them. Finally the systems must undergo appropriate developmental and final evaluation to ensure effective and efficient field use.

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MAINTENANCE ERROR DECISION AID PROJECT

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It is a pleasure to get a chance to speak with you here this morning about some issues and some subjects that we are working on jointly with Boeing. Dave will tell you more in a few minutes about what we have been doing in terms of maintenance error analysis. He will describe in some depth the project that we have been working on with Boeing. I would be quick to point out also that Continental Airlines is not the only airline participating in this project. British Airways and United Airlines are involved as well.

We have chosen to define maintenance error for you this morning and this is a definition that we have "grappled with" amongst ourselves. We define it as an undesirable outcome of a required, planned, or unplanned maintenance event, resulting from personnel error, creating personal injury, or aircraft degradation. There are a couple of end results from error: People can get hurt, or airplanes can be degraded -- mechanically or physically. With that definition in mind, we ask "Why is maintenance error important?" Maintenance error today in the air carrier industry affects us all in one form or another. People make mistakes. Systems are designed to the best of people's ability, yet somehow, humans seem to produce failures within those systems in spite of best intentions. And that is an important issue we are trying to keep in mind. Many of you have been exposed to and are aware of our crew coordination concepts program. We have had that program within our organization for the past two years and have seen some fairly positive results in terms of effect on our organization. In that course we talk about why we make mistakes; how we communicate with each other from an interpersonal standpoint; how we solve problems and make decisions; all of the things that go toward influencing outcomes of events.

So with that definition in mind, I want to press forward. The data in **Figure 1** (provided by Boeing) shows maintenance and quality control events as the second leading cause of major aircraft accidents over that ten-year period. GE also put together some data that showed 50 percent of engine related flight delays and cancellations are caused by improper maintenance. So there is some evidence and some empirical data that says maintenance error impacts the way we do business. It impacts performance and certainly impacts people's lives in terms of injury.

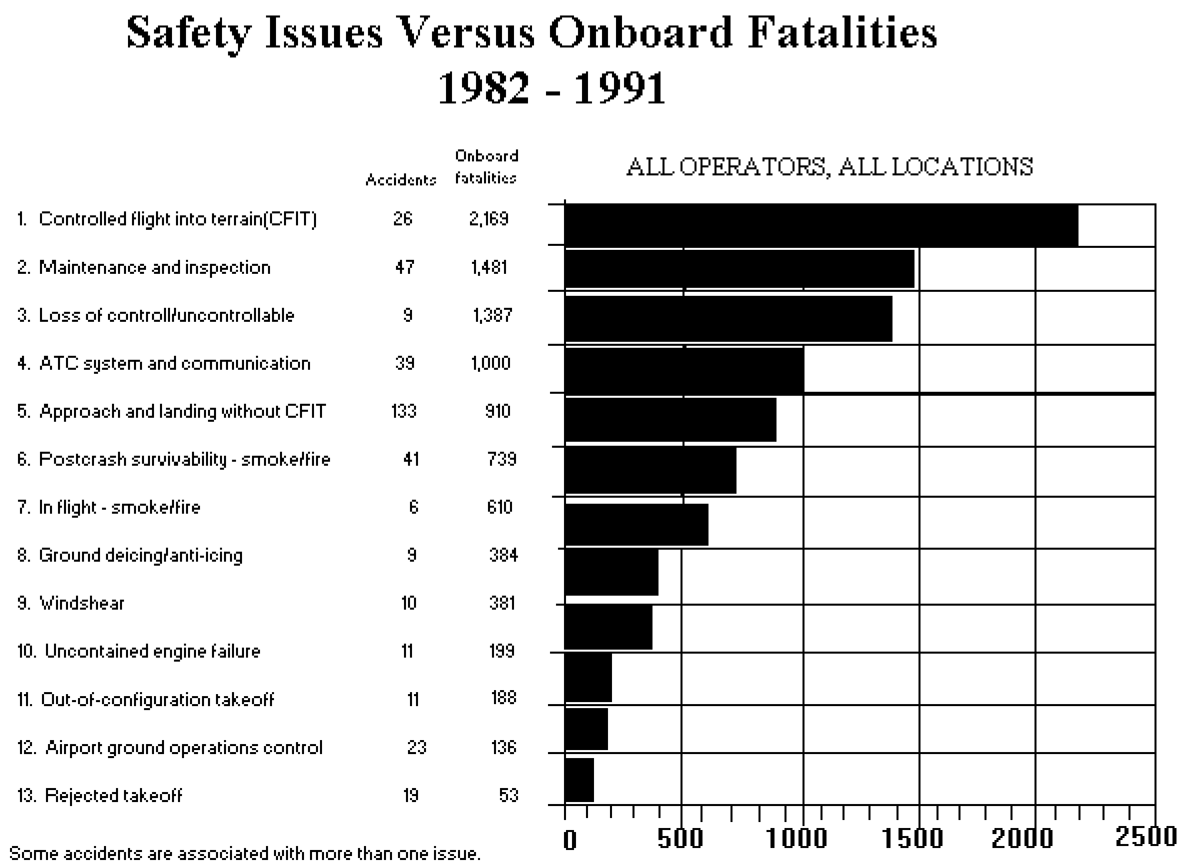

Figure 1 Leading Causes of Major Aircraft Accidents

Let us explore some of those causes a little bit closer. **Table 1** lists the top eight maintenance error causes; this data comes from a U.K. civil aviation study that was done recently. Those of us who work for airlines probably hear anecdotal evidence that these problems occur every day across our systems. Yet what do we do with this data? And how does it affect our operation? I will air a bit of Continental Airline's dirty laundry. From 1988 through 1991, we had significant numbers of mishaps and incidents involving maintenance personnel (**Table 2**). There were 203 total mishaps resulting in damage to aircraft. It also includes towing, pushback, and servicing in addition to scheduled or unscheduled maintenance events -- acts of maintenance, if you will, under the FARs. These events resulted in 13,299 total hours out of service and an estimated $16,580,135 of repairs expended only on parts and labor. To factor in lost revenue multiply that figure by about four. One of the big reasons we are standing before you today is that approximately 95 percent of those errors are attributable to procedural error. Not necessarily willful error, but still procedural error. The numbers for 1992 and 1993 are not looking much better in some respects.

Table 1 Top Eight Maintenance Problems, 1992

- Incorrect Installation of Components
- Fitting of Wrong Parts
- Electrical Wiring Discrepancies
- Loose Objects Left in A/C
- Inadequate Lubrication
- Access Panels/Fairings/Cowlings Not Secured
- Fuel/Oil Caps and Fuel Panels Not Secured
- Gear Pins Not Removed Before Departure

Table 2 Ground Mishaps Involving Maintenance Personnel*

- 203 Total Mishaps Resulting in Damage to Aircraft
- 13,299 Total Hours Out-of-Service
- An Estimated $16,580,135 Repair Expended on Parts and Labor - Excluding Lost Revenue
- Approximately 95% Attributable to Procedural Error

* Includes MX, Towing, Pushback, and Servicing

Maintenance error also has a significant impact on our work force. We are presently in the midst of an on-the-job injury awareness campaign. Our objective is to raise awareness of on- the-job injuries across our system and to eventually shoot for a reduction of 50 percent. But as you can see, June 1991 to June 1992 data indicate that the actual number of injuries in our Technical Operations Division (**Figure 2**) have not decreased much. Many lives are disrupted by error, error that either results in aircraft degradation or personal injury.

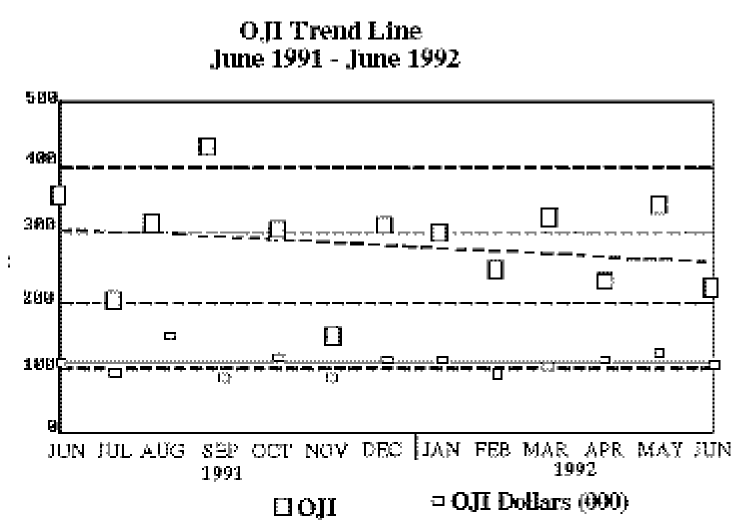

Figure 2 OJI Trend Line

I want to talk for a few minutes about how we do error analysis today in our environment. I have titled it "Turf Protection." How we do error analysis today, how do we react when we hear of a maintenance error or a damage event that is resulting from maintenance? What do we do? Well, there are a couple of levels that error analysis goes through. The nature of our operating environment today typically puts responsibility for error analysis on the front line management personnel, the supervisor, or the highest ranking member at the station. That person is given a task of doing an investigation, determining a probable cause, and in many cases mediating discipline if it is judged necessary. All within the context of having to fill out a large and cumbersome package of paperwork detailing what occurred, why it occurred and any actions taken. He must do this in addition to continuing to perform his normal duties and responsibilities, with no disruption to the operation. Filling out the paperwork is a form of punishment in itself. People do not want to have mishaps simply because they do not want to fill out the paperwork. Yet maintenance error continues to happen.

When I say error analysis today is primarily the responsibility of the front line personnel, that is depending on severity. We all can look into our own environments and see that if something minor happens, it is fine for the local supervisor to take responsibility for initiating an investigation and assuring that all the i's are dotted and t's are crossed. But what happens when something more significant happens? What happens when, for instance, a wide body airplane goes down for an extended period of time because of a maintenance error? All of a sudden it is a fairly visible event within the system. It gets on conference calls; beepers go off; yelling and screaming and gnashing of teeth is accomplished; and eventually the airplane is put back into service after repairs are accomplished and (figuratively speaking) we hang the guilty party at sunset. In extreme cases, we get a note from the FAA that says, "We'll be looking for some further information from you as to why this event occurred -- in the form of a letter of investigation; we'd like a response in about 30 days or so." That is when things really get interesting. That is when the turf protection issue really comes to the fore. We then do an "official" investigation, and we really find out what happened. Well, the jury is still out on whether or not that is truly an effective way to investigate that event. But it certainly exists today.

We think that a maintenance organization can profit from a different kind of error investigation, a different kind of error analysis. That is the reason we chose to get involved with Boeing and with our other fellow airlines on the project called MEDA (Maintenance Error Decision Aid). We want to get away from the standard blame and train scenario, where we do an investigation based on severity, elevate it to necessary levels, mediate punishment, and move on, never really learning anything from the investigation nor necessarily even having done anything profitable for the person involved.

Well, I will answer my own opening question: Do maintenance organizations profit from this type of error analysis environment? I think not, if we are honest. What is the role of a technician today in error analysis; in investigation? Does the technician investigate his own error? Not really. They are probably the most valuable source of knowledge as to why that event happened and what could possibly be done from a systemic point of view to prevent it from happening again. But they are an under-utilized resource in a lot of cases because we are intent on fixing the other potential side effects of the event such as letters of investigation or an out of service airplane. The nature of our operation dictates that we have to do that. Yet we are letting a source of valuable knowledge from a safety and investigation standpoint go untapped. This is another reason why we think participation in this project is valuable. It will begin to tap that resource. Not only can we utilize that untapped resource of the technician or the person involved directly in the mishap, but we can also apply the information to system analysis as well. So it is a win-win situation. You are able to capture the human issue within the error, but you are also able to apply it to your system to make improvements, to help ensure that down the road somewhere the chain of events will not come together to put that person potentially at risk again.

Instead of turf protection, we would like to move toward a team approach. A team approach that says: We are not going to blame and train anymore, or we are going to at least try to avoid it. We want to get to a point where that technician's experience and voice are heard so that valuable human performance information is extracted from that event. If systemic type corrections need to be made, we can make them at that point too.

What we want to get in error investigation is what you can see on the right side of the page (**Table 3**), performance-based error analysis. Today we have the search for the guilty party, or the blame and train mentality. We want to move toward the right side where error is formally investigated; focus is on the contributing factors influencing performance; and the conclusions are objective and based on analytical, scientific method rather than someone's best guess. Hopefully the system improves with lessons learned. That's our vision. Most human factors analysis is presently done by non-human factors people, because, again, if we go back to our earliest points, we know that error analysis or investigation is typically pinned on the front line person. They are given the responsibility to do it.

Table 3 Error Investigation

Error Investigation

Today "Search for the guilty party"	Tomorrow "Performance-based"
▪ Non-existent or limited in scope	▪ Error is formally investigated
▪ Inability to assess factors contributing to error	▪ Focus on contributing factors influencing technician's performance
▪ Conclusions are subjective; mechanic is often assumed to be at fault	▪ Conclusions are objective and based on analytical assessment
▪ System performance does not improve	▪ System performance does improve

If we go on the assumption that this analysis is done by non-human factors people, another question to ask is what do the rest of us know about these maintenance events? The rest of us who sit in offices and environments and probably do not even hear of a large number of the errors that occur in our systems every day. We depend on conference calls and grapevines and informal information systems to relay this information to us. I know for a fact that I do not hear about error that occurs every day in a station that is two miles down the road from my office. Yet this knowledge is valuable, it is important, and it impacts how we operate. Our natural evolution should be to get to a point where we provide human factors-based support tools to those people who are given the responsibility of investigation so that they can consistently analyze error and develop intervention strategies without our help, literally. If that error analysis indicates that there is a system problem, then other people can be called to come in and help with those systemic type issues. At Continental we want to go even one step further than that. We want to get to a point where we do those things and make those systemic changes but we also want to assure that we have a closed loop by bringing that technician or participant in the error directly into the loop and say, "You are a valuable resource and a source of information in this event. We want your help, we want you to help us capture all these things that led you to be involved in this error." That will allow true human factors analysis to be performed, not just the standard blame and train. It can be performed by anyone in the organization, including the front line maintenance technician.

At this point, I am going to turn it over to my colleague from Boeing and he is going to tell you what that new performance-based approach is going to look like.

Jerry has just presented why we need to improve the methodology by which we investigate maintenance error. I will address how we are planning to move to more performance-based analysis.

