Meeting 1: Human Factors Issues in Aircraft Maintenance and Inspection (1989)

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

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FOREWORD

The Federal Aviation Administration (FAA) is mandated to ensure the highest level of safety in American aviation. A matter of concern recently has been the increasing age of jet aircraft in the air carrier fleet. Many of these aircraft now are entering their second and third decade of use.

In June of this year, the FAA sponsored a meeting of representatives of the aviation industry to review problems associated with aging aircraft. While much of this meeting addressed issues of hardware, metal fatigue, and corrosion, there was a discussion of human factors in maintenance. Today's meeting reflects a growing interest in human factors and its potential contribution to continuing aviation safety.

I hope that the perspective of today's meeting will extend beyond just the aging aircraft problem. We should consider new technologies such as use of composite materials, for example. The effect of automation, advanced electronics, new aircraft design techniques, and training innovations also should be reviewed. Any issue that bears on the performance of maintenance personnel should be included.

All segments of the aviation industry concerned with maintenance are is attendance today. We have representatives from the Federal Aviation Administration, The National Transportation Safety Board, aircraft manufacturers, airline operators, regional airlines, helicopter operators, the maintenance training establishment, those concerned with new technologies, and, in particular, several human factors scientists with impressive research credentials relating to inspection and maintenance. With the skill and expertise represented here, I am certain we will develop positive recommendations of real value to the FAA and to aviation as we consider ways to ensure optimum use and support of maintenance personnel.

William T. Shepherd, Ph.D.
Federal Aviation Administration

EXECUTIVE SUMMARY

The Federal Aviation Administration sponsored a two-day meeting in October 1988 to address issues of human factors and personnel performance in aviation maintenance and inspection. Presentations were given by some 13 individuals representing the full spectrum of interests in commercial aviation. Presentations also were given by three human factors scientists with backgrounds in vigilance and industrial inspection technology. Each presentation, as well as the following question and answer period, was recorded for transcription and study.

The objective of the meeting was to identify human factors issues of importance, particularly as such issues might contribute to inspection or maintenance error. The desired outcome was to be (1) an improved understanding of personnel performance in aviation maintenance and (2) recommendations, as appropriate, to the FAA concerning needed research efforts and/or possible new or revised regulatory actions.

Recommendations presented to the Federal Aviation Administration are summarized as:

1. More recommendations centered on communication than for any other topic discussed. Apparently the changing structure of the airline industry has disrupted communication networks with existed in earlier years. These networks were quite useful in disseminating maintenance information. Accordingly, it is recommended that the FAA foster at least one additional meeting of this kind to review specific topics noted in subsequent recommendations.

2. The FAA should consider means for encouraging or developing a data base of industry information concerning maintenance technologies, procedures, and problems. Many individual data bases exist. These should be consolidated and expanded.

3. The current review of Part 147 should be expedited as feasible. Results should include provision for specialization training as an advanced part of the curriculum of approved schools. Licensing procedures for avionics technicians also should be reviewed.

4. The supply of trained maintenance personnel is inadequate. The FAA should encourage or develop promotional materials regarding maintenance as a career.

5. "Advances in Training Technology" should be addressed extensively in any future FAA-sponsored meeting.

6. The pressure of "gate time" is an ongoing problem. All parties should consider ways to insulate inspectors from production and from the rest of maintenance.

7. Consideration should be given by the FAA to the conduct of a task analysis, or some modified version, of both mechanic performance and inspector performance. This provides critical information for any job redesign and improvement.

8. A research center, or program, where maintenance concepts could be studied in detail would be of great value. This could exist either at the FAA Technical Center or the Civil Aeromedical Institute.

9. Effective maintenance requires appropriate maintenance information. The FAA should review the preparation and delivery of maintenance manuals to ensure that the latest and most appropriate maintenance data are available to maintenance personnel as rapidly as possible. Particular attention should be given to information concerning wear limits, damage limits, repair schemes, and aircraft wiring diagrams.

10. A number of organizations are conducting research activities relating to maintenance performance. Channels should be established so that details of these activities can routinely feed into the data base noted in Recommendation Number 2. In addition, any future meeting should include a full session devoted to "Requirements and Improvements in the Preparation and Delivery of Maintenance Information."

MEETING WELCOME

Anthony J. Broderick
Associate Administrator for Regulation and Certification
Federal Aviation Administration

There is considerable interest today at the FAA in the subject of aircraft maintenance and inspection. I personally am very excited about the fact that people are willing to spend their valuable time to get together and talk about something which, it is fair to say, we know little about. We in the FAA are not sure where this interest and this take us somewhere that we would rather be compared to where we are today. Because of the lack of maturity of the subject matter, as some might say, we are in a position where we might be able to make significant contributions to aircraft maintenance and aviation safety with a fairly modest investment of time and resources. It will be exciting to be a part of this activity.

I am impressed with the cross section of professional brought together to address today's topic - people from academia, the airlines, the manufacturers, the FAA, and a number of other fields with activities relating to aircraft maintenance. Only a collective effort and cooperation of this type, in a nice quiet room, will result in the progress we need.

What we are really talking bout today is human performance in aircraft maintenance, including everything from training of maintenance personnel to development of procedures for maintenance of complex digital flight equipment. We are particularly concerned with the human's role in the inspection of older aircraft which have been in the fleet for twenty or more years. We begin, of course, with the full realization that a large measure of professionalism exists in the maintenance business today. The problem is complex and will not be solved simply by urging the industry to bring more professional aboard or recommending a nice warm room in which to perform maintenance.

The problem, as I see it, is that we do not have an organized body of information that we can apply when an engineer determines the an inspection is needed for cracks in a particular section of an airplane. How do you do that inspection? What should the engineer know about principles of human performance that will ensure that the inspection is performed with best accuracy?

The FAA at this time is preparing an Airworthiness Directive for release which will require additional inspections for certain older aircraft. For illustrative purposes, and these may not be quite the correct numbers, these inspections use a 40,000 landing cycle threshold to begin inspections, followed by a 4,000 landing cycle for repeat inspections. In this case, we are applying the same inspection criteria to an aircraft with 70,000 cycles as we are to one with 30,000 cycle. This bothers me because the process for deriving the threshold to inspection and repetition assumes that the development of cracks may be detectable at 40,000 cycles and that, if cracks are not found, the aircraft may be flown safely for another 4,000 cycles before new cracks can develop to a hazardous extent. When this process is applied to an aircraft with 60,000 or 70,000 cycles, we are saying that if the aircraft is inspected in the next 500 cycles and then 4,000 cycles later, it will be safe. We now have evidence from two recent instances, well known to most of you, in which we found that this may not be true.