One year ago Boeing formed a team with Continental, United, and British Airways to develop a new "human-centered" methodology for the investigation of maintenance error. We have additionally invited the Federal Aviation Administration to join our program. The outcome of our project is what we call the Maintenance Error Decision Aid (MEDA). As the chart shows, we are building an investigation technique (**Figure 3**). I would like to point out a few key elements in our mission. First, the decision aid is event-driven. That is, it is a tool to investigate maintenance error events, whether they be actual events, or hypothetical events resulting from the awareness of some risk. It is not an audit tool, per se. Auditing and event investigation are two distinct tasks, and we felt that event analysis was the right place to start. Secondly, the goal is not simply error reduction. The goal is preventing airplanes from being dispatched with error-induced discrepancies. This is "error management." Error management encompasses the understanding that some errors may not be eliminated and that often the best strategy is to capture the error or build tolerance into the system to lessen the effects of the error.

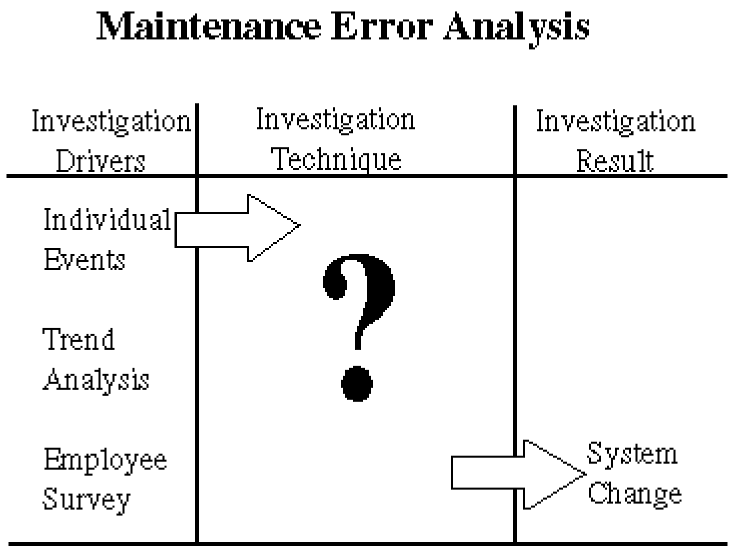

Figure 3 Maintenance Error Analysis

Before I go into the details, I would like to briefly discuss the deliverable. MEDA will be a paper-based human error investigation methodology tailored to the needs of aircraft maintenance. The deliverable will consist of two documents (**Figure 4**). The basic document will provide the tools for error investigation. The supplement will provide the training material required to teach MEDA analysis. You will notice the chart says "local factors analysis." The MEDA tool developed in 1994 will specifically address the needs of the maintenance manager performing what we describe as local factors analysis.

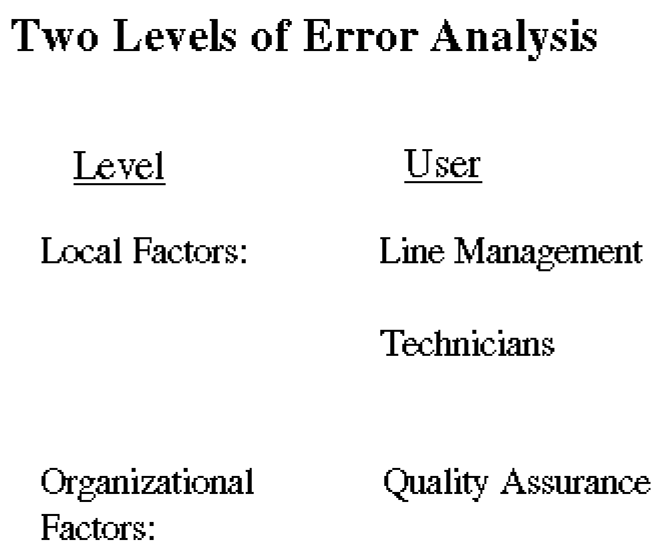

Figure 4 Two Levels of Error Analysis

During our investigation over this last year, we found that maintenance error analysis occurs on two distinct levels (**Figure 5**).

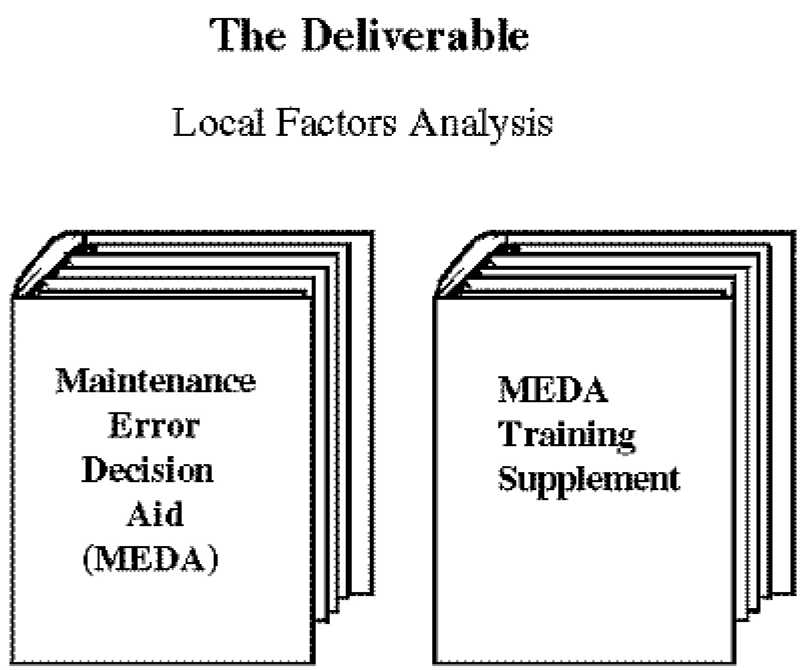

Figure 5 The Deliverable

First there is the analysis that occurs within a local area of the airline, performed primarily by the management of the technician who erred. Error analysis often remains within this level unless there is some aircraft event that raises visibility of the error beyond the local area. The second level of analysis happens at the organizational level. This analysis gets launched when the event causes a significant operational impact or the local investigators need the assistance of some outside organization such as Engineering, Quality Assurance, or Training.

I will quickly review what our development team has established as the five preferred steps in maintenance error analysis performed at the local level (**Figure 6**). The first thing a maintenance manager will do when he or she learns of an event is to determine whether it will be investigated. Today, this step in error analysis occurs almost subconsciously. If maintenance is informed by the cabin crew that the coffee maker is incorrectly installed, the crew chief or maintenance manager will quickly decide if the event is worthy of investigation. Within MEDA, we have termed this "first cut analysis." It is the quick development of an error scenario, the assessment of the potential criticality or impact of the event, and the determination of the level of investigation commensurate with the impact of the error. Within MEDA an impact decision tree is being developed to establish the relative impact of the error.

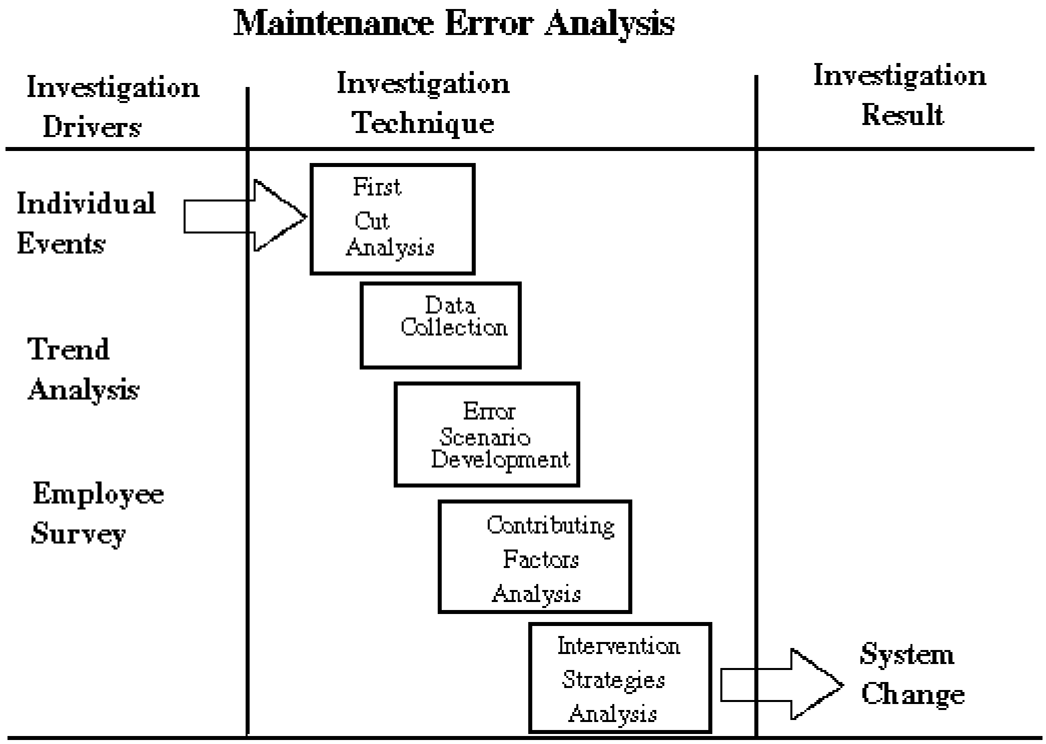

Figure 6 Maintenance Error Analysis

The second step in error analysis is data collection. Within MEDA, sample data collection forms are being developed to ensure that appropriate information is captured during the investigation. These data collection forms will be structured around the contributing factors analysis step I will discuss in a few moments.

The third step in the investigation is what we call "error scenario development." Error scenario development is designed to determine what happened during the event, including the identification of pertinent organization norms. Often, error occurs when the technician deviates from a particular policy or procedure. However, in some cases the system has adopted norms that have, over time, drifted away from the written procedure. In our investigation we found cases where aircraft events occurred when a technician broke from the social norm to follow a "bad" procedure. MEDA will provide event-charting techniques that will help systematically capture the actual error scenario.

The fourth and most human-factors-intensive step in error investigation is contributing factors analysis. The goal of this analysis is simply to determine why the error occurred. Within MEDA, a factors checklist will be provided to ensure that the investigator is addressing most of the contributing factors that may have contributed to the error. Additionally, supplementary assessment material will be provided for each potential contributing factor on the checklist to ensure that the investigator knows how to assess the merits of each factor within a particular error scenario. At this point, the impact decision tree used in the first cut analysis will be used to determine a revised relative ranking of the impact of the error scenario from both a safety and economic perspective.

The last step in the analysis relates to the selection of intervention strategies. Within MEDA, an intervention strategies checklist will be provided as a guide to ensure that available options for addressing contributing factors are considered. Supplementary assessment material will be provided as an extra resource of the applicability and effectiveness of different types of intervention strategies.

In addition to the investigations conducted subsequent to individual events, trend analysis must be conducted to identify common factors or links among events. When it appears there is a common factor contributing to a number of events, it is appropriate to launch an organizational level investigation. Our MEDA development team has deferred work on this level of investigation until the local factors analysis work is complete.

As an overview, the MEDA development team is working to develop methodology to improve the investigation of individual error. Our schedule for completion of this local factors analysis is to have MEDA in the field by mid 1994 and made available to all airlines by early 1995.

Many of you have seen this chart with the flying public being supported by the three legs of the stool: regulatory authorities, airlines, and manufacturers (**Figure 7**). We have been talking about how airlines can improve their analysis of maintenance error. I would like to speak briefly on what role the regulatory authorities and manufacturers must play in order for the goals of MEDA to be realized.

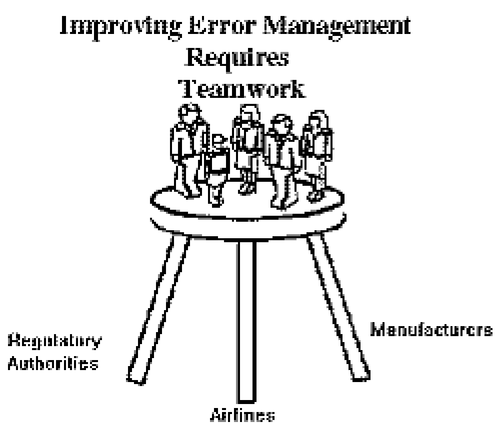

Figure 7 Improving Error Management Requires Teamwork

First, manufacturers must begin to better understand human performance. Over the years we have become very adept at analyzing equipment failure. When it comes to maintenance error, however, we often fall back to the search for the guilty party approach. The adding of caution notes to maintenance manuals and the subtle recommendations for your mechanics to be more careful in their work will rarely realize the performance improvement sought. We must continue to push our understanding of maintenance error so that we can design equipment and procedures that are truly less error prone and more error tolerant.

The regulatory authorities must help by putting less emphasis on punitive measures that will deter the erring individual from recommitting the error, and putting more emphasis on development of the intervention strategies that will improve overall system performance.

Principal maintenance inspectors must look beyond enforcement action. They must look to why the error occurred.

With the airlines, manufacturers, and regulatory authorities working toward improved maintenance error investigation, both safety and economic improvement will undoubtedly result.

HUMAN FACTORS ADVANCES AT CONTINENTAL AIRLINES

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Abstract

In Phase IV of the human factors program, two distinct projects have been undertaken. The continuing involvement with Continental Airlines and SUNY at Buffalo on workcard design has now produced a portable computer-based system. This combines the successful improvements to the paper-based workcard (Phase III) with the advantages of a hypertext system allowing multi-level access to documentation for A-check and C-check tasks. Evaluation on the A-check task of landing gear inspection showed the computer-based workcard to be a significant advance over the original paper-based system. The second project was development of a program to audit human factors issues in aircraft inspection. This ergonomics audit program consisted of a sampling plan, an audit checklist, and a computer program to compare audit measurements against accepted human factors standards. Evaluation of the audit program showed that high reliability could be achieved by careful design of checklist items and that automated production of audit reports saved considerable time.

1.0 INTRODUCTION

This paper describes two complementary human factors improvements in the inspection area of Continental Airlines' maintenance program. Their common thread is in applying human factors techniques from other fields (e.g., manufacturing, computer-aided decision making) to the specific problems of aircraft inspection documented in this project's previous phases (**Shepherd et al., 1991**; **FAA/AAM & GSC, 1992** and **1993**).

The first project was a direct continuation of Phase III's demonstration of improved workcard design. Because the redesigned paper-based workcards received such good evaluations, an obvious next step was to incorporate the increased flexibility of document access available using a portable computer. A system was produced and demonstrated on five C-check tasks and three A-check tasks. The development and evaluation of this system is presented in Section 2.

The second project was performed in conjunction with another airline partner, a regional operator of scheduled helicopter services. It arose from the need to integrate the various human factors investigations sponsored by FAA/AAM into a tool for measuring potential mismatches between inspectors and the tasks, machines and environment with which they work. The outcome is an ergonomics audit program designed to measure the current level of ergonomics/human factors within a hangar and hence to focus attention on those aspects needing to be changed. This program was produced and evaluated at both airline partners, as detailed in Section 3.

2.0 DEVELOPMENT OF A COMPUTER-BASED WORKCARD SYSTEM

2.1 Issues of Computer-Based Workcard Design

The workcard is the primary document that controls an inspection task. It has, therefore, a great influence on inspection performance. During Phase I, many human-system mismatches were identified which could contribute to errors. Costs, due to undetectable faults or faulty detection, when weighted against the cost of providing quality documentation, make a strong case for developing optimum documentation and a methodology (coupled with a set of guidelines) for designing such documentation. This study develops such a methodology, based on the application of human factors knowledge to the analysis of aircraft inspection tasks. In Phase II, a paper workcard was designed to replace the current workcard. From this design, a set of guidelines was developed to improve workcard design. The methodology developed, being highly generic, can also be extended for the design of portable computer-based workcards.

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

Advances in the technology in portable computing systems are making the realization of these benefits more feasible. Hence, a combination of the increasing information needs of inspectors, and technological advances, ensures that the use of portable computer-based workcards to replace the more traditional hardcopy workcards is inevitable in the long term. While specialized computer hardware and software systems have been designed for automating complex diagnostic tasks in maintenance, such as the Air Force Integrated Maintenance Information System (IMIS) (**Johnson, 1989**), there is a need for a simpler, less expensive system using off-the-shelf components. Also, so far such computer-based systems have been traditionally aimed at diagnostic tasks, but here they are applied to more information-intensive procedural tasks which form a major portion of the aircraft inspection activity. Therefore, the objective of this study is to develop and test a prototype of a simple, inexpensive inspection workcard implementation on a lap-top computer. Specifically, the design had to be proven for both A-checks and C-checks.

While most of the issues concerning good design of information for workcards raised in Phase III applied directly to the design of a computer-based system, there were two new factors to take into account: hardware and software, particularly hypertext.

The choice of the hardware for implementing the computer-based workcard is one of the critical issues. The original paper-based system studied lacked a convenient hand-held integrated workcard holder although one was designed for the improved paper-based system. Current lap-top systems are inexpensive and getting smaller with new sets of features, while sacrificing little in computing power. Key breakthroughs in technology are feeding this process: storage devices are getting smaller, IC designs support fewer chips and thus power requirements are getting lower (Linderholm, et al., 1992). Also, designs are getting more rugged, which inspires confidence if a computer is intended for field usage. Using these systems is still inconvenient though, due to keyboard and pointer interfaces. Systems operated by keyboards and mice partially defeat goals of accessibility and connectivity (Meyrowitz, 1991). Pen-based computing allows links between information to be created by a mere pointing gesture, but this technology is still a year or so away from field use without special support.

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

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

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

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

2.2 Development of the Computer-Based System

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

The design of the system adhered to the lessons learned from the development of the paper-based workcard as identified by the taxonomies given in the **Phase III report**. The design also followed guidelines given specifically for the design of computer interfaces (Brown, 1988; Smith and Mosier, 1986). The following specific guidelines were used to develop the computer-based systems:

Information Readability

1. Layout
   - Use a fixed set of proportions/grids
   - Use spatial layout as a primary cue for object grouping
   - Use a consistent layout across fields
   - Use fixed size/location for "functional category fields"
   - Left justify most important information
   - Use blank lines in place of graphic lines to reduce clutter
2. Typography
   - Use upper case only for short captions, labels, and headings
   - Use conventional punctuation and formalisms
3. Metaphors
   - Be very explicit in the use of metaphors
   - Use explicit screen transitions: e.g. iris open versus scroll
   - Use paper form metaphor for data input
   - Use soft button metaphor for all external links
4. Contrast
   - Use contrast sparingly and as a last option
   - Use contrast to attract attentional resources to select portions of text

- Use maximum three levels of contrast coding

Information Content

1. Input information
    - Use familiar mnemonics for input
    - Use congruent command pairs: e.g., R/Wrong & not R/Close
    - Use "radio buttons" for all multiple choice information
2. System output information
    - Use the display as an external working memory of the user
    - Provide screen identity information
    - Display only the necessary information
    - Condense all unnecessary information into icons
    - A display density higher than 15% should be avoided
    - Use the inheritance metaphor to identify position in hyperspace
    - Use affirmative dialogue statements
    - Provide input acknowledgments and progress indicators
    - Use auditory feedback conservatively
    - System messages should be polite and instructive
    - Do not provide a system initiated help feature
3. Graphic information
    - Use graphics to reduce display density
    - Show all spatial, numeric, temporal information graphically
4. Iconic information
    - Use icons for all direct manipulation
    - Use icons to save display space and reduce clutter
    - Use icons for all external links
    - Use icons to permit cross cultural usage

Information Organization, Manipulation, and Access

1. Linking
    - Provide contextual internal links
    - Use internal links for all reference information
    - Use external links sparingly and only for non-contextual information
    - Provide a link backtrack option
    - Provide an UNDO option for navigation
    - Make linking explicit, do not leave anything to exploration or browsing
    - Use linking sparingly to avoid user confusion and disorientation
    - Label links where possible
2. General organizational philosophy
    - Organize for progressive disclosure and graceful evolution
    - Keep layered information optional
    - Do not use scrolling fields
    - Organize tasks in a fixed linear as well as optional nested structures

Other Pragmatic Issues

1. Physical handling and infield usability
   - Develop and implement standards for reverse video, contrast for varying lighting conditions
   - Follow a pencentric display design philosophy
   - Design for single handed operation
   - Minimize the use of key entries, use direct manipulation
2. Hardcopy
   - Provide feasible options for obtaining hardcopies in a fixed format
3. System response time
   - Keep the system response times for all actions within standards
4. User acceptability
   - Honor user preferences
   - Provide only those functions that a user will use

Features of the System

The design of the computer-based workcard follows these guidelines by the following features. The first screen of the workcard is the input manager in which the inspector enters data that normally would be found at the top of every page of the workcard such as the inspector, supervisor, and aircraft identification number. This information is then reproduced on all other documentation generated, such as the Accountability List and the Non-Routine Repair forms, thus relieving the inspector of repetitive form filling. The global view displays all of the tasks for the inspection and highlights the tasks completed, serving as an external display to augment working memory. While performing the tasks, the inspector has direct access to information for both input and output such as the general maintenance manual, the airplane's manufacturer maintenance manual, engineering change repair authorization, air worthiness directives, and attachments. This eliminates the need for the inspector to carry bulky attachments or leaving the inspection site to refer to a manual. For each task, the inspector has the option of signing off, reporting a non-routine repair, making a note on the writeup note feature, going to the home screen which shows the signoffs remaining for the task, going to the global screen, viewing an overview feature which displays the number of signoffs that were completed, or using a help feature. All of these features reduce memory and information processing requirements on the inspector. A continuously-updated accountability list may also be viewed at any time. This feature is a record of the inspector's activity using the workcard such as signoffs done, notes made, and tasks previewed. The outputs of the system are the accountability list and the non-routine repairs that the inspector wrote up.

Accessing these features is done by selecting icons or radio buttons which have pictures or labels designed for rapid learning. The links between these features are explicit and always have a backtrack option. Information for performing the tasks were categorized and layered to assist both experienced and inexperienced inspectors. General information was separated from specific task directive information. All spatial information was conveyed through graphics.

Thus, these features serve to meet the design requirements and follow both the issues for developing workcards for aircraft inspection and guidelines for human computer interfaces.

2.3 System Evaluation

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

Two analyses of the evaluation response data are of interest:

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

For the first analysis the 39 questions asked about the computer-based workcard were divided into those where it was rated significantly better than neutral, not significantly different from neutral, and significantly worse than neutral, using the Sign Test with a significance level of $p < 0.05$. **Table 1** gives the results..

Table 1 Numbers of Items for Computer-Based Workcard Judged Against a Neutral Response

Outcome	**Number**	**Percentage**
Better than neutral	25	64%
Not different from neutral	13	33%
Worse than neutral	1	3%

The inspectors were highly enthusiastic about most aspects of the system. Many of the items judged better than neutral were overall evaluations (e.g., degree to which workcards like those should be used), but some were for very specific features (e.g., readability of buttons and icons), indicating that both the overall concept and detailed design were approved of by the users. Most of the neutral responses came from completeness and organization, or from features not used by the respondents on this task (automatic generation of Accountability List and Non-Routine

Repair forms). Two of the questions which were not significantly different from neutral were not expected to be. Amount of information and amount of graphics information were not changed for the computer-based workcard, and were judged as not too much but not too little. The only feature significantly disliked by inspectors was one which gave time information, i.e., what percentage of the standard time had been spent. As has been found consistently in earlier phases of this project, inspectors strenuously resist implications of time pressure in their jobs. The time feature has now been removed from the system.

The computer-based workcard also compared favorably against the current and improved paper-based workcards. **Table 2** shows the numbers of responses where it was possible to make a direct comparison of the computer- and paper-based systems, using the Friedman Analysis of Variance with a significance level of $p < 0.05$.

Table 2 Numbers of Items for Computer-Based Workcard Judged Against the Two Paper-Based Systems

Outcome	**Number**	**Percentage**
Better than paper-based system	14	74%
Not different from paper-based system	5	26%
Worse than paper-based system	0	0%

On no issues did the inspectors rate the computer-based system worse than the paper-based system. Fourteen of the nineteen issues were judged significantly in favor of the computer-based system, including all of those issues which represented an overall evaluation of the system (e.g., overall ease of usability of workcard). Amount of information provided was judged almost the same in all three systems, which was expected as no information was added to, or subtracted from the original workcard in developing the two new systems.

Although the main comparison was between the original paper-based workcard and the computer-based system, the inclusion of an improved paper-based workcard was instructive. In all of the significant comparisons, the computer-based workcard was as good as or better than the improved paper-based workcard. However, for most questions, the major difference was seen between the original and improved paper-based systems, rather than between the improved paper-based and computer-based workcards. The conclusion is that many improvement can still be made without resorting to computer-based systems. It should be noted that the text and graphics which went into the computer-based hypertext system were the same ones used in the improved paper-based system. Thus any company would be well- advised to modify their paper-based system, as this completes most of the work needed to implement any future computer-based system.

Not shown in the results is the fact that all inspectors quickly became familiar with the computer-based system, none taking more than one hour to learn the system well enough to go through the steps of this single A-check task. More time would obviously be required for inspectors to become really adept at navigating the system and using all of its features, but the point to be made is that the time and test overhead associated with the introduction of this system is very low. This was a vindication of the design philosophy which utilized detailed task analysis and human factors interpretation of the inspectors' jobs, plus feedback from the inspectors themselves, to produce the final design.

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

3.0 ERGONOMICS AUDIT FOR AIRCRAFT INSPECTION

3.1 Audit Systems for Human Factors

Arising from this human factors analysis of the inspection job, a number of specific studies have been completed under the auspices of the Federal Aviation Administration, Office of Aviation Medicine (FAA/AAM). Projects with the airline industry have considered improved lighting (**Reynolds, Gramopadhye and Drury, 1992**), better documentation design (**Patel, Prabhu and Drury, 1992**), revised training for visual inspection (Gramopadhye, Drury and Sharit, 1993) and the impact of posture and restricted space (**Eberhardt, Reynolds and Drury, 1993**). The aim of these studies has been to allow airlines to use some of the benefits of ergonomics without necessarily having trained ergonomists. At this time there is a need to provide integrative tools to enable a maintenance organization to develop an overall strategy for applying human factors principles in a systematic manner. The audit program developed in this report is an essential step towards integration.

In order to know where to apply human factors, for example using the FAA/OAM developed Human Factors Guide (Parker, 1993), it is first necessary to know where there are mismatches between the human (inspector) and the system (equipment, tools, environment). The audit program provides a convenient, quantitative way to determine these mismatches. It starts from the common ergonomics basis of inspection as a task/operator/machine/environment system. The output from the audit can be used to focus design/redesign efforts where they will have the greatest impact on reducing the human/system mismatches which cause inspection and maintenance errors.

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

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

The ergonomic audit developed here provides an overview of the ergonomics (human factors) of the inspection system. It will not point out the specific human errors that might result during the task, but rather indicate the **important** human factors issues that need to be addressed if the performance of the operator doing the task is to be improved. It provides a comparison of the current condition and the standards prescribed by current human factors good practice, incorporating national and international standards where appropriate. The report generated by the computer program gives guidelines to prioritize and systematize the application of human factor techniques, so as to develop improvements and achieve the set standards.

As with the previous audit programs for manufacturing (Mir, 1982), continuing observations of the task specify a series of measurements which need to be made. Some of these are measured with the help of instruments (e.g., light-meters, tape measures etc.), while some others are answers to checklist questions. The audit program has been designed to be modular so that the auditor can apply the particular measurements needed in each task.

3.2 Development of the Audit Program

There are three steps in the audit program designed here. First, a method must be developed to choose the correct tasks to audit. Second, a reliable audit checklist is required. Finally, a computer program is needed to compare the audit results against human factors standards.

3.2.1 Sampling of Tasks

The first decision which needs to be made is the basic unit to be audited. In a manufacturing environment the natural unit is the **workplace**, but in inspection (or maintenance) the task, represented by the workcard, is more appropriate as all job and quality control procedures already are based on this unit.

Of the various statistical sampling techniques available, the only two that can be effectively used to decide on which task to be audited are random sampling and stratified random sampling (systematic sampling). In random sampling, all tasks (workcards) are given an equal chance of being selected. This ensures that the sample selection is unbiased, but it may require larger sample sizes to provide appropriate coverage. However, an additional consideration is the fact that all inspection tasks may not be considered of equal importance. It may be more appropriate to concentrate the sampling on those tasks considered most critical. Stratification can be used to segregate items to be examined by sampling within pre- determined groups, or strata, of tasks. Some care must be exercised while establishing the strata. They should be determined so as to form a group having similar characteristics. As part of this program, a detailed technique, similar to those used in job evaluation, was developed to apply stratified sampling (Koli, et al., 1993). However, only the simpler random sampling is presented here.