In the well-publicized Aloha Airlines incident, the airplane was inspected and an airworthiness action performed just a few months before it had the tragic inflight episode. Then, just recently we found another airplane, with another airline, which had about 50,000 to 55,000 cycles and had developed a major crack and a number of smaller ones. This airplane also had been inspected earlier, with its cracks discovered only as it was going in for repainting. So here we have two airplanes, with all the attention focused recently on 737's, for which somehow the system did not work. We have professional involved in engineering and professionals involved in maintenance and yet cracks developed undetected.

We must develop an improved approach to the inspection process and, more important, it must be an organized approach. We need to take a technological approach, break the process into its components, and then examine each component to see if we can build a body of knowledge that will apply.

Is vigilance the issue? The job of performing these inspections can be terribly boring and the job frequently must be performed under adverse conditions. Is vigilance simply the answer? Or are we expecting too much of people at any level of vigilance?

What about training? Aircraft of today are more complex and employ a variety of material and construction techniques. New systems are available for the inspector. Has our training establishment kept pace with these changing technologies. While I suspect that it has at least to certain extent, I do not know whether additional attention is required on training.

Another issue is communications. How do engineers at a manufacturing facility, where a Service Bulletin is written, and FAA engineers, who approve that Bulletin, communicate with engineers at an airline and with airline maintenance personnel? How do we communicate what we expect and suspect we do a heart-felt job but I do not believe we have good guidelines to follow. This is a part of the system that has never been critically analyzed.

Then there is the work environment. Chicago in the winter can be a cold place to be. Tasks that normally are routine and that must be performed hundreds of times can be quite difficult under these conditions. When you look toward some of the more subtle inspections we are talking about, there is a question as to whether we are realistic in expecting quality performance under adverse working conditions.

So, how have we gotten away with it? Well, I am not sure we have gotten away with it. We have seen some significant maintenance-related accidents in the last decade. Also, the average age of the fleet is increasing. As a result, greater demands and greater reliance are going to be placed on the maintenance and inspection functions. We must know the good and bad points of these functions and how to deal with them.

One avenue for consideration, and a favorite topic of mine, is the use of robots. When I visit Boeing, I see huge wings being automatically drilled and riveted. Excellent use is being made of robotics technology. But when I go to an airplane on the line or in a maintenance operation for heavy checks, I do not see a lot of automation being applied. Why not? Possibly because it is expensive and not readily available. But shouldn't this be something we look to as a basis for improvement? Shouldn't we encourage industry to develop effective ways to use robotics? While this might not provide an ultimate answer, it could contribute significantly.

In the future, we will be relying not so much on the genius of the designer and the production staff but, with the aging fleets, on the genius and the dependability of the maintenance staff. In other FAA programs related to the aging aircraft fleet, we are looking at the structural aspects of aircraft design, our database requirements, and actions to be taken. But no matter what we do with regard to design improvements or production improvements, we must recognize that we will rely more and more heavily on maintenance in the coming years.

Let me close by again thanking you for coming. We are here to exchange information and listen to ideas. Even if, as a result of all the thinking and talking we do here, not a single FAA Directive is written, I am confident that the exchange of information among leaders in this part of the aviation industry will be worthwhile and, in itself, will result in safety improvements. Thank you.

INTRODUCTION

The Federal Aviation Administration sponsored a two-day meeting in October 1988 to address issues of human factors and personnel performance in aviation maintenance and inspection. Presentations were given by some 13 individuals representing the full spectrum of interests in commercial aviation. Presentations also were given by three human factors technology. Each presentation, as well as the following question-and-answer period, was recorded for transcription and study.

The objective of the meeting was to identify human factors issues of importance, particularly as such issues might contribute to inspection or maintenance error. The desired outcome was to be (1) an improved understanding of personnel performance in aviation maintenance and (2) recommendation, as appropriate, to the FAA concerning needed research efforts and/or possible new or revised regulatory actions.

The following section presents recommendations developed through a synthesis of comments and suggestions made by attendees both in their formal presentations and during subsequent discussions. The recommendations have been reviewed for intent and for accuracy by each of the presenters. Following the recommendation, an edited version of each presentation is included as Appendix A.

AVIATION MAINTENANCE PARAMETERS

Aviation maintenance operates as an indispensable element in support of the larger U.S. aviation industry. A review of human factors issues affecting the quality and efficiency of aviation maintenance personnel should be conducted with an understanding of industry parameters. An overview of the industry will illustrate the scope and diversity of maintenance requirements faced by the industry.

The mix of aircraft in the air carrier and general aviation fleets is shown in Table 1. The data for air carriers in Table 1 include scheduled, supplemental, commuter, air taxi, and air cargo carriers. These data illustrate who primary attention is being given to air carrier operations today. The carrier fleet constitutes almost exactly two percent of the entire number of aircraft operating within the United States. However, this fleet carries four times the passenger load of other classes of aircraft. In terms of safety of the general public, air carrier operations warrant the first look. However, no one should be insensitive to the fact that over 100 million passengers also are carried annually in general aviation operations.

TABLE 1
U.S. AIRCRAFT FLEET
(1986)

Aircraft	Air Carrier	General Aviation
Turbine	4,063	10,500
Piston	364	195,700
Rotorcraft	4	6,900
Passengers Carried	419 million	119 million

Air Transport Association (ATA)

Table 2 shows the projected growth of the U.S. aircraft fleet over the next ten years. This shows that growth as foreseen will take place in air carrier operations and in commuter airlines. No growth is projected for general aviation over this ten year period. New general aviation aircraft will enter the fleet but certainly not at the rate seen in 1978, the peak production year. Other aircraft will retire during this period, and as a result there will be no growth for general aviation.

TABLE 2
PROJECTED GROWTH OF
U.S. AIRCRAFT FLEET
(1987 - 1999)

Fleet	Forecast Annual Growth
Air Carrier	2.6%
Commuter	2.9
General Aviation	0.0
Domestic Passenger Load	4.6

Note: In past two years, 759 large jet aircraft were delivered.
Very few older aircraft were retired.

Federal Aviation Administration (FAA) (1988)

Table 2 also shows that during the past two years, 759 large jet aircraft have been delivered to the airlines. Over that same time period, very few older aircraft - the DC-9s and early 727s - have been retired. This illustrates the changing dynamics in fleet characteristics.