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

As the aim is to determine which aspects (task, operator, machine, environment) may impact inspector-system mismatches, the content of the audit checklist can use any convenient taxonomy of factors affecting human performance. The generic task description developed in Phase I was used here, breaking any inspection job into the seven tasks of Initiate, Access, Search, Decision, Respond, Repair and Buyback. These can be grouped together into a pre-inspection phase (Initiate), an inspection phase (access, search, decision, respond) and a post-inspection phase (repair, buyback).

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

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

With these in mind the audit system was designed, and is described in the following section.

3.2.2. The Audit Checklist

From the taxonomy of factors, and the three phases of the audit, a checklist was produced. It is either a paper-based system or can be entered in the field to a portable computer, whichever is more convenient. Two versions of the paper-based system are available, a larger version with detailed instructions and pictorial examples, and a much shorter version to be used when the auditor is sufficiently practiced to be able to work without these aids.

A. Pre-Inspection Phase

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

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

This information is gathered before the actual inspection to reduce the effort of the auditor (and any interference with the inspector) to a minimum once the task progresses.

B. Inspection Phase

During this phase the auditor evaluates the main issues, i.e., information, environment, equipment and physical activity, but the focus of attention is the task at hand, and the way in which this task is executed. The issues are:

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

C. Post-Inspection Phase

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

3.2.3 The Computer Program (ERGO) for Audit Analysis

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

1. opening the data file
2. accepting answers or values to the various questions in the checklist
3. updating the counter
4. writing the answers to a data file
5. accessing the data file
6. comparing values with correct value or answer
7. setting flags and proceeding to the next data set if the two answers are unequal
8. checking the position of all flags at the end of all data input
9. printing recommendations or prescribing guidelines for all the flags set.

A simple manual accompanies the program, showing how to:

- install the software onto a personal computer
- run the program
- create and view data files
- access data files for analysis
- create and view output files
- print data and output files and
- abort from within the program.

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

3.3 Evaluation and Evolution

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

The Audit checklist evolved over three different versions.

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

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

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

The differences between the two auditors were analyzed using the Cochran Q test, which is a strong test to determine whether the same treatment generates different responses between subjects. The value of the test statistic X2 for each test is shown in **Table 3**, where all differences are significant at $p < 0.05$.

Table 3 Test for Significance of Differences Between Auditors

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

Table 3

The conclusion is that results did change between the two auditors. Specific questions whose responses were different between the auditors were not indicated by the significance test, and had to be determined by post-hoc investigations. As these differences were found, redesign of the audit program was required to provide a checklist which gave the same results for each auditor.

In order to better understand the disparities, the checklist questions were segregated into three categories dependent upon the type of question, and hence the possible errors in answering the question. Thus, any question on the checklist can either result in either a Reading Error, an Operator Perception Error, or an Auditor Judgment Error. Overall, 54% of the questions were of the reading off type questions, 24% were the operator perception type and 21% were the auditor judgement errors. **Figure 1** shows the percentage of each error type made on the three tests.

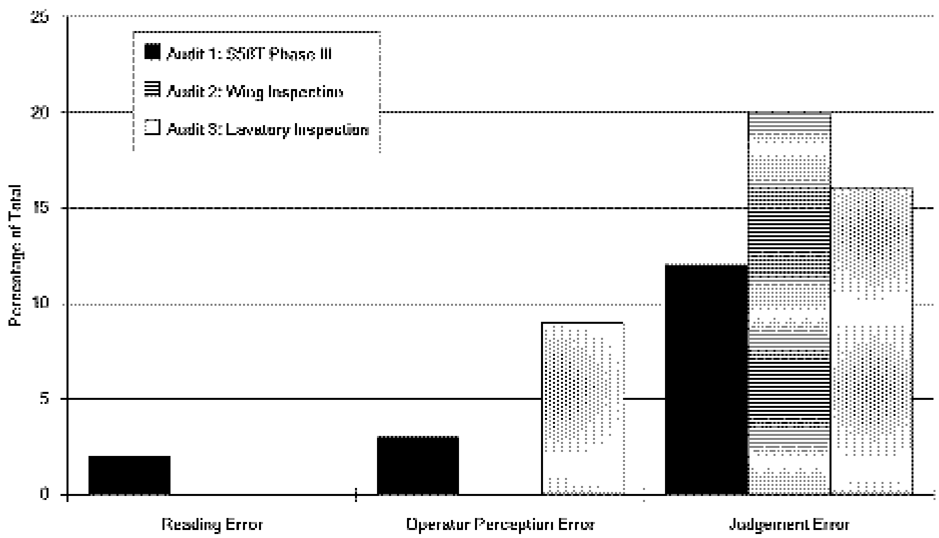

Figure 1 Percentage of Each Error Type on East Test

As can be seen from this figure, the maximum errors were due to **auditor judgement** followed by **operator perception errors**. **Reading off errors** contributed to only a very small percentage of the total errors.

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

1. More explicit instructions assigned to auditor judgement questions
2. Reduce the number of "auditor judgement" type questions and increasing the number of "read off" type of questions.
3. Better training of auditors.

Version 3.0 of the audit checklist incorporated all of the above recommendations and was tested for reliability by administering simultaneously by two auditors on the task (Audit 4) of the Left Power Plant Inspection on a DC-9 (**Table 4**).

Table 4 X^2 Table to Test for Significance

Audit	Task Audited	X^2
4	Audit 4 - Left Power Plant Inspection/DC-9	2.1

Table 4

The differences between the two auditors was analyzed using the Cochran Q test, referenced earlier. The value of the test statistic X2 was now not even significant at $p < 0.10$, showing that results did not change between the two auditors. Thus, Version 3.0 of the audit was deemed to have proven reliability.

3.4 The Audit System in Practice

The audit evaluation emerges in the form of a memo to a supervisor from an auditor, using heading information generated within the program. This format can readily be changed, as the output file is a simple text file suitable for input into any word processor. Note also that the output does not just give information that there is a mismatch, but provides some guidance as to how corrections can be made, for example by giving recommended illumination levels or recommended air temperatures. The audit program is no substitute for a detailed ergonomic analysis, but it does provide a rapid tool for identification of error-likely situations. For more detailed recommendations, the FAA/AAM Human Factors Guide (in press) should be consulted.

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

The audit system has now been used by both airline partners, using the training version of the checklist and the computer documentation produced. It has been used in two rather different ways. At the rotary wing operation, several audits were performed and the results combined to provide guidance to management in the implementation of changes. From this compilation it was determined that the major ergonomic needs were documentation redesign, task lighting and access equipment redesign. Steps have now been taken to begin implementation of changes based upon those findings, and the audit program will be used after implementation to measure the effectiveness of the changes.

Our other airline partner has incorporated the audit program into its on-going Quality Assurance system. A single auditor has been trained in its use, and regularly uses it to produce audit reports on specific inspection activities.

4.0 OVERALL CONCLUSIONS

These two projects were separate but complementary. The first showed how a specific inspection subsystem (the workcard) can be enhanced using modern portable computer systems. Direct access to documentation reduced reliance on memory and waiting time to retrieve the information. Compared to the original paper-based workcard, the computer- based system was easier to understand, reduced the effort to locate information, increased organization and consistency of information, and increased overall usability of the workcards. The inspectors found the computer-based workcards interesting and would like to see them implemented at the workplace. Time to become familiar with the system was brief.

The second project showed how an overall assessment could be made of the quality of human factors design of inspection workplaces. This project also showed how sensible use of a computer system could enhance performance.

Perhaps the greatest point of similarity between the two projects was their impact on efficiency. Both were designed to reduce human/system mismatches, and thus impact inspection errors. But both systems impacted favorably upon the time required to perform the task. With computer-based workcards, unnecessary re-entry of information was eliminated, and all required documents were where the inspector needed them, thus removing the need to seek out other information sources. For the audit program, the ability to produce a typed audit report more rapidly than by hand has led to its adoption in the maintenance organization. Good human factors design eliminates human/machine mismatches and can result in time savings as well as error reduction.

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EFFECT OF WORKING POSTURES IN CONFINED AREAS

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Abstract

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

1.0 INTRODUCTION

Aircraft structures are designed as a compromise between aerodynamics, strength, weight, and access. In many instances, designers must concede optimum access in order to meet thee other requirements. This leaves many aircraft inspection and maintenance tasks to be performed in non-optimum conditions, which may lead to fatigue on the part of inspectors and maintenance personnel.

Task performance under extreme conditions can produce both physical and cognitive fatigue. *Physical fatigue* may be defined as a state of reduced physical capacity (Kroemer et al., 1990). Work can no longer be continued because the involved physical subsystems are not capable of performing the necessary functions. For example, a posture can no longer be maintained due to exceeding the endurance limit of the muscles (see Rohmert, 1973). *Cognitive fatigue* is a term normally associated with stress; it is a generalized response to stress over time where stress is the perceived inability to meet the task demands. The effects of fatigue may reside as a psychological state within the individual or extend to affect performance. Symptoms of fatigue include restricted field of attention, slowed or impaired perception, decreased motivation, subjective feelings of fatigue and task aversion, and decreased performance in the form of irregularities in timing, speed, and accuracy (Bartlett, 1953; Grandjean and Kogi, 1971).

An inspector's response to the environment is a function of the associated stress and fatigue effects. In most instances, this response cannot be described by one variable but is manifested in various physiological, psychophysical, and behavioral patterns. Inspectors attempt to respond to or cope with a stressful situation in order to lessen or eliminate the fatiguing or stressful situation's effect on them (Cox, 1985). They do so through one or more modes of response (Meister, 1981). For example, while performing maintenance or inspection in a cramped area of an aircraft, there may be an initial physiological response to the postural demands such as lack of blood flow to the leg muscles, which in turn causes a behavioral response (e.g., posture shifting) and/or subjective response (e.g., perceived discomfort). In addition, such a behavioral response may alleviate one component of the fatigue response, while causing another. Continuing the example, a change in posture may reduce the physiological response, but the new posture may make the task more difficult to perform and cause feelings of frustration.

In order to describe, and eventually predict, the effects of operator response on performance and workload, there is a need to understand the effects of stress and fatigue on the operator. During Phase III, ergonomic factors which may produce fatigue and ultimately affect performance and well-being were identified and are listed in **Table 1** (**FAA/AAM & GSC, 1993**). This compilation of factors is not an exhaustive list, and there are a number of other, lesser environmental, task, and operator characteristics which could contribute to fatigue effects (e.g., temperature, gender, age, etc.). However, the listed factors have been identified as the most salient and prominent factors as possible contributors to fatigue in the aviation inspection/maintenance environment and provide a starting point to focus investigation.

Table 1 Ergonomic Factors

ERGONOMIC FACTORS
Area/Volume of Workplace
Duration of Task
Equipment/Tooling Used
Lighting at the Workplace
Social Factors (e.g., resource availability)
Surface Condition of Adjacent Surfaces

2.0 BACKGROUND

2.1 Workplace Area/Volume

One of the most noticeable deviations from ergonomically optimum conditions is that tasks must be performed in restricted spaces, whether it be during access to, or inspection in, a given area. Confined spaces are normally associated with whole-body restrictions occurring when an inspector enters an intervening structure or works within an area confining the entire body to that specific area (e.g., cargo hold). Restrictive spaces are also created when the surrounding physical space is unlimited, but the immediate working area is restricted. These partial-body restrictions result in limited movement of a specific body part; for example, tasks aided by access devices (e.g., steps, cherrypickers) cause lower limb restriction because the feet must reside within a limited area. Other examples include reaching arms through access holes and positioning various body parts in and around fixed aircraft components (e.g., inside a small access panel). These partial-body restrictions may occur in addition to whole-body restrictions, as in interior inspection of the tail compartment which demands that the inspector climb into the area (whole-body restriction), as well as place their head and arms through narrow confines to check components (partial-body restriction).

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

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

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

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

Restricted areas may also prohibit easy access to any extraneous material in the immediate working area (e.g., workcards on the illustration). This forces inspectors to make decisions without their having comparison standards, increasing their memory load, or requires additional time for them to obtain information from the workcard, a manual, or a supervisor. Moreover, when viewing angles are less-than-optimum, this further decreases sensitivity and increases the difficulty of decisions. Thus, restricted spaces can make the decision-making more memory-intensive, lengthy, and difficult.

Conversely, pressures for cursory decision-making may motivate the operator can get out of the space quickly. Decision-making tasks exhibit a speed/accuracy tradeoff (SATO), with speeded performance associated with inaccurate decision-making. However, inspectors are highly motivated to perform accurately (**Shepherd et al., 1991**). Thus, it is predicted that accurate decision-making performance would not be compromised by even the most extreme space conditions, but that workload and stress may increase.

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

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

2.2 Task Duration

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

2.3 Equipment/Tooling

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

2.4 Workplace Lighting

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

2.5 Social Factors

Social aspects of the environment may also increase fatigue. As the number of people in a given area increases, the amount of space for each person decreases. If uncomfortably close spacing is required between individuals, their tolerance to the environment may be limited. If many individuals in the same area perform the same tasks, the available resources may become limited, and people may become frustrated (e.g., specialized/portable lighting not available).

2.6 Surface Condition

The surface condition of many areas in an aircraft hangar where work must be performed is poor: dirty, uneven, or rough. These surfaces force inspectors either to limit the postures they are willing to adopt or to adopt inefficient postures. For example, operators may stoop or crouch instead of sitting in a certain area to avoid oil-soaked clothing. These surfaces also present a safety hazard; at times they cause inspectors to slip or trip. Furthermore, continued kneeling or laying on rough or uneven surfaces can cause re-occurring aches and pains.

In summary, the effects of restricted space and the associated posture effects have been hypothesized to be the largest contributor of producing a fatigue response, and possibly affecting workload and performance. Thus, this evaluation focussed on this factor while simultaneously considering other factors in the aviation environment. On-site evaluation was undertaken in order to 1) measure and determine if increased stress and fatigue levels existed in the aviation maintenance and inspection environment; 2) determine if techniques and methods used successfully to measure fatigue and workload in non-aviation environments could be applied to this environment; and 3) if increased levels of stress, fatigue, and workload were found to exist, provide ergonomic interventions to improve this environment.

3.0 ON-SITE EVALUATION AND ANALYSIS

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

3.1 Evaluation of Pre-Existing Conditions

This evaluation is important in that it can assist in determining if there is any need for ergonomic intervention, and if so, focus analysis towards the problem areas. In addition, it can guide the implementation process by emphasizing and prioritizing interventions. OJIs were reviewed because the data was already collected and thus easily accessible. The OJIs represent an extreme form of human/system mismatch, one which has led to an error severe enough to cause injury.