An important characteristic of both the air carrier fleet and the general aviation fleet is that each is growing older. Table 3 shows the average age for a group of selected aircraft currently in use in the U.S. air carrier fleet. While these aircraft obviously were selected to demonstrate the aging characteristic, nonetheless they are representative of aircraft used in current operations. Note that four of these aircraft have an average age in excess of 20 years. Also, considering that these data are current as of the end of 1987, the average age of the aircraft shown is now somewhat greater that indicated.

TABLE 3
AGE OF SELECTED AIRCRAFT
IN U.S. AIR CARRIER FLEET

Aircraft	Number	Average Age
DC-8-50	16	23.1
727-100	344	21.7
BAC-1-11	38	21.6
DC-9-10	91	21.0
707	35	19.8
737-100	20	19.2
DC-8-70	85	19.2
747	167	13.9

Average age of all aircraft in U.S. air carrier fleet = 12.1 years. Data as of year-end 1987.

ATA(1988)

The age of the U.S. general aviation fleet is depicted in Figure 1. It is obvious that general aviation has the same problem with aging aircraft as the air carriers. Considering that these data now are probably two-years old and thus are shifted to the right slightly, the average age for the entire general aviation fleet is in the order of 20 years, with some aircraft more than 35 years old. It is also interesting to note that every year the data in Figure 1. are being pushed to the right slightly because of the fact that aircraft are not being retired from the general aviation fleet as had been initially anticipated and very few new aircraft are being introduced.

Figure 1 Age of U.S general aviation aircraft. (FAA, 1987)

While the age of an airplane is important, maintenance requirements for air carrier aircraft are determined more directly by the number of landing cycles and pressurization cycle. Table 4 shows the "economic design life objective" established by Boeing for four of it's widely used commercial aircraft. Note that for each airplane a twenty-year service-use objective is set. Objectives for landing cycles vary, however, depending on anticipated use patterns (short flights- many landing vs. long flights-few landings).

TABLE 4
ECONOMIC DESIGN LIFE OBJECTIVES
FOR FOUR AIRCRAFT

Aircraft	Landing Cycles	Hours	Years
707	20,000	60,000	20
727	60,000	50,000	20
737	75,000	51,000	20
747	20,000	60,000	20

Boeing Commercial Airplanes, 1989.

Figure 2 shows for nine aircraft types the number of landing cycles made by the high-time airplane compared with the economic design life objective for that aircraft type. In many instances, the landing cycle for the high-time airplane exceeds by a considerable amount the cycles established initially as an objective. This does not mean, of course, that these aircraft are in danger of falling apart at any moment. Each of these aircraft has been periodically inspected and maintained, with worn parts and systems replaced, as these landing cycles were accumulated. "Economic life objective" is simply a concept established during the design of the airplane. The objective is not set as a limitation on the airplane.

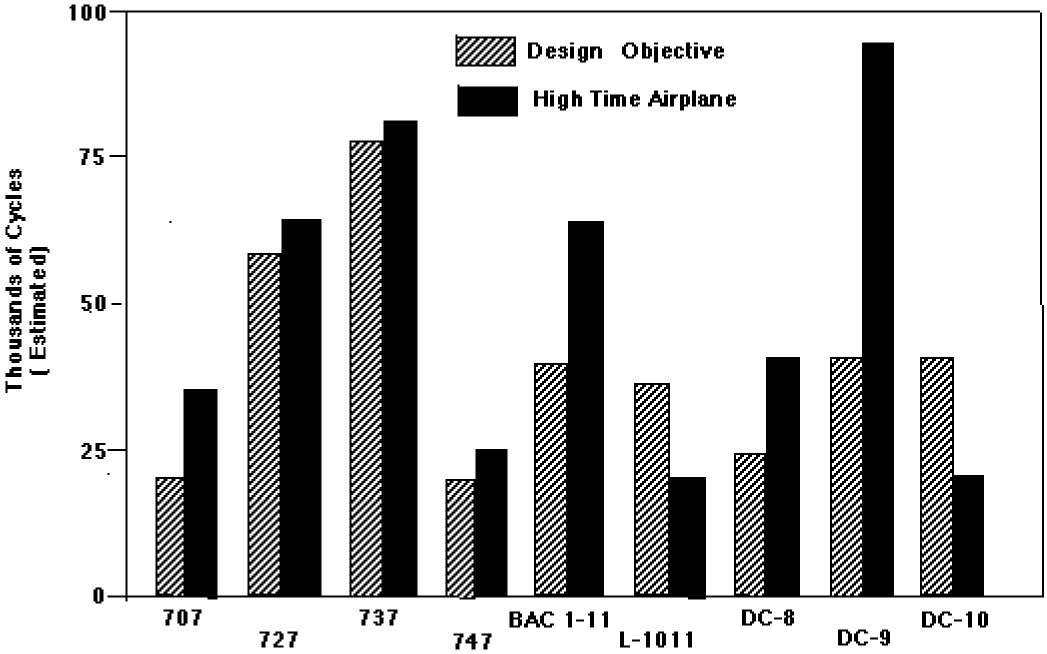

Figure 2 Landing cycles for selected active air carrier aircraft.

As the commercial aircraft fleet in the United States ages, and as landing cycles increase, the burden on maintenance grows. The maintenance industry today is large and continues to grow in parallel with the expansion of airline operations. Table 5 shows that over 50,000 mechanics are employed today, with a total cost for maintenance operations which exceeds $6 billion per year. At the present time, about eleven percent (11%) of maintenance activities are contracted, with the major part of maintenance being accomplished by the airlines themselves. The $6 billion cost for maintenance shown in Table 5 represents an outlay of some eleven percent (11%) of airlines operating revenues. Maintenance is expensive.

TABLE 5
MAINTENANCE PARAMETERS
FOR U.S. SCHEDULED AIRLINES

Mechanics employed	=	51,233
Maintenance expenses	=	Over six billion dollars
Major carriers contract 11% of maintenance work		

ATA (1988); Office of Technology Assessment(OTA) (1988)

Maintenance costs as a percentage of total operating costs is important but it may not be the best indicator of maintenance expense. The percentage will be influenced by the contribution to operating costs made by fuel costs and non-maintenance labor, both of which are known to have wide fluctuations. Therefore, maintenance expense trends for specific aircraft are considered more meaningful. Figure 3 shows the average flight equipment maintenance expense for the B727-200 fleet. This shows that for each revenue aircraft departure since 1982, there has been an almost steady increase in maintenance expense.