3.1.1 OJI Analysis

OJI reports from 1/1/92 to 6/30/93 were reviewed. The procedure outlined by Drury and Brill

(1983) was employed to identify accident patterns. Accident/injury data were separated in order to identify OJI's which occurred in the hangar and OJI's which were specifically related to restricted space. The OJI's identified to be space-related were then grouped based upon age, job, years on the job, area, activity being performed, days out, type of injury, and body part injured. Thus, a small number of repetitive scenarios or patterns could be developed.

3.1.2 Results

The percentage of OJI's in the hangar which were space-related was 20.4% and is presented in **Figure 1**. This indicates that ergonomic interventions, particularly those related to space, should be addressed. **Figure 1** also shows other data that were meaningful in this analysis. Generally, a majority of injuries were sprains to the lower limbs or back/neck, and primarily occurred during repositioning, working, and access-type activities (i.e., climbing, slip/trips). **Table 2** presents a summary of the most predominant scenarios.

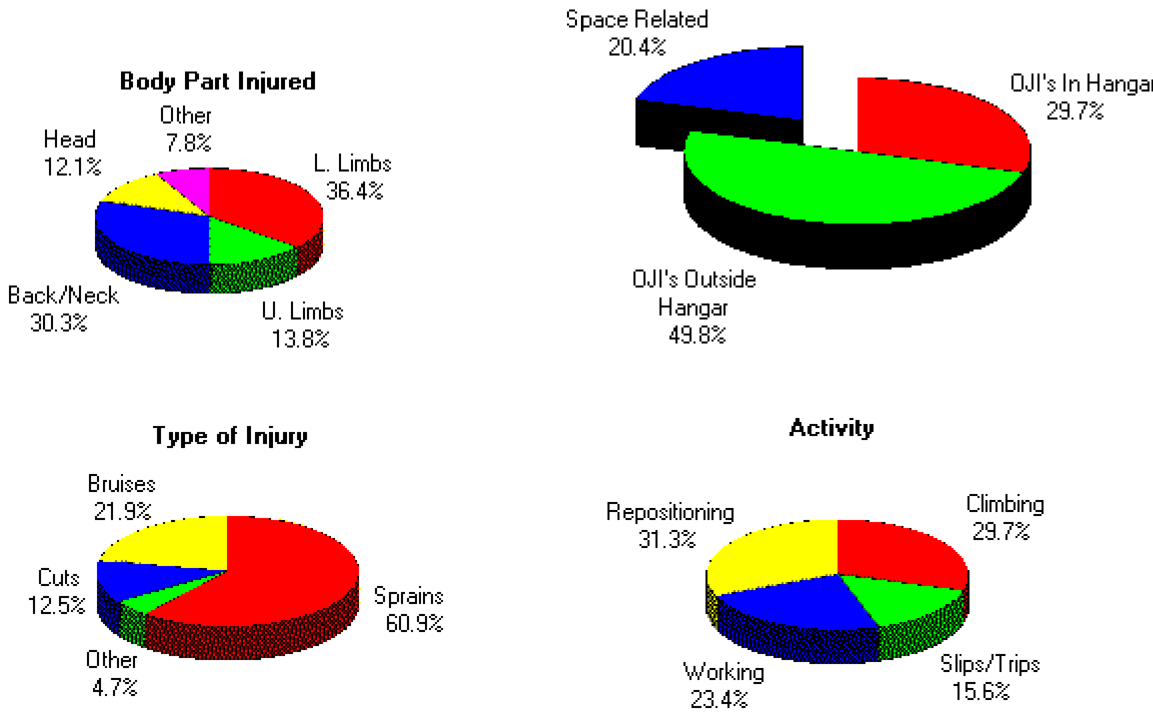


Figure 1 OJI Report Summary

Table 2 Summary of Space Related Hangar OJI's

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

3.2 Evaluation of Existing Conditions

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

3.2.1 Behavioral Measures

Whole-body postures were recorded throughout task performance. In addition, detailed descriptions of each task were obtained. This step included having human factors analysts work with inspectors during the completion of workcards. While obtaining task descriptions, emphasis was placed on documenting ergonomic factors identified in Section 2 which create, or exacerbate, stress and fatigue effects.

3.2.2 Psychophysical Measures

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

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

3.2.3 Experimental Protocol

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

3.2.4 Results

An adapted version of the Ovako Working Posture Analyzing System (Louhevaara and Suurnakki, 1992) postural recording scheme was utilized to classify whole-body postures during task performance. This system has been found to be valid and reliable (Karhu, et al., 1977, 1981). It categorizes whole-body postures into action categories based upon the severity of different postures, thus making it useful as a step in determining which postures need to be addressed by workplace changes. **Table 3** lists the categorization scheme and corresponding action categories. The postural data were categorized by action categories and averaged across inspectors for each task with the results presented in **Figure 2**. These data indicate that inspectors adopted the largest percentage of extreme postures (i.e., AC2, AC3, and AC4) in the aft cargo and tail interior areas; although there was still a large percentage of extreme postures in the other areas.

Table 3 OWAS Classification Table

Trunk	Upper Limbs	Lower Limbs								
		2 S	1 S	2B	1 B	K	W	S	L	C
Straight	2 Below	\\\\\\	\\\\\\	\\\\\\			\\\\\\	\\\\\\		
	1 Above	\\\\\\	\\\\\\	\\\\\\			\\\\\\	\\\\\\		
	2 Above	\\\\\\	\\\\\\	\\\\\\			\\\\\\	\\\\\\		
Bent	2 Below				^^^^^	^^^^^			^^^^^	^^^^^
	1 Above				^^^^^	^^^^^	^^^^^		^^^^^	^^^^^
	2 Above	^^^^^		^^^^^	^^^^^					
Twisted	2 Below	\\\\\\	\\\\\\	\\\\\\	^^^^^		\\\\\\	\\\\\\		
	1 Above		\\\\\\	\\\\\\			^^^^^	\\\\\\		
	2 Above		\\\\\\					\\\\\\		
Bent & Twisted	2 Below									
	1 Above	^^^^^		^^^^^						
	2 Above			^^^^^						

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

Action Category 1. The overall posture is ordinary. Normal posture. No action is necessary. These postures are marked with ****.

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

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

Action Category 4. The strain imposed by the overall posture is of great significance. The load of the posture is extremely harmful. A better working posture should be sought immediately. These postures are shown with **shading**.

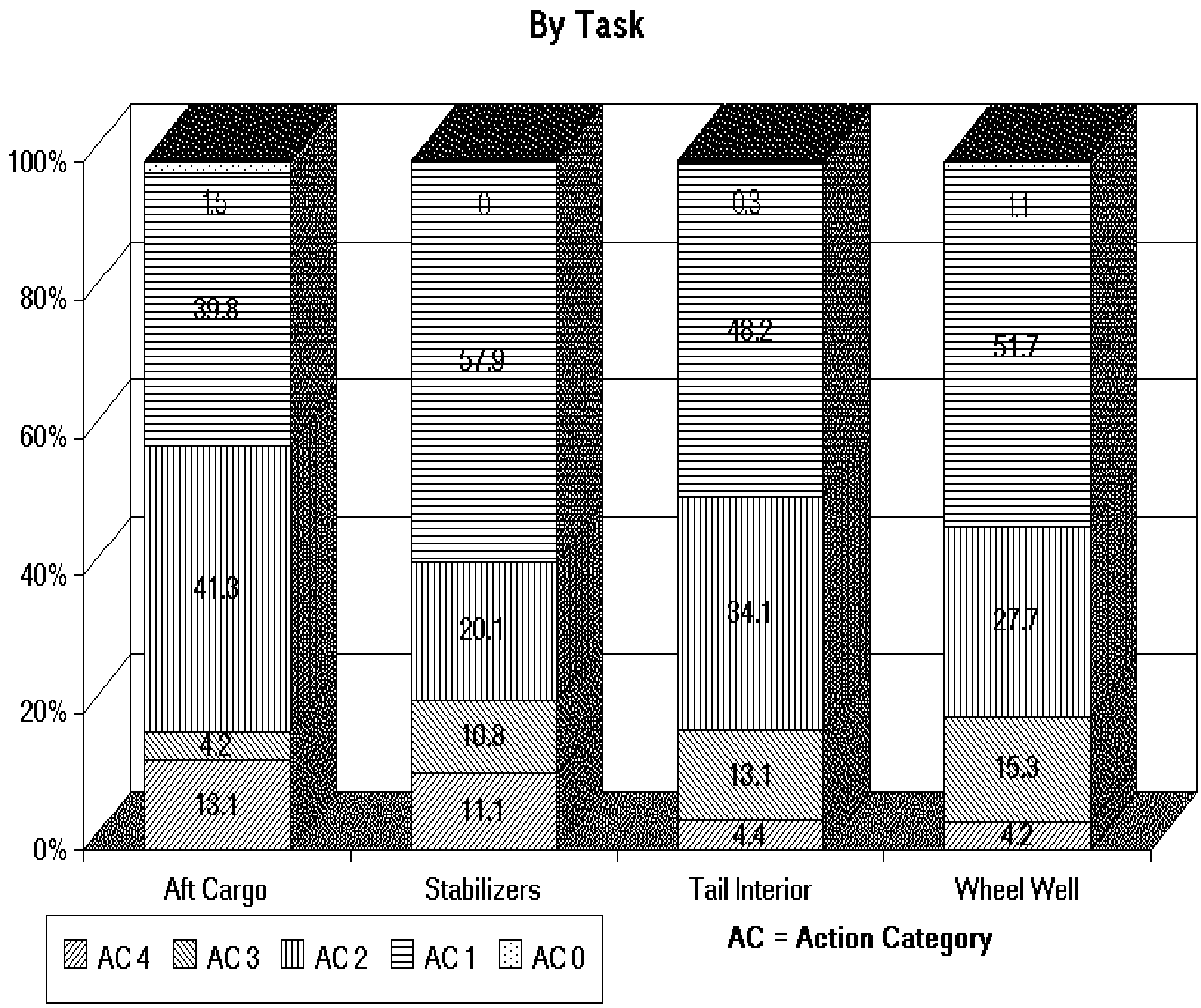
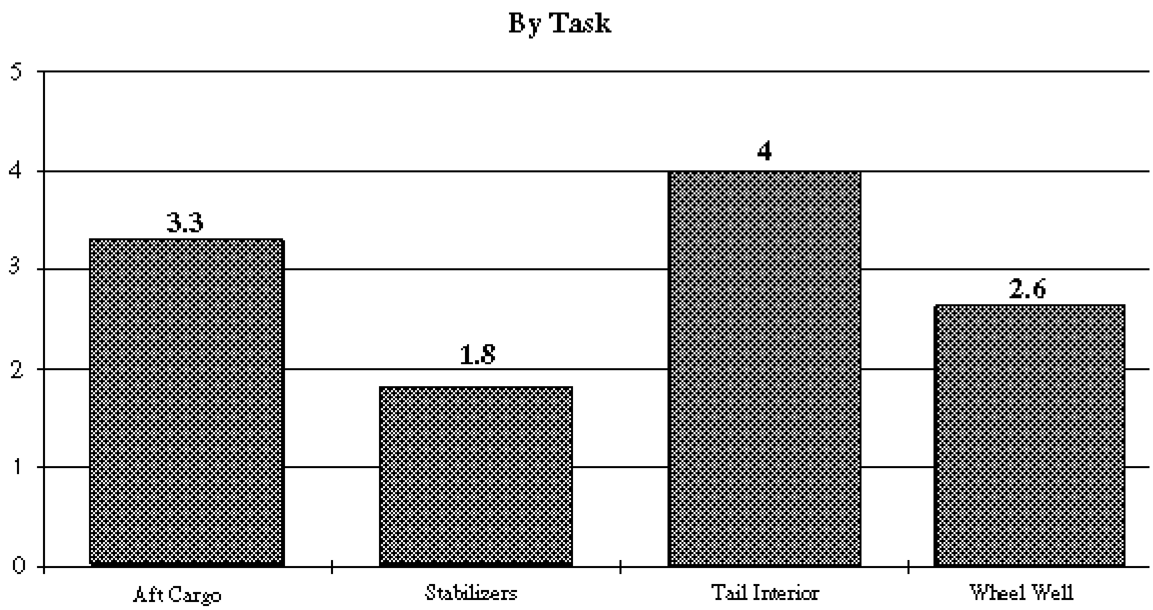


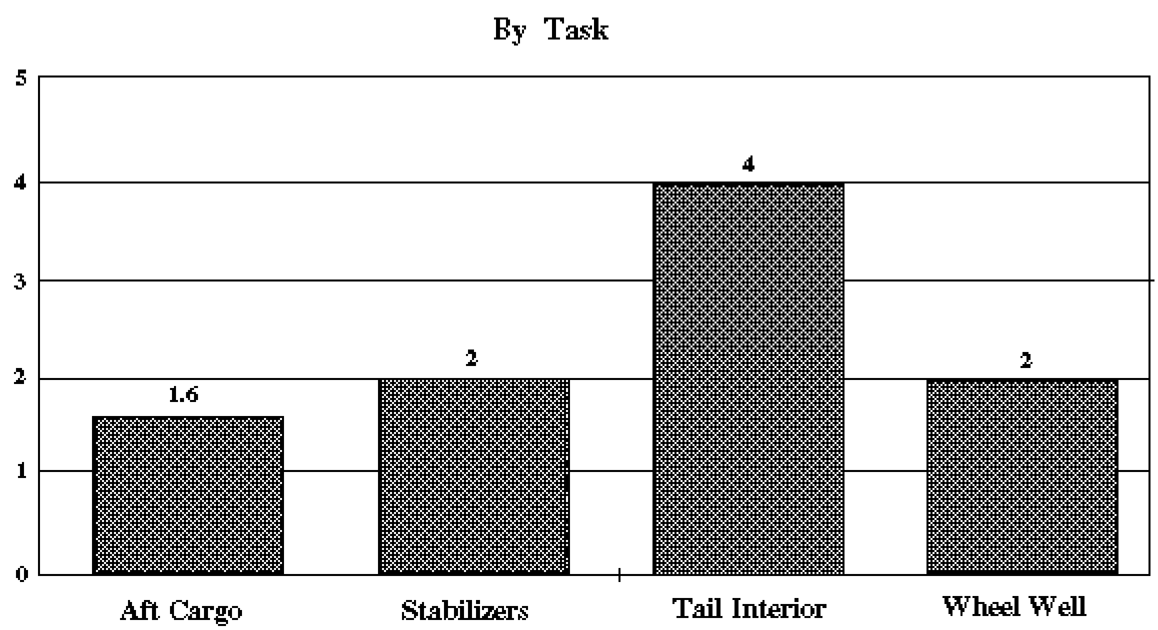
Figure 2 Posture Ananlysis

The BPD and FTC difference values (i.e., end of task - beginning of task) were averaged across inspectors and are presented in **Figures 3** and **5**. **Figure 3** indicates that inspectors experienced the greatest body part discomfort in the aft cargo and tail interior areas. Likewise, inspectors indicated the most fatigue after inspecting the tail interior. Fatigue was also judged to be high in the aft cargo area; although, the average value was skewed by the judgement of one inspector who rated his fatigue to be less (**Figure 4**). The TLX data was averaged across inspectors and is presented in **Figure 5**. Workload was rated to be highest in the aft cargo and tail interior areas, with the primary contributors being physical demand and effort.