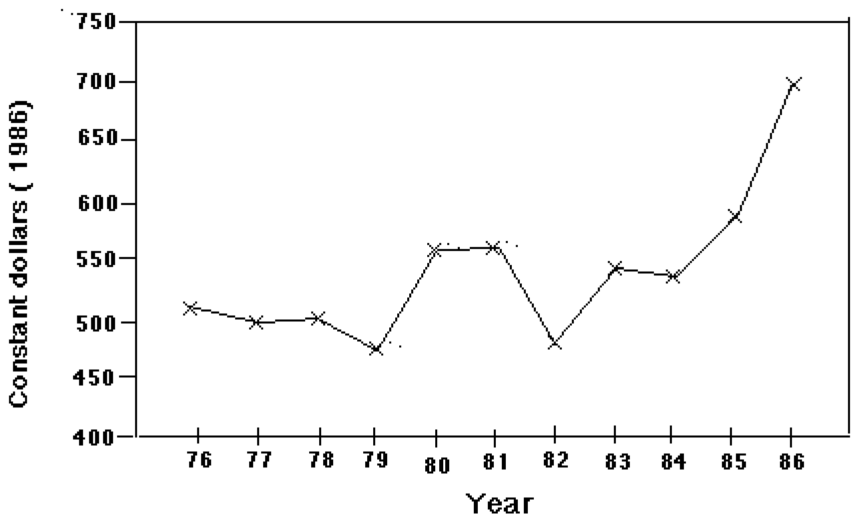

Figure 3 Average flight equipment maintenance expense for B727-200 fleet.

In summary, data describing the U.S. aviation industry and its supporting maintenance base show an expanding industry in which the average age of aircraft used both by commercial airlines and by general aviation increases each year. There is a corresponding increase in maintenance costs. Both of these trends point to a need to ensure that aircraft maintenance, and the use of maintenance personnel, is conducted as efficiently as possible. The safety of the public and the economies of air transportation support programs to optimize maintenance operations.

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CONCLUSIONS AND RECOMMENDATIONS

The attendees at this two-day meeting had diverse allegiances, some being from the Federal Aviation Administration and the National Transportation Safety Board, some from aircraft manufacturers, others from the airlines, and others from remaining segments of the industry. As a result, many of the suggestions and recommendations which were offered were specific to that part of the industry represented by the attendees. However, some themes are apparent. The following recommendations represent a grouping of attendees suggestions according to these themes, with specific recommendations included within each major topic. Some of the recommendations are directed to the FAA; others toward the industry itself.

Communications

Communication" formed some part of more recommendations than for any other topic addressed during the meeting. Comments were made by several members that even if the meeting accomplished nothing else, it served a very useful purpose by allowing representatives from all parts of the industry to get together and exchange views. Credit was given to the FAA for providing the forum in which this exchange could take place. Apparently the changing structure of the airline industry as it proceeds through deregulation has seriously disrupted industry networking. In earlier days, there existed a more effective communication network among airline operators, a network which also included manufacturers. This network does not seem to exist today, at least not to the same extent, and attendees voiced a real need either to rejuvenate the network or replace it in some manner. At the conclusion of the meeting, several attendees expressed a desire that the FAA not let this meeting be a one-of-a-kind affair. They wished to see some comparable get-together occur at least once a year.

The purpose of a periodic meeting would be to review maintenance problems and to spread word through the industry concerning new procedures and new technologies. One attendee stated, "If we have a safety situation and have options to resolve the problem, everyone should know about it."

Another expressed need, as part of the communication entreaty, was for a data base of maintenance information to be shared throughout the industry. There does not exist at this time any central repository containing assembled knowledge concerning maintenance procedures, technologies, equipment capabilities and limitations, unique aircraft problems, personnel variables, and so on. This need is supported by the circumstances surrounding the loss of an engine by a DC-10 during take-off several years ago. In this case, apparently one operator had learned that removing the engine and pylon together for maintenance could cause cracking of part of the structure at the attach point between the pylon and the wing. While this airline obviously stopped using the procedure, work of their experience did not become immediately available to the rest of the industry.

The point was made that manufacturers need to team with aircraft operators in the collection of necessary data for an industry data base. By so doing, both parties would have better insight into the kinds of maintenance errors being made, the most frequent types, and aircraft design features relating to increased error.

The importance of continually striving to ensure good communications between airline management and the labor force was noted. Morale of the workforce can be influenced positively by letting workers know when a job has been well done. Also, the workforce should have some insight into the problems being faced by management. For example, one airline had numerous occurrences of engine oil leaks, some involving inflight shut-downs and unscheduled landings. While airline management was quite concerned over these occurrences, it apparently viewed them as a series of unrelated mechanic discrepancies instead of a systemic problem. As a appropriate information and concern was not passed to the workforce. Consequently, maintenance personnel did not give this issue the full attention it should have received.

Finally, note was taken of the fact that not all airline operators attend industry meeting, such as those sponsored by the Air Transport Association. In fact, the point was made that operators who do not attend industry meetings are the same ones who are not achieving the same level of maintenance quality as other operators. The communication value of such meetings is undeniable. Some means must be found to encourage all operators to attend these meetings.

Recommendations

1. The FAA should sponsor at least one more meeting addressing human factors and personnel problems in aircraft maintenance and inspection. All airline operators, including regional carriers, should be invited. One topic would be to assess the desirability and appropriate means for institutionalizing this industry meeting. While there might be some invited speakers to discuss new technologies or comparable matters, a good part of the meeting should be set aside for panel discussions led by an industry member and open to all other members.
2. The FAA should consider means for encouraging or developing a data base of industry information concerning maintenance technologies, procedures, and problems. An FAA-sponsored Clearinghouse for Maintenance Information would be of great value to the industry. Apparently over the last several years the Electric Power Research Institute (EPRI) has been nuclear power plants. Possibly a representative of EPRI could describe this data base, and methods for developing a similar one, as one item in the FAA/industry meeting described in Recommendation 1.

Personnel

Recruitment/Availability. The airline industry has expanded rapidly in recent years with a consequent need for larger numbers of qualified maintenance and inspection personnel. Resources to meet these new staffing requirements have not always been there. This is true both for trunk carriers and for regional airlines. In fact, regional airlines may be even harder hit as some of their personnel move to major carriers. Commuters then must fill their ranks from maintenance schools, the military, and from fixed-based operators. The result os that, both for major carriers and for regional carriers, the workload is expanding and the experience level of maintenance personnel is decreasing. To illustrate, the following statistics apply to Inspectors for one major carrier.

46% have less than three years

22% have less than two years

12% have less than one year

This is in an operation in which the Manager of the Inspection Department estimates that it takes an inspector two years to become effective; six years to become efficient.

The result of the lowered level of experience for inspectors and mechanics is that work is done more slowly and more mistakes are made that must be corrected. An additional burden is placed on the inspector force.

Training Much discussion during the meeting centered on adequacy of training for maintenance personnel. Much of the problem was attributed to requirements for training established by the FAA in Part 147 of the Federal Aviation Regulations. Some parts of the initial training covered by Part 147 deal with woodwork, welding, fabric skin repair, and radial engines, all topics of little consequence for the carrier jet fleet. The A & P curriculum was generally viewed as inadequate.

Another problem is that avionics technicians who have completed an FAA-approved avionics school are treated differently than those who have completed an airframe and power plant school. For example, an Avionics Manager cannot be Director of Maintenance without acquiring an A&P license. However, an A&P license alone qualifies one to become Director of Maintenance, while understanding little about the microprocessors, integrated circuits, and sophisticated avionics which are critical to modern aircraft.

The general dissatisfaction with Part 147 should be tempered by the knowledge that the FAA currently is reviewing this document for change. One member of the training establishment offered the suggestion that during this period of change consideration be given to expanding coverage to include topics covering professional ethics, professional communications, and personal commitment to one's job. He felt that such training could be of considerable value in expanding the professionalism of maintenance personnel in the next decade.

One suggestion for improvement was that training be expanded to include certain post-graduate specialty programs. Such programs would be added to the existing curriculum and would be elective. This would be one way of dealing with such issues as the fact that at this time no training is required for helicopter maintenance. Also, advances in nondestructive testing (NDT) technology and procedures have exceeded the number of qualified NDT personnel. One of the graduate courses might include use of such advanced test systems.

Training for maintenance personnel is ongoing, extending to some extent throughout their career. For example, one operator has five percent (5%) of the inspector force in formal training at all times. During such training, maximum use should be made of new training technologies. For instance, videotapes produced in-house are now being used by one carrier to illustrate compliance with latest Airworthiness Directives. This carrier is quite pleased with results of its video program. This and other technologies should be used industry-wide.

Licensing/Certification. The issue of "type rating" mechanics in different aircraft was raised as means of ensuring that a mechanic's qualifications are appropriate for the aircraft on which he works. Aircraft are becoming more sophisticated; helicopters are extremely complex; and avionics systems represent the very latest in technology. At this time, airline operators, in keeping with their insurance coverage, limit the duties of certain mechanics to their experience level. However, no regulation covers this. A suggestion was made that current licensing procedures, particularly with respect to avionics technicians, be reviewed and that consideration be given to the establishment of new levels of licensing and certification. The Canadian Aviation Regulations, which require licensing by aircraft type for mechanics, was cited as a possible model.

Discussions among all attendees brought forth pros and cons concerning increased licensing or certification. Concern was expressed over additional layers of regulation. However, if new licensing techniques would add to the quality of maintenance, they would meet with approval.

Recommendations

1. The current review of Part 147 should be expedited as feasible. Results should include provision for specialization training as a formal and advanced part of the curriculum of approved schools. As part of this effort, consideration should be give to current licensing procedures for avionics technicians. These procedures should be revised consistent with the growing role of avionics personnel in aircraft maintenance. The result of all of this will be a better entry product into airline operations and the resolution of some current job problems.
2. Consideration should be given to ways of promoting aviation maintenance as a career. The FAA can play a useful role by encouraging or actually developing some promotional materials. Are brochures describing aviation maintenance available for distribution at the high school level? Is there an up-to-date video which describes the profession and its rewards?

3. Should there be another meeting of this type, as recommended earlier, "training technology" should be a key topic. The FAA should invite some expert who is familiar with

all of the latest training systems to conduct this session.

Job Pressures

Time pressure, also known as "gate time," is considered by many to be the most important factor affecting performance of mechanics and inspectors. Management and the mechanic force have the pressure of getting the airplane to the gate on time. Inspectors have the pressure of being certain the aircraft is airworthy. Inspectors have the pressure of being certain the aircraft is airworthy. The conflict between these two driving pressures can produce an adversarial relationship which does not benefit either side.

Ground time available for maintenance also can produce job pressures. Striving for higher aircraft utilization means that more maintenance must be accomplished in fewer hours, with these hours frequently being at night. Under these conditions, the need to meet an early a.m. departure time can again cause friction between the maintenance and inspection groups.

The consensus is that inspectors must be insulated from production and from all the rest of maintenance, yet these groups must complement one another. In some operations, this insulation is expressed in writing and supported verbally. Yet the pressure for on-time service inevitably will cause some group dissonance. The objective is to insure that such dissonance does not seriously impact the performance of either group. One way, of course, is to have inspectors and mechanics report to management through different organizational chains. Even here, however, the pressures remain.

Another factor impacting job performance is fatigue. Young mechanics just out of school who may be starting a family find it difficult to do son on entry wages. As a result, they take a second job and are quite fatigued by the end of their maintenance shift, particularly if it is the night shift. In other instances, the shortage of mechanics requires overtime work which itself contributes to fatigue. All of this tends to make maintenance personnel more error-prone.

Recommendations

1. All parties should consider ways to insulate inspectors from management and from the rest of the Maintenance Department. Inspectors should not feel the "gate time" pressure. With older aircraft, it is particularly important that inspector performance be of the highest quality. This might mean a review of inspection tasks to see how many, if any, might be shifted from ongoing maintenance activities to the longer schedule maintenance visits, where gate time is a more distant concept. Supervisor personnel should be given some training in the detection of fatigue and its insidious effect on work performance. If fatigue appears to be a constant problem, some rescheduling of maintenance activities might be considered. The first step, of course, is to determine whether fatigue is or is not a problem.

Performance Improvement/Job Design

Many individual variables can be considered in a program to improve performance for maintenance personnel. A human factors scientist in attendance indicated that, for inspector performance, such variables include conspicuity of the signal (flaw), signal-to-noise ratio, length of inspection period, social atmosphere, and others. Pursuing this list, in effect, constitutes job redesign, which has high potential for performance improvement. A proper job redesign, however, would not consider each of these variables separately.

A full job design, or redesign, would begin with a specification of overall system objectives and the contribution of the human. The human would be considered as one system component with the designer's job then being one of matching other system elements to the human. This is done on the basis of a task analysis of operator activities. The task analysis points to man/machine mismatches, workloading of the human, and many other variables related to performance. A meaningful job redesign requires a task analysis as a starting point.