BPDFS = Difference Values (End of Task - Beginning of Task)

Figure 3 Body Part Discomfort Over Time



FTC = Difference Values (End of Task - Beginning of Task)

Figure 4 Fatigue Over Time

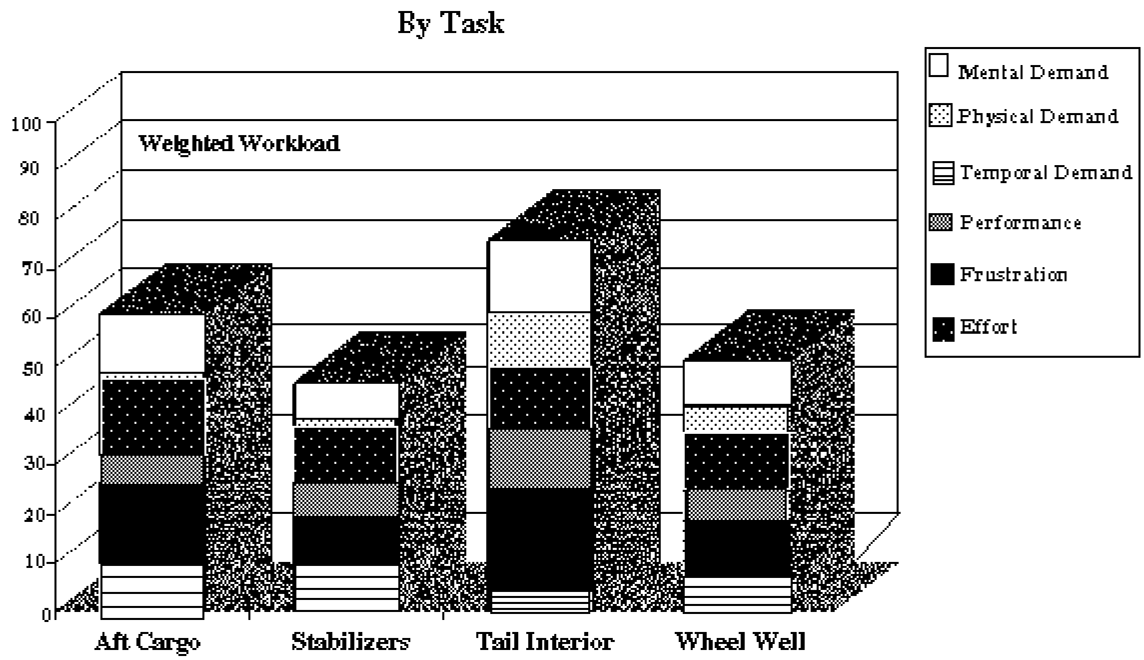


Figure 5 TLX Workload Data

4.0 FINDINGS

The above analysis and results indicate that inspectors often experience increased stress, fatigue, and workload levels. The psychophysical data provides a consistent pattern of stress being experienced during task performance in different areas. Generally, fatigue, body discomfort, and workload were judged to be higher in the aft cargo and tail interior areas than in the other areas. There was some disassociation between the postural and psychophysical data. The stabilizers and wheelwell/MLG were not rated to be extremely fatiguing, although there were many extreme postures (i.e., AC3 and AC4) noted while inspectors worked in these areas. This indicates that posture may be just one factor which contributes to fatigue, and that other factors (e.g., space, lighting), in combination with extreme postures, play a role in eliciting fatigue, as expected from the discussion in Section 2.

5.0 PRACTICAL INTERVENTIONS

Based upon the above evaluation, specific ergonomic interventions were provided for each task analyzed. These were generated from a logical analysis of the factors contributing to fatigue in each area, and the possible steps which could impact upon these factors. In addition, the techniques and tools used for this analysis can be applied and used to develop and guide a comprehensive ergonomics program.

5.1 Design Requirements/Interventions

For each task, design requirements were stated and are presented in **Table 4**. Design requirements are positive statements about what needs to be accomplished during redesign. Notice that these are not solutions, but requirements, and that there may be several alternative solutions which address each requirement. Formally stating these requirements can assist in the generation of solutions and reduce the probability of overlooking potential solutions (Drury, 1987). For each design requirement, alternative solutions are advanced in an attempt to address each design requirement. In addition, these requirements were prioritized according to the OJI's which occurred in each area. This assists in selecting interventions which will maximize the reduction in injury for a given budget.

5.2 Ergonomic Program

This evaluation has only addressed a small subset of ergonomic problems which exist in the aviation maintenance environment, particularly those related to restricted space and posture, although other factors were considered during the evaluation and recommendation phases. This work has revealed the need for a comprehensive ergonomic program which could address all components of the aviation maintenance environment. There were many issues which were not addressed (e.g., safety concerns), which could be evaluated and improved using tested ergonomic techniques and tools.

The techniques applied in this project were found to be sensitive and could be adapted and utilized to further investigate other areas of the aviation maintenance environment.

Ergonomic programs have been developed for manufacturing environments with great success (e.g., Reynolds and Drury, *in press*). These programs are based upon the idea of continuous evaluation and intervention using the tools and techniques applied above to improve the fit between human and system, and hence reduce error-causing mismatches.

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WORKFORCE PROCEDURES AND MAINTENANCE PRODUCTIVITY AT SOUTHWEST AIRLINES

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Manager of Maintenance Control
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When I meet people from other airlines, I enjoy visiting and talking about the way we at Southwest Airlines approach our job. I find that people either are not very familiar with Southwest or that they are familiar with our operation because they have flown Southwest. Quite often, people want to know if we really have a maintenance department or if we contract it all out. We do have a maintenance department to do overnight maintenance; we do our own B-checks, C-checks, quarter-Ds, and half-Ds. The only part we contract out as is major overhauls which Tramco does. We have major overnight maintenance bases in Dallas, Houston, and

Phoenix capable of doing anything we might schedule. We also have overnight maintenance at Midway and Oakland. In our 1994 Budget, we have included daytime maintenance in Las Vegas.

Every decision we make is based on what is best for Southwest Airlines. We do not want to invest money that we are not going to recover. Although I have been listening to all the claims for various computer programs, Southwest Airlines is only slowly adapting to the computer age. Our maintenance program is slowly becoming computerized. In December 1990, we first turned on the computer, and it is a slow process. Currently, we are inputting our records into the computer system, working our way up to the point that we probably will have computerized job cards some time in the near future.

For the most part, however, Southwest is still a pencil and paper airline. Although our dispatch office will have one of the most modern computer systems in the airline industry, they currently route the airplanes and operate the flow sheet with a pencil. They have 160 airplanes listed on one flow sheet that looks like a Dead Sea scroll. When Southwest has to reroute, it is all done with a pencil. Actually, it is a good system because it allows us to feel intimate with the airplane. If an airplane is broken in Sacramento, we might have to send some people from Phoenix to Sacramento. Once we get the airplane flying again, we can put our hands on the routing sheet and discover where the airplane will be for maintenance that night. The current system also benefits our minimal equipment list (MEL). We are fortunate to be able to route approximately one-third of our fleet into maintenance every night. That means that there might be eighteen planes in Phoenix, even though they do not like that sometimes. However, that allows us to limit how many open items we carry on the MEL. While I was at Eastern, our goal was two per airplane, so we felt successful if we had 600 open items.

Until 1992, Southwest started each day with a clean MEL sheet, that is, zero deferred items. As the fleet has grown and aged, of course, we have had to use our MEL more and more. We now average eight to nine open MELs at the beginning of a day, which is pretty good. We sometimes receive phone calls from captains who have not been on an airplane with an MEL. They call and say something like, "I have only been a captain for six months, and you are going to have to walk me through this procedure because I have never put an MEL out on an airplane." Conceivably, a co-pilot could become a captain without ever taking part in maintenance control procedures.

How do we keep our MEL list low and fly on time? We rate our performance daily on our MEL and our delays. We don't have a hub and spoke system; as most of you know, we fly point-to-point and so does our maintenance. If we defer an APU (auxiliary power unit) at 8:00 o'clock in the morning, we can look at the line an airplane is going to be on and see the segments it is going to be flying through. Particularly last summer, it was almost categorical that an airplane was going to go to all the hot Texas cities, all the hot New Mexico cities, and to Los Angeles. Naturally, we try to clear these items before our passengers complain

We do not want to inconvenience our passengers, so there might be a situation in Houston or San Antonio when we might call a mechanic and have him see if the APU Inlet door will open. When the airplane arrives in Phoenix, we might already know that the ignition system is not working. We can have a Phoenix mechanic standing by with the parts that we prescribe, ready to install them, hopefully clearing the MEL. If we work on the ignition system in Phoenix and do not fix it, we will contact a dispatcher. If we can put the airplane back in Phoenix, or wherever, the mechanic is going to get another shot at trying to clear the MEL for the flight day. The amount of turn time we have can be tricky, so we have to be on top of things. We have to know what we defer, how it operates, and what it is going to take to fix it. We are really active in that area, and that is how we manage our fleet.

Although we do not have any more 10-minute turns, we do have 15-minute and 20-minute turns mechanics use to change tires or brakes. Sometimes we do take a delay, but our airplanes are well-maintained. When an airplane comes to the gate and there is a crew change, the crew first performs a walk-around inspection. Any discrepancies they find are addressed right there. We try to do everything necessary at an airplane's scheduled time for maintenance. This approach really works. It is fascinating to watch one of the airplanes come into the gate from this angle, to watch the ramp truck from this angle, and to watch the mechanic from this angle, knowing that we all work for the same company. It is impressive to see.

As I mentioned, we have started putting more records in our computer. We also carry a dent manual on the computer. If a captain is performing a preflight in Ontario and sees something odd about the airplane, the captain can call us and we can provide him the information we have immediately. We track our lightning strikes and the various other things that happen during the day similarly. Southwest Airlines takes a hands-on approach, and I expect it to remain a hands-on airline as long as we understand that our business is to fly airplanes safely at a low cost.

Southwest Airlines employees generally have very good attitudes. When an airplane comes in with a problem, we address the problem and give plenty of consideration to the airline's schedule. We do not rush or hurry anyone or ask an employee to do anything illegal or questionable; our mechanics have to feel comfortable with the job they did. Southwest Airline's corporate culture makes our people feel good about their jobs. Our employees feel good when they go to work, and they feel good when they go home. This applies even to the job I have. I get to witness everything that goes wrong; the maintenance control department is a negative department because we are called in whenever there is a problem. We have some days when our cancellation rate is a little too high, and we have other days when our delay sheet is lengthy. Even though busy days for us are bad days for the airline, we usually feel good when we get home because we know we have done a good job. We use the Delay Sheet to capture, correct, coordinate, change, and discuss what we do. If we have a five- minute delay in Phoenix to change the landing light, we do not hammer anyone, but we do discuss it.

At 8:00 a.m. every morning I meet with the Vice President of our department and read every item that delayed an airplane the previous day. Major delays are those which results in a delay of an hour or more. A major delay would also include anything that resulted in a cancellation. We also have minor delays which really do not impact the schedule. We discuss each delay, whether it is major or minor, and I think that is a benefit. When I first learned that I would read the Delay Report to the Vice President daily, I wondered if he would ask any questions. He does. He needs to know how we arrived at a conclusion and what thought process we used when, for example, we called the mechanics at our Phoenix hub to come and unplug the lavatory. Generally, if we take a delay for a passenger item it is because we do not want to fly away with something like a blocked lavatory that could make for bad business. We make these types of decisions based on our dispatch input. On Friday, for example, our airplanes are extremely full so we take the opportunity to have a clean fleet: we want our lavatories working; we want our lights intact; and we want the airplane to be ready for a full day of paying passengers. As I said, we do take a hands-on approach; we track each problem and resolve each problem as quickly as we safely can.

We have a group of engineers and mechanics that monitor day-to-day operations. Most of that is the function of the Maintenance Control Group. Southwest's Maintenance Control Group is a little different than most maintenance controls. We have our most experienced people working in that group. They monitor the maintenance situation to determine when something repeats or when we did not fix something we thought we had fixed. There is a reliability group called the Honey Bees that pick up on this information; they are getting the information off our computer system now. They use different categories for repetitive items. When we have something that is approaching what they call a Category 5 (meaning, "This is getting embarrassing for you; fix it the right way"), it is brought up, discussed, and directly routed into a maintenance base.

I would like to talk about how we do our C-checks. We currently do C-checks in Houston and Phoenix, flying in the airplane needing the C-check during the day. We do not ground an airplane for an extensive time unless it needs a major structural job. We do our 200s and 500s in Houston. When an airplane arrives at about 8:00 p.m., we take it into the hanger for C-1, C-2, C-3 and C-4. We perform a segmented C-check; mechanics will do one wing, one elevator, and the cockpit maybe on, say, Monday and Tuesday night. They then do the opposite side, and six months later the airplane will be back in maintenance for another C- check. C-checks are performed on 180-day intervals.

Phoenix recently accomplished a coup when they took the 300 C-check line out of Dallas and put it in Phoenix. That was the result of a logistical measure from the dispatch office. Since certain legal restraints are placed on Love field, we were not able to service any airport out of Love field unless its state touches the state of Texas. In other words, an airplane cannot fly from Love field to Phoenix without having to stop in Albuquerque. That law was enacted to protect DFW. Since it is still on the books, as the airline grows, Dallas does not. Phoenix can grow; Houston can grow; and all of our other cities are able to expand. However, we can only fly Dallas so many times before the demand decreases. With eighteen airplanes overnight in Phoenix, it is natural that they got the C-check work and also took over some APU work.

In Dallas, we do our quarter-D checks and our half-Ds. These are pretty impressive for Southwest. We pull the airplane in the hanger and take its interior out, e.g. we pull the floor boards up. The quarter-D check is supposed to last three days. Unfortunately, during our transition period, the quarter-D check probably requires five or six days now because a lot of these airplanes have not been on this schedule very long. Next, the airplane comes in for a half-D check, a more extensive visit that can last as long as eight to ten days. That is the only time we plan on having an airplane out of service for so long.