An important product of a task analysis is a description of the kind of performance feedback required and the manner in which it should be presented. Human factors scientists noted that feedback must be complete, relevant, and timely to be effective. However, the requirement for feedback is highly dependent on the nature of the task. In one study for feedback is highly dependent on the nature of the task. In one study cited, performance in a visual inspection task was markedly improved simply by providing feedback concerning the inspector's performance more rapidly. The importance of feedback to job design was very apparent.

One attendee noted the need for a research center, or at least a coordinated research effort, which might be dedicated to studies of job design and aircraft design and the contribution of each to maintenance error. He noted that there is no place where regulatory agencies, operators, and manufacturers can team together to examine concepts and other variables assumed to play a part in maintenance effectiveness.

Recommendations

1. Consideration should be given by the FAA to an effort in which a task analysis could be conducted both of maintenance performance and inspection performance. To be useful, such an analysis need not describe performance on a second-by-second basis. It should be done in sufficient detail, however, that the physical, perceptual, and mental aspects of the task can be reviewed. Input/output requirements and task loading must be defined. In all, the task analysis should be conducted in sufficient detail that results can feed directly into computer-based efforts to model maintenance and inspection performance.
2. The suggestion concerning development of a research center where maintenance concepts might be studied in detail warrants careful review. In as much as either the FAA Technical Center or the Civil Aeromedical Institute could undertake such a program, no new facilities would be needed. An additional task element to either facility, with appropriate guidance and funding, could initiate this research center.

Maintenance Information

Effective maintenance is predicated on a continuing flow of information. The information supporting maintenance must be timely, accurate, appropriate to user requirement, and in a form readily understood. A number of comments indicated concern over the adequacy of maintenance information today.

The demand for new generation aircraft apparently has resulted in aircraft being placed in service before a full technical support program can be developed. One consequence, according to regional air carriers, is that maintenance manuals are inadequate. They leave much to be desired in terms of wear limits, damage limits, repair schemes, and adequate or accurate wiring diagrams. As a result, operators must frequently make requests of manufacturers for repair limits, repair schemes, and other relief. This information is only forthcoming after it has been developed by engineers and approved by FAA representatives. This causes delays in the provision of good technical information and is a source of frustration. Maintenance personnel are precluded from proceeding with subjective repair judgments which might conflict with later maintenance documentation.

Where a number of individuals are doing the same work, standardization of information is essential. Although there is an ATA system which specifies a standard format for finding material in a maintenance manual, the material itself differs among manufacturers. Maintenance manual, the material itself differs among manufacturers. Maintenance and inspection manuals themselves are not standard in terms of shape, size, of format. Standardization of language requires additional work. For example, turbine temperatures for different aircraft are expressed as: EGT, T4, T5, TIT, and TOT. Although areas of pickup on the engine may differ, all of the figures produce the same information. Standardization of format and language would be of value.

The aviation industry well recognizes the need for proper maintenance information. In an effort to improve the situation, several years ago the Douglas Aircraft Company developed an "Advanced Maintenance Information Packet." In this, maintenance tasks were presented in sequence, with accompanying graphic presentations, with cautions and warnings, fit into the sequence, and with tools and special equipment identified prior to the task. Tests showed a considerable reduction in errors when this packet was used.

The Boeing Company, in another program to improve the situation, developed an Automated Customized Task Card. In this system, material from the maintenance manual is computerized, thus eliminating the task card reader and the microfilm reader/printer. Material now is accessed directly from the computer and is more readily available. Errors encountered previously in preparing data for the mechanic have now been eliminated.

Many attendees noted issues with Service Bulletins. These bulletins, prepared by the manufacturer and reviewed by the FAA, are used to identify aircraft problems and maintenance needs after the airplane has entered service. They are prepared by engineers and con be complex, often using language more meaningful to engineers than mechanics. The Boeing Company is attempting to improve these bulletins by using "Simplified English." Apparently, however, much remains to be done by the industry at large with respect to Service Bulletins.

In an effort to extend the state-of-the-art of information presentation, the Air Force has been working for some years on an Integrated Maintenance Information System in which needed information is provided to a mechanic directly at the flight line through use of a video display. Through this display, the technician can access a number of different data bases to support his immediate requirements. In the preparation of this system, scheduled for field testing within the next few years, the Air Force has addressed many of the human factors issues involved in preparation and delivery of maintenance information.

Recommendations

1. Any program to improve maintenance performance must address the issue of adequacy of maintenance information. Technical documentation to support maintenance must be accurate and timely, must meet the needs of the user, and must be presented in a completely intelligible format. The FAA should review its surveillance of maintenance manual preparation to ensure that proper technical data are supplied to operators, particularly concerning wear limits, damage limits, and repair schemes.
2. The FAA should sponsor a program to collect and categorize information on research activities pertaining to maintenance data. We know of other industry initiatives or of relevant research outside the aviation industry. Should there be another meeting addressing human performance in aviation maintenance, one session should be devoted entirely to "Requirements and Advances in the Improvement of Maintenance Information."

Appendix A: Meeting Presentations

FAA REGULATORY REQUIREMENTS FOR AIRCRAFT MAINTENANCE AND INSPECTION

Raymond E. Ramakis
Manager, Aircraft Maintenance Division
Federal Aviation Administration

The attention of this meeting is on the human factors of aircraft maintenance and inspection. Rightfully so, since this is where the problems are. If we find some failure in aircraft design, we can issue an Airworthiness Directive and thus correct the situation. Procedures for dealing with design issues and aircraft faults are clearly specified by the FAA. It is the area of human factors that has not been touched.

I would like at this time to review in very general terms the regulatory requirements established by the FAA for aircraft maintenance and inspection and note the human factors implications of these regulations.

In the certification process for a new aircraft, regulations require the manufacturer to develop an appropriate maintenance program. Basically, he is required to provide an airplane manual and a continued airworthiness program for his airplane.

The basic maintenance and inspection program, for large transport-category airplanes, is developed through a Maintenance Review Board and a failure-fault analysis system. This system allows the manufacturer, the Federal Aviation Administration, and the airlines to work together in shaping a maintenance plan. The result is the initial program for maintaining an airplane. The process offers the manufacturer an excellent method for establishing a program that is acceptable both to the airlines and to the FAA.

As the aircraft enters revenue service, it comes under Part 121 of the Federal Aviation Regulations. Within Part 121 is Subpart L, "Maintenance Requirements," which contains the federal regulation that governs, in a broad sense, what airlines can and cannot do with that aircraft. These regulations are adopted and reviewed by the FAA through what we call Operations Specifications. This allows the development of a complete and comprehensive maintenance program which has been put together and agreed to by all parties.