As to Southwest's corporate culture, most everybody has seen Herb Keller on television, whether in an American Express commercial or with Sam Donaldson on a Sunday morning news program. Herb does a good job of presenting to the public that Southwest Airlines is just plain smart. That is the company's logo. I think Herb even arm wrestled a fellow in South Carolina because there was another company using the same logo. Instead of going to court and having a protracted legal battle about the logo, just plain smart Herb invited the other company's president to come to Dallas and arm wrestle. If you have seen Herb, you know he is not much of a physical specimen: he smokes four packs of cigarettes a day; we do not know how much Wild Turkey he drinks, but he does drink Wild Turkey. When the fellow from Stevens Aviation from South Carolina or North Carolina showed up, it appeared that he was a physical specimen. He looked like he benched pressed 300 pounds and worked out regularly. That did not detract Herb who had a couple of professional wrestlers show up with him, and he also provided the cheerleading squad. Herb collected the most beautiful women at Southwest Airlines to be in his corner, and not the most beautiful women to be in Stevens' corner, which did not go unnoticed by Mr. Stevens. They actually arm wrestled after Herb was finished. It is this type of event that Herb uses to make a media spectacle of himself, and he enjoys that persona.

Herb encourages departments to get together with other departments. We do not have a secluded maintenance department; we have a very open maintenance department. I communicate daily, sometimes hourly, with the people in flight ops. All three chief pilots and those at our four crew bases know that if they encounter a problem, have a personality problem with a maintenance employee, or experience some kind of a flash in the cockpit, they can give me a call. We will find out what went wrong and what we were thinking. We can, if necessary, get everyone involved together to resolve any problem. When we finish, those involved will come out knowing what went wrong.

We have a very active Crew Resource Management (CRM) Program in our pilot group, and our maintenance group is invited to participate. We try to schedule maintenance people to be with the flight crews as they go through the captain upgrade process. As the captain and the people in the CRM program review airline incidents and problems that have been documented through the years, they talk about what they can do differently and where the mistakes were made. Our maintenance people benefit by learning how a pilot thinks, just as a pilot benefits by learning what a mechanic is thinking. The Crew Resource Management Program instructors ensure we are available and invited to participate. All production managers have been involved and we make every effort to involve as many line mechanics as possible. Hangar mechanics have not yet been able to participate due to the limited amount of space available in the CRM training. Currently, only two mechanics per session are permitted. There are two CRMs: the two-day upgrade Crew Resource Management, and the one-day refresher. We just ask what course is coming up. If it is a two-day, we schedule for two days, or if it is one day, we schedule one day. We kind of blend in; we want mechanics to feel comfortable with that segment of the airline since it is our internal customer.

I probably should elaborate on that; it is one of our philosophies that if you spend as much time as you need to working on your internal customer, your external customer will be most grateful. Each department identifies its internal customer. My group is Maintenance Control; our internal customer is dispatch because that is whom we work with the closest. We try very hard to work with our internal customers so that they feel comfortable with what we are doing. Mechanics' internal customers vary depending on where they are. If a mechanic is at the terminal, internal customers are pilots, flight attendants, and probably a supervisor. This is all incorporated into

CRM training as they go through that. They spend a lot of time on internal customers because most of the CRM is spent discussing airline problems.

We have a Training Department that actually spends most of its time flying around the Southwest system. Due to the nature of our airline, we do not have maintenance at every station. Since we have five maintenance stations and we serve 38 cities, like most airlines, we do use contract maintenance. However, our Training Department regularly visits our Quality Control Group and our vendors to make sure that everybody is up to speed. Anytime we have to change a part, we generally send our own mechanics. The only time this would not happen would be if the part was an indicator and we were at Las Vegas. American West hired mechanics to help with the Southwest contract because we had 100 flights a day to Las Vegas and we have not been able to hire new mechanics until our 1994 budget has been approved. During our downtime, American West hired some mechanics so that they could handle our contract. This helped us out.

This is Southwest maintenance in a nutshell. There are no gimmicks, no tricks, no magic. Southwest maintenance is simply a group of people who understand Southwest's objectives. For the most part, our 500 mechanics, 24 supervisors, and 6 managers are quite happy to be on the Southwest team. It is a good outfit to work for. We have identified our primary competition, which is the automobile, and we have also identified the airline we want to be most like. We most want to be like Southwest was last year. As long as we keep emulating Southwest and knock on wood, maybe we can participate another year.

IAM/FAA AIRCRAFT AND MAINTENANCE SAFETY PROCEDURES AT TRANS WORLD AIRLINES

Fred Liddel
IAM/FAA Conformance Committee
Trans World Airlines

Good afternoon. Today, I am going to share with you the TWA-IAM/FAA Conformance Committee Procedures program. This procedure allows individual maintenance workers to bring to TWA's attention their concerns dealing with FAA and procedural matters that affect the efficient operations of TWA's maintenance plan. IAM Local 1650's leadership felt that members had the right and the obligation as professional aviation maintenance technicians to air their concerns in a structured and orderly manner to protect themselves and the company, and to ensure efficient operations.

As a FAR Part 121 carrier and a Part 145 Repair Station, the corporate manuals TWA uses are approved by the Federal Aviation Administration and have the same effect as Federal Air Regulations.

Our members must perform under the following regulations and rules:

FAR Part 13 - Investigation and Enforcement Procedures: Any personnel involved in aircraft maintenance must report to the administrator or his representatives known violations of the regulations.

FAR Part 21 - Certification Procedures for Products and Parts: Airworthy parts with proper documentation. Mechanics must assure that any part they certify as airworthy, is airworthy and that proper documentation has been presented.

FAR Part 39 - Airworthiness Directives are followed and adhered to as required by the Airworthiness Directive.

FAR Part 43 - Maintenance: Proper procedures are followed and applied during preventative maintenance, rebuilding, and any alterations.

FAR Part 65 - Certification: Airmen Other Than Flight Crewmembers: Certificates and proper application and use thereof are followed.

FAR Part 108 - Airport Security: Responsibilities to adhere to and enforce rules and procedures for the airports at which they are employed.

FAR Part 121 - Certification and Operations of a Domestic, Flag, and Supplemental Air Carrier: Maintenance rules and procedures under which they perform.

FAR Part 183 - Representatives of the Administrator: Response and responsibilities toward these representatives.

Company corporate manuals:

> General Policies and Procedures: TWA's Maintenance Program, including any and all maintenance procedures TWA uses.
>
> Administrative Systems and Procedures: Administration of TWA's maintenance program and special procedures employed at the Ground Operations Center.
>
> Parts and Material Handling: The handling and procurement of parts and materials, that all parts and materials are of an airworthy condition when installed on an aircraft, powerplant, or component part.
>
> Manufacturers' Manuals and Drawings: Directions and instructions are followed and do not conflict with any other rule, regulation, or procedure.

Confusion exists as to which of the previous items carries the greatest authority for the technician and what management's involvement is in ensuring adherence to the correct procedures. The Committee's mandate is to find out for the technician, when he or she has a question, what should be observed. My liaison, Tom Mealie, TWA's Manager-Quality Assurance, and I confer to try and decide what is best for the individual and for the company.

The Committee was organized by the International Association of Machinists Local Lodge 1650 early in 1987 to meet these obligations. TWA recognized the Committee in September 1991. The procedures I am presenting today were established in May 1992.

Table 1 lists the Committee's Scope and Objectives from the Union's standpoint. It is to assure that workmanship, methods, and materials used are in compliance with the Federal Regulations, Company specifications, manual procedures, and accepted standards and good practices. As an inspector who is also a member of this Committee, I am quite aware that there is quite a bit of confusion as to what are accepted standards and good practices. There are very few arguments over manual procedures, but quite a few over accepted standards. We are also to assure that all our products, i.e. the airplane, engines, and components, are overhauled, repaired, and maintained in accordance with published specifications. We had gotten into a bad habit where people were doing maintenance tasks by word of mouth. More experienced people would tell younger people that this is the way we have done it, this is the way it should be done, it works. We found through experience that this is not always right. Thus, we have implemented 0this standard, and these last two words are important to us, "published specifications."

Table 1 Committee Scope and Objectives

SCOPE

To assure that workmanship, methods and materials used are in compliance with Federal Regulations, Company specifications, manual procedures, accepted standards and good practices.

To assure that any airframe, engine or component (appliance) is overhauled and/or repaired and maintained in accordance with published specifications.

OBJECTIVES

Report to this committee, who in turn may report to the Company, IAM, FAA and any other concerned parties any violations of maintenance practices that are not in accordance with Federal Regulations, Company specifications, manual procedures, accepted standards and good practices.

The objectives are pretty much the same. People are to report to the Committee, who in turn may report to the Company, the IAM, or the FAA, any violations in maintenance practices. We invoke this very rarely because we try to solve a problem at the first step between the individual technician or maintenance worker and the front-line supervisor. I think this program is important because it brings about a dialogue between the floor worker who actually does the work and the people who have to make decisions as to how well the system is working. If there are any discrepancies in the procedures we have established, there is a mechanism whereby procedures can be changed in an orderly manner and documented. We do not want to change procedures if they are correct, and we do not want anybody causing havoc.

As a union official, I have a legal obligation to provide representation on matters brought to my attention. Tom, as the company representative, has the obligation to protect and serve the company's interests.

Workplace barriers and apprehension are being overcome. The program is still in an evolving, education process. I am appointed to my position by IAM Local's Executive Board with TWA's concurrence. The Committee covers TWA's Ground Operation Center and Flight Operations in Kansas city with two union members and Tom. The Committee also answers questions and acts as an advisor to our membership during FAA investigative and informal hearings at a member's request.

The union and company leadership decided to appoint Inspectors to this committee because, among other things, inspectors work with regulations, engineering, and maintenance requirements daily. Also, it has been said, "Inspectors have the memory of an elephant, and the skin of a Rhinoceros."

The IAM/FAA Conformance Committee at TWA has been established to help TWA and IAM promote greater efficiency and to develop guidelines for the Ground Operations Center at Kansas City, Missouri. In the future, it may be used throughout TWA's entire maintenance system. **Tables 2** and **3** present the step-by-step procedures the committee uses. As you can see in the procedures, for the first step ("A"), an individual must first discuss what he or she believes is wrong with the immediate supervisor. The supervisor investigates and takes appropriate corrective action. If the supervisor finds that the finding is not valid, he or she explains the situation to the individual. In a lot of cases, this is not the end. The next step, when the individual does not agree with the immediate supervisor's assessment, is to meet the union steward to discuss the same matter again. I know this sounds repetitive, but for the next step ("C" in **Table 3**) there is a form that has to be filled out. Filling out the form creates a written record, so we do not have to rely on hearsay. In this business, one grows tired of relying on hearsay and rumors.

Table 2

TRANS WORLD AIRLINES
GROUND OPERATIONS
ADMINISTRATIVE SYSTEMS AND PROCEDURES MANUAL
PART 2 - GROUND OPERATIONS CENTER SYSTEMS

IAM/FAA Conformance Committee

The Director FAA/ATA/Liaison and Quality Assurance is primarily responsible for the policies and procedures in this section.

I. Purpose

To assure that individuals may bring to the attention of their departmental supervision and the IAM Conformance Committee matters which they feel might be in conflict with Federal Regulations, Company specifications, manual procedures, accepted standards and good practices within their department (area) and to establish procedures for the prompt handling of these findings.

II. Procedure

A. The individual must first discuss the finding with the immediate supervisor. The supervisor will investigate the finding and take appropriate corrective action. If finding is not valid, the supervisor must explain his/her position to the individual.

B. If the finding is not resolved, the individual and his/her Shop Steward will present the finding to the supervisor. The supervisor will investigate and initiate corrective action or explain why corrective action is not necessary.

C. If the finding is still not corrected, the involved individual may request further handling by the IAM/FAA Conformance Committee.

D. The IAM/FAA Conformance Committee, in conjunction with the Office of the Director - FAA/ATA Liaison and Quality Assurance, will process valid findings. Valid findings will be presented at the manager level. If satisfactory corrections are not made, findings will be presented to successive levels of management up to Senior Vice President of Maintenance and Engineering for final determination.

E. The Aircraft and Component Maintenance Procedural Report Form No. ICC001 will be utilized to present findings to departmental managers.

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Table 3 Step Procedure for IAM/FAA Committee Complaints

STEP PROCEDURE FOR IAM/FAA COMMITTEE COMPLAINTS

I. Individuals who observe, suspect and/or believe that workmanship, methods and materials are not being used in compliance with Federal Regulations, Company specifications, manual procedures, accepted standards and good practices will bring to the attention of his/her immediate supervisor by the following means.

A. Contact the immediate supervisor first and discuss the matter. If the matter cannot be resolved, then the Steward for the area will be contacted.

B. If the finding is not resolved, the individual and his/her Shop Steward will present the finding (complaint) to the supervisor.

C. The Steward will record all information provided by the individual on Form IAM/ICC 001 (Aircraft and Maintenance Component Procedural Pre-Investigation Report).

II. The Steward will contact the IAM/FAA Committee with this form.

III. The IAM/FAA Committee will evaluate the report and investigate the matter.

IV. After a thorough investigation, the findings will be recorded and copies presented to the Steward and individual together.

V. A determination will be made by all parties to either proceed or drop the matter.

A. Present the findings to higher management.

If an individual reports an extremely serious problem, and the supervisor has not addressed it, the individual should fill out the form, sign it, and present it to the Committee. That way, we at least have a record. We do not intend to point fingers, but we want to be able to back track for ourselves. If the finding is not corrected after filing the form. the individual may return the form to the Committee.

The Committee includes myself and another union member. We get together or we independently assess what is written down to determine if we should take it further, i.e. to Tom. For a lot of cases, we take the written form and go the supervisor ourselves to find out exactly what the problem was and to explain the individual's problem. If the problem cannot be resolved, the Committee will meet with the Office Of Quality Assurance and proceed to validate the findings. **Figure 1** is the form the union steward and the individual prepare to present to the Committee before the Committee is involved. It is straightforward; the important parts are for the nature of the complaint and the references they use. Also, the individual provides a brief synopsis of the discussion with the immediate supervisor.