The final document resulting from the above process is called a Continuous Airworthiness Maintenance Program. It covers every aspect of maintaining that airplane from A to Z - not a stone is left unturned; but it does not address the human process. The document describes the intervals between maintenance checks; that is, when a "A" check is required, when a "B" check is required, etc. It describes all programs that the airline must comply with in order to be in accordance with the regulations. But, again, it does not address the human process.

Federal Airworthiness Regulation Part 121 does speak, in broad terms, of the requirement for a certificate holder to ensure that competent personnel and adequate facilities and equipment are provided for the performance of maintenance. This is the extent to which human factors are addressed. Ideally, interpreting those broad terms fully means that when an aircraft comes in for a check, there will be an abundance of well-trained mechanics and inspectors, available in well-lighted, well-heated and cooled hangars with plenty of ground time to accomplish the required maintenance and inspections.

Unfortunately, the world described above does not exist in reality. Aircraft typically fly all day, with utilization rates of 8 to 12 hours per day, and are scheduled for maintenance late at night. Maintenance personnel, in turn, face a demanding schedule to ensure that the airplane is available to meet the next schedule. The nature of the flight leg, since deregulation, in which "hub and spoke operations" are used, adds to the problems of the mechanic.

The constant pressure of ensuring that flights maintain an on-time schedule, partially caused by the Department of Transportation, has the inevitable result of placing heavy pressure on maintenance operations and increasing the likelihood that maintenance will be hurried and possibly inadequate.

Training of maintenance personnel is another matter for consideration. The quality of training varies through the industry. Some airlines have training programs that would rival a university, with considerable time and resources invested. In other instances, training is not nearly as good, although it will meet minimum standards established by the FAA.

Facilities built for aircraft maintenance bring their own problems. These structures are large simply because they have to hold large aircraft, test stands, and other maintenance equipment. They do not lend themselves to good environmental control. Even the newest hangars used by some of the largest airlines are very cold during the winter and very hot during the summer. In addition, the lighting may or may not be optimum for the kind of maintenance being performed. However, all of these facilities are completely in compliance with FAA regulations.

The final factor for consideration is that of economics. Aircraft maintenance definitely is affected by the financial condition of an airline. Facilities, tools, and the work environment are negatively affected in an airline with financial difficulty. This is unfortunate, but it is true. All too frequently, financial attention is given first to operations, next to marketing, and finally to maintenance. Yet, even with an austere maintenance activity, an airline can remain in compliance.

Considering that all airlines essentially are in compliance with FAA regulations, do we have a problem? Unfortunately, there are indications that we do. There is, of course, the well known Aloha Airlines accident. There also are instances, in which human factors definitely played a role, that could have resulted in an accident but fortunately did not. In one case, discussed earlier, a 737 was found to have a number of cracks, one of which was 55 inches long. This was covered by three layers of paint. A related Airworthiness Directive said, "do a visual inspection." The visual inspection, of course, was not adequate to reveal these cracks even though there was a slight bulge (3/64") under the three layers of paint. The problem was only noted when the paint was stripped.

In the case of a DC-9 accident at Minneapolis some time ago, there were spacers in the engine that were to be replaced if cracked. The results of the accident's investigation by the National Transportation Safety Board indicated that, although this could not be proved without doubt, there were cracks in the spacers and the spacers were not replaced. The investigation determined that there were no training records for the person doing the inspection. There also were no records indicating whether his eyesight was good or bad.

When maintenance programs fail in some manner, as we have discussed above, the FAA must assume a measure of responsibility. Airworthiness Directives and other FAA messages to industry are perhaps not as practical as they could be or as well written as they should be.

FAA regulations also deal somewhat superficially with training requirements for maintenance personnel. For example, consider the training for "required inspection personnel." These are the individuals who inspect an aircraft area where maintenance, if done improperly, could lead to a catastrophic result. In effect, these inspectors provide a double set of eyes to ensure adequacy of maintenance. While this position is of obvious importance, the regulation simply states that "each certificate holder must ensure that persons who perform required inspections are appropriately certificated, properly trained, qualified, and authorized to do so."

Finally, keep in mind the inspector who may be on top of an airplane at 3:00 a.m., under cold conditions, and working his way down lines of rivets that in all might be 1,000 feet long. This is the individual who must perform his job with complete precision if the aircraft is to be totally safe. We must consider these human factors issues and not build potential errors into the system through neglect of them.

MAINTENANCE AND INSPECTION ISSUES IN AIRCRAFT ACCIDENTS/INCIDENTS, PART I

Barry Trotter
Aviation Safety Investigator
National Transportation Safety Board

The data bases maintained by the National Transportation Safety Board include listings of aircraft accidents and incidents related to maintenance and inspection factors. For Part 135 operators, those offering air taxi and charter services, approximately 200 such events have been recorded for over the past ten years. This includes those offering both scheduled and unscheduled services. For Part 121 operators, the commercial air carriers, the number is 49.

In terms of any statistical assessment, the above numbers are quite small. However, these numbers must be approached cautiously since they may represent only the tip of the iceberg. In the sequence of events leading to any aircraft accident, one may find that a maintenance or inspection lapse played some part, even though the lapse might not represent a primary cause of the accident.

An example of an event in which inspection lapses played an important part is provided by the account of a commercial 727 which lost an engine, in the literal sense, while approaching San Diego several years ago. In this case, water from a leaking toilet caused a block of blue ice to form by the engine, causing the engine to break loose from the airplane. In a review of the circumstances leading to this accident, it was found that the toilet had been leaking for some time and no one had picked it up during any of a number of inspections of the aircraft. These included routine inspections as well as the customary preflight walk-around by the flight crew. Why the leak was not discovered is not easy to explain since the blue lavatory water had caused a blue streak back over the aircraft and over the wing. On examination of the aircraft it was found that the stain had been there for some time.

Some inspection problems arise as a result of complexities in the regulatory process which overlies aircraft maintenance. An example is provided by a 737 airplane which was delivered to a commercial airline in 1969. Subsequently it was acquired by another airline, which completed the mandatory Airworthiness Directive inspection of exterior rivets in May of 1988, about five months ago, and was given a clean bill of health. This Airworthiness Directive did not require inspection down to Stringer 14 below the window line. However, there are Service Bulletins, which are not mandatory in the regulatory sense, covering that area of the aircraft. Obviously, the new operator was not informed concerning whatever compliance the previous operator had made with these Service Bulletins.

When the aircraft was stripped for repainting recently, a 12-inch crack was discovered in the Stringer 14 area. This crack had nicotine stains and other buildup indicating it had been there for some time. Along the line trailing this crack were multiple smaller cracks, adding up to approximately a 55-inch area with a potential for a serious rupture of the aircraft's structure. We do not believe that these cracks appeared between May and the time aircraft was stripped for painting. In order to learn more about this, the NTSB has had that part of the aircraft cut out and brought to our laboratory for in-depth study.

Other inspection issues arise from procedures established by operators to conduct specific maintenance activities. In some cases the procedure may be entirely adequate, but the next higher procedure - the one designed to ensure that maintenance personnel comply with the basic procedure - is inadequate. In a classic example, an L-1011 airplane was proceeding from Nassau to Miami when it suffered multiple engine failures due to loss of oil. Chip detectors had been replaced in the engines with out the required O-rings, and the oil simply ran out.

In the procedures used for replacing chip detectors, a maintenance supervisor would remove the 0-rings from a sealed packet, put them on the chip detector, and hand it to the mechanic in exchange for the chip detectors removed from the aircraft. In the case at hand, the supervisor was not present, so the mechanic simply picked up a set of chip detectors having no 0-rings in place and installed the detectors in the engine. While the usual practice of the airline precluded such an occurrence, there was no specific procedure designed to prevent this from happening. In the case of the mechanic, one can only surmise that perhaps boredom and the repetitive nature of this process might have played a role.

The use of Service Bulletins to define maintenance requirements deserves a special comment here. Service Bulletins, prepared by the manufacturer and reviewed by the FAA, are used to identify aircraft problems and maintenance needs after an airplane has entered commercial service. Service Bulletins often advise compliance if an operator is engaged in a particular type of operation and also suggest a schedule for compliance. Service Bulletins are not mandatory.

A problem arises when an aircraft is not large enough to have an engineering staff capable of evaluating the many Service Bulletins that arrive to select those which address particularly the type of flight activities in which the operator is engaged. There may also be issues of economy. In any event, many Service Bulletins may not get proper attention and thus, when the airline is acquired by another operator at some later date, the new owner has only a hazy idea of the maintenance condition of his new aircraft. He may not have specific information concerning which Service Bulletins were done and which were not done.

On one occasion, one cargo airline acquired an aircraft from another carrier and received all maintenance records in a cardboard box. In the changeover, records were not systematically reviewed and some procedures, including the mandatory Airworthiness Directives, were not followed. One Airworthiness Directive required trailing edge flap spindles to be replace after 18,000 hours of service. While making an approach in this airplane, two of these spindles broke due to stress corrosion, causing serious flight control difficulties. In the investigation it was found that the operator, unaware of the 18,000 hour requirement, had scheduled replacement on their normal schedule to occur at 28,000 hours. They were running approximately 10,000 hours past the time for replacement required by the Airworthiness Directive.

The above examples illustrate some of the aviation accidents and incidents reviewed by the National Transportation Safety Board which have been caused, at least in part, by problems in maintenance and inspection. In general, however, one must conclude that the system, as it now exists, works pretty well. Millions of hours are flown each year with very few accidents. Nonetheless, there are two exceptions to this system which I think should be noted. One is the individual, whether it be an airline operator or a single mechanic, who is not performing to the standards of the rest of the industry. In this case, I believe it is incumbent upon the FAA surveillance system to be able to spot this individual and implement a program to endure that his work improves. This is especially true for the airline operator. For the individual mechanic, the responsibility falls more upon the airline management. However it is done, we must have consistency of maintenance and inspection through all of aviation. In general, this will involve more than simply "complying with minimum FAA standards."

The second exception concerns the phased maintenance program in which a full maintenance activity, such as a D check, is spread across 52 blocks over eight years. This means that the airline operator does not get a complete look at any one time at any of the aircraft's systems. It also means that seven years in a high cycle operation may pass before the operator looks again at a critical portion of the aircraft. This may simply be too long to ensure adequate surveillance of developing aircraft problems.

The National Transportation Safety Board conducts extensive investigations of aircraft accidents and incidents of the type I have just described. Some of these events can be traced to the performance of personnel conducting maintenance and inspection operations. Although aircraft accidents directly traceable to lapses in maintenance and inspection are rate, they warrant continuing attention by the aviation industry.

MAINTENANCE AND INSPECTION ISSUES IN AIRCRAFT

ACCIDENTS/INCIDENTS, PART II

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Chief, Human Performance Division
National Transportation Safety Board

We at the National Transportation Safety Board are visited frequently by persons wishing to use our data systems as they seek answers for a variety of questions in aviation. Usually the visitors come away somewhat disillusioned and with considerably less than they had hoped for in the way of answers. The statistics we maintain, while they can be very useful, just do not always offer complete answers for aviation questions. This is particularly true concerning maintenance and inspection. The number of accidents and incidents in which maintenance and inspection errors are cited as causal or contributory factors is quite small. This small number of recorded events does not mean that such occurrences are not significant and pervasive. Rather, it merely indicates that accidents and incidents are not a sensitive measure of the significance of the maintenance and inspection problems.

From a philosophical standpoint, we must realize that an accident or incident is at the end of a sequence of events which, in some respects, could be thought of as a complete breakdown of our aviation system. In such case, all of the measures and safety margins which have been contrived to prevent accidents have broken down; in that same sense, a mid-air collision represents the ultimate breakdown in the traffic control separation system. In the chain of events leading to an accident, maintenance errors generally happen way upstream, with many opportunities to interrupt the chain and prevent the accident. Accidents thus can be seen to be a very poor indicator of the real frequency of maintenance and inspection errors.

Earlier during this meeting, the comment was made that the aviation community has barely scratched the surface in looking at the human element in maintenance and inspection. This certainly appears to be true. A look at the Safety Board's categorization of errors in its aviation accident and incident data system indicates there is only limited coding capability to realistically tally the errors that occur in maintenance and inspection tasks and which might have contributed to mishaps.

Quite a bit has been said about the environmental aspects of maintenance, i.e., the excesses of temperature, vibration, noise, illumination, precipitation - all those workplace environmental factors that can adversely affect human performance and could contribute to errors of omission and commission. These undoubtedly are important factors influencing performance. However, I submit that we should not focus solely on these environmental factors in our study. One of our investigators returned from Aloha Airlines accident and stated informally that "the problem isn't so much a coveralls problem as it is a coat and tie problem." It was his belief that the mechanic and inspector, who at times work under adverse conditions, often bring a high level of motivation and professionalism to the job which helps them cope with of motivation and professionalism to the job which helps them cope with such conditions and sustain good performance. What is required is a more comprehensive approach to providing the maintenance team with the full wherewithal to do its job. All of the key elements in the aviation industry