Report No: ________________
Procedural Report No: _________________

AIRCRAFT AND MAINTENANCE COMPONENT
PROCEDURAL PRE-INVESTIGATION REPORT
Pre-Investigation and Verbal Handling Report
(Steward Use Only)

Aircraft Type: ______________________________ N-NO: __________ S/N: _________
Engine Type: ____ S/N : _________
Component Mfg. No: ________________ TWA No: _________________ S/N : _________
Type Maintenance: ____
Date: ________________________ Local Time(24 hr. clock): ___________________
Nature of complaint and/or request: ____
____
Reference: (FAA Reg., GP&P, AS&P, M/M, etc.): ___________________________
____

Describe the verbal discussion with immediate Supervisor, (include with this report all documentation. If available: e.g. n/r's, routines, M/M pages, M.O.'s, E.R.'s, ARA's and any other pertinent information. Copies will suffice.): ___________________________________
____
____
____
Steward: ________________________ Shift ________________ Classification: ______
Shop, Area or Department: ________________________ Location: ________________
Phone No: ______________________________
Report Submitted Date: __________________ Time: _________ Complaint: _________

Form IAM/ICC 0001

Figure 1

I am sorry to report that in a lot of cases the individuals do not know the reference material, so the Committee fills this in for them. This is the stumbling block when they are wrong. This is why the form comes to the Committee: it is a learning process on both parts. If an individual does not know the reference material and thinks that he or she has a complaint, they fill this out and bring it to the Committee. The Committee investigates it and finds the reference material. If the complaint is held valid by the Committee and we think we have a valid reason and a valid finding, I take the form shown in **Figure 2** and fill out the top part of the form. This is the form Tom and I work with. We fill in almost the same information as for the previous form, except that I have to be more precise. I often have to rewrite the form to satisfy Tom. In any case, we go over the form together to find out if we have a valid finding.

Report No: ________

AIRCRAFT AND COMPONENT MAINTENANCE PROCEDURAL REPORT

TO: ______________________

COPIES TO: ____

Originator Name: ___________________________ Phone No.: ______________

Position: ____________________________ Area: __________________

Steward/Committeeman: _________________ Shift: __________ Dept.:________

Location: _______ Bldg. No.: ____

Aircraft Type: ________________________ N-No.: _________ S/N: _________

Engine Type : ________________________ S/N: _________

Component Mfg. No.: ___________________ TWA No.: ______ S/N: _________

Type Maintenance: ____

Date: ________________________________ Local Time (24 hour clock):_______

Originators finding and/or request:

Answer:

(Manager or delegate's reply. Actions taken to correct the problem; or reasons for rejecting the finding.)

Signed: ______________________ Location: ________ Date: _________

CORRECTIVE ACTION OR STATUS REPORT SHOULD BE FORWARDED TO QUALITY ASSURANCE, RM 1-465, MCI, WITH 30 DAYS AFTER RECEIPT OF THIS EVALUATION.

FORM ICC-D01(3-92)

Figure 2

While I could present numerous examples, I have picked three. The first example involves engineering instructions and incorrect form usage. Production management requested an engineering approval to revise a repair procedure, as directed by the Component Maintenance Manual. The mechanics thought that the procedure requested was incorrect.

The Committee investigated and assured the mechanics that the engineering department's instructions were correct; the part would be airworthy. But they were using the incorrect form. However, we could not convince the engineers to change the form; this issue was finally resolved after the Quality Assurance Office initiated a change in procedures. The Staff Vice-President, Engineering, confirmed the Committee's position.

The second issue involved a part being removed from the shop area and installed on an aircraft without documentation or procedures being followed. The committee found that the part was unserviceable and that procedures were not followed. In an effort to save time, individuals ignored procedures. The part was located and returned to the shop area. All individuals involved were informed of their mistakes, and the situation did not proceed beyond the hanger supervisor.

The third issue involved unserviceable booster pumps being shipped to another facility and the receiving facility making the pumps serviceable. The receiving facility was not equipped to accomplish this by following the required procedure, and the documentation making the pumps serviceable was at the first facility. Investigation and conversation with the engineer resolved the issue. The questioned pumps were returned to the proper facility, procedures were changed, and the necessary equipment was obtained.

The previous examples show the mechanics' willingness to come to the Committee with problems they observe. The Committee then fully investigates these problems and brings them to the attention of those who can affect corrections. This creates an orderly procedure where decision-makers can make decisions after the *facts* are presented. Communications have been established through *all* levels in the maintenance organization.

The program is working. An informal analysis of issues on file with the committee revealed that the Committee addressed 40 issues before it was recognized; 25 issues have been addressed since recognition, with 12 of them presented at the manager level. One issue has been presented at the director level, and one issue at the vice-president level.

The committee enhances productivity by encouraging awareness of proper procedures. The spirit of our company has taken a turn for the better with the inclusion of direct and greater communication between the decision makers and personnel performing tasks. When workers follow correct procedures, any necessity to do the same job twice is reduced or eliminated. Savings in time and material can release needed capital for other uses. Inadequate and outdated procedures can be identified and eliminated after a complete investigation and discussion with the affected parties. A fast, effective two-way communication system from the floor to the decision level has been established. The IAM/FAA Conformance Safety Committee at TWA fosters Quality Assurance and enhances productivity.

I want to thank you for the opportunity to share this important tool for dealing with Human Factors in Aircraft Maintenance and Inspection that TWA and the IAM have adopted.

Appendix A: Meeting Program

FAA Office of Aviation Medicine

8th Meeting on Human Factors in

Aviation Maintenance and Inspection
TRENDS AND ADVANCES IN

AVIATION MAINTENANCE OPERATIONS

Alexandria, Virginia

November 15 - 17, 1993

Monday, November 15, 1993

3:30 p.m. - Registration (Atrium)

4:30 p.m.

No other activities planned

Tuesday, November 16, 1993

7:30 a.m.	Coffee Service and Registration
8:30 a.m.	Meeting Objectives *William T. Shepherd, Ph.D.* **Office of Aviation Medicine** **Federal Aviation Administration**
8:45 a.m.	Keynote Address: FAA Human Factors Program Emphasis *Brooks Goldman* **Deputy Associate Administrator for Aviation Standards** **Federal Aviation Administration**
9:15 a.m.	FAA Regulatory Oversight: An Update *Leslie K. Vipond* **Office of Flight Standards** **Federal Aviation Administration**
10:00 a.m.	Break

<u>CHANGES AND ADVANCES IN AIR CARRIERS PROCEDURES</u>

10:15 a.m.	Improvements Through Reorganization of British Airways Maintenance *Michael Skinner* **Maintenance Training Manager** **British Airways**
11:00 a.m.	Application of Computer-Based Training for Improved Maintenance Training Efficiency *Dieter Reichow* **General Manager, Technical Training** **Lufthansa Airlines**
11:45 a.m.	Lunch (In Hotel/Hosted in Atrium)
1:15 p.m.	Recent Changes in Aircraft Maintenance Worker Relationships *Robert Scoble* **General Manager of Inspection** **United Airlines**

Tuesday, November 16, 1993 (Cont'd)

<u>CHANGES AND ADVANCES IN AIR CARRIERS PROCEDURES - (Cont'd)</u>

2:00 p.m.	Environmental Requirements of Maintenance Organizations *Fred Workley*

Manager of Maintenance
National Air Transportation Association

2:45 p.m. Break

TECHNOLOGY ADVANCES SUPPORTING AVIATION MAINTENANCE

3:00 p.m. Human Factors Effects in the FAA Eddy Current Inspection
Reliability Experiment
Floyd Spencer, Ph.D.
Sandia National Laboratories
and*Don Schurman, Ph.D.*
SAIC, Idaho Falls

3:45 p.m. Dual-Use Technology for Flight Control Maintenance

Diagnostic System (FCMDS) in the Commercial Environment
Harry Funk
Principal Research Scientist
Honeywell, Inc.

4:30 p.m. Pen-Based Computer Use in Aviation Inspection
William Johnson, Ph.D.
Vice President, Information Division
Galaxy Scientific Corp.

5:15 p.m. Adjourn

5:30 p.m. Social Hour (Atrium)

Wednesday, November 17, 1993

7:30 a.m. Coffee Service

TECHNOLOGY ADVANCES SUPPORTING
AVIATION MAINTENANCE - (Cont'd)

8:30 a.m. Maintenance Error Decision Aid Project
Jerry Allen
Systems and Procedures Senior Analyst
Continental Airlines
and*David Marx*
Special Programs Engineer
Boeing Commercial Airplanes

9:15 a.m. Human Factors Advances at Continental Airlines
Jay Lofgren
Quality Assurance Division
Continental Airlines
and*Colin Drury, Ph.D.*
SUNY Buffalo

10:00 a.m. Break

10:15 a.m. Effect of Working Postures in Confined Spaces
Steve Eberhardt
Director, Inspection, Technical Records, Training and Safety
Northwest Airlines and *Colin Drury, Ph.D.*
SUNY Buffalo

ADVANCES AND ISSUES IMPACTING THE MAINTENANCE WORKFORCE

11:00 a.m. Workforce Procedures and Maintenance Productivity at Southwest Airlines
Steve Day
Manager of Maintenance Control
Southwest Airlines

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

1:30 p.m. Quality Assurance at TWA Through IAM/FAA Maintenance Safety Committee

Fred Liddell
IAM/FAA Conformance Committee
Trans World Airlines (TWA)

Wednesday, November 17, 1993 (Cont'd)

RECOMMENDATIONS AND CONCLUSIONS

2:15 p.m. Group Discussion

William T. Shepherd, Ph.D.
Federal Aviation Administration and*James F. Parker, Jr., Ph.D.*
BioTechnology, Inc.

3:00 p.m. Adjourn

Appendix B: Meeting Attendees

Eighth Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection
16 - 17 November 1993

Trends and Advances in Aviation Maintenance Operations

MEETING ATTENDEES

Greger Ahlbeck, Director Technical Operations, Scandinavian Air Systems, Frosundaviks Alle'

1, Solna, S-161 87 Stockholm, SWEDEN

Jerry Allen **(GUEST SPEAKER)**, Continental Airlines, 3663 N. Sam Houston Parkway E., Houston, TX 77032

Dennis M. Ashbaugh, Senior Test Engineer, Science Applications International Corp., 2109 Air Park Rd., S.E., Albuquerque, NM 87106

Spencer Bennett, Manager, Federal Express Corporation, Maintenance Technical Training, 2851 Lambs Place, Suite 13-14, Memphis, TN 38118

Hans-Joerg Benninger, Manager Aircraft Maintenance IERA, Fleet Manager A310, SWISSAIR (Department TWI), P.O. Box 8058, Zurich Airport, SWITZERLAND

Malcomb Brenner, Ph.D., Senior Human Performance Investigator, National Transportation Safety Board, 490 L'enfant Plaza East, SW, AS-50, Washington, DC 20594

Alfred Broz, Ph.D., National Resource Specialist, NonDestructive Evaluation (NDE), Federal Aviation Administration, New England Region, ANE-105N, 12 New England Executive Park, Burlington, MA 01803

Dave Buchanan, IAM International/NWA, 215 E. 98th Street, Bloomington, MN 55420, CDR

Thomas Ciarula, Department of the Navy, NAVAIR-Naval Air Systems Command Headquarters, PMA 205-3C, NAVAIRSYSCOM, 1421 Jefferson Davis Highway, Arlington, VA 22243-1205

Diane G. Christensen, BioTechnology, Inc., 405 N. Washington Street, Suite 203, Falls Church, VA 22046

Capt. John Cox, Airline Pilots Association, 4463 39th Street, S., St. Petersburg, FL 33711

Edward Czepiel, Research Analyst, Northwestern University, 1801 Maple Avenue, Evanston, IL 60201

Steve Day **(GUEST SPEAKER)**, Manager of Maintenance Control, Southwest Airlines, 2832 Shorecrest Drive, Dallas, TX 75235

Pamela Desmond, Senior Associate, Performance, Safety and Health Associates, 4767 NE 178th Street, Seattle, WA 98155

Tonja Drake, BioTechnology, Inc., 405 N. Washington Street, Suite 203, Falls Church, VA 22046

David Driscoll, Manager, Regulatory Compliance - Quality Assurance, USAir, Inc., RIDC Building #4, 173 Industry Drive, Pittsburgh, PA 15275

Colin Drury, Ph.D., Professor **(GUEST SPEAKER)**, SUNY Buffalo, 342 Bell Hall, Depart of Industrial Engineering, Buffalo, 14260-2050

Anne Duncan, BioTechnology, Inc., 405 N. Washington Street, Suite 203, Falls Church, VA 22046

Lew Dunning, Area Manager - International Maintenance, United Airlines - IADMM, Dulles International Airport, Washington, DC 20041

Steve H. Eberhardt **(GUEST SPEAKER)**, Director, Douglas DC-9 Inspection, Northwest Airlines, Inc., 1000 Inner Loop Road, Atlanta, GA 30337-6072

Tom Eismin, Professor, Purdue University, Aviation Technology Department, 761 North 400 West, W. Lafayette, In 47906

Don J. Fernette, Director, Narrow Body Aircraft Maintenance, Northwest Airlines, Inc., Department C8512, 5101 Northwest Drive, St. Paul, MN 55111-3034

David Finch, Structural Airworthiness Consultant, 12 Rectory Close, Windsor, Berks SL45ER, ENGLAND

Ronald E. Fontenot, Logistics Evaluation Manager, HQ AFOTEC/TF Kirtland AFB NM, 8500 Gibson Blvd., SE, Kirtland AFB, NM 87117-5558

Carolyn L. Foss, Senior Systems Analyst, Aircraft Technical Publishers, 101 South Hill Drive, Brisbane, CA 94005

Harry Funk **(GUEST SPEAKER)**, Principal Research Scientist, Honeywell Technology Center, MN65-2500, 3660 Technology Drive, Minneapolis, MN 55418

Bob Gleason, Manager - Inspection, Northwest Airlines, Inc., 5105 Northwest Drive, Dept. C8840, St. Paul, MN 55111-3034

Brooks C. Goldman **(GUEST SPEAKER)**, Deputy Associate Administrator, for Aviation Standards, AVS-2, Federal Aviation Administration, 800 Independence Avenue, Washington, DC 20591

Willard Gregory, Jr., Manager, Rel/Maint/Human Factors Genrg., GE Aircraft Engines, Mail Drop T-25, One Neumann Way, Cincinnati, OH 45215-6301

Franklin G. Haag, Maintenance Training Director, AirBus Service Company, Inc., 5600 NW 36th Street, Miami Springs, FL 33266-0037, (P.O. Box 660037, Miami Springs, FL 33266-0037)

David J. Hall, Senior Surveyor, Civil Aviation Authority, Safety Regulation Group, Aviation, House, 1E, Gatwick Airport South, West Sussex, RH6 0YR, ENGLAND

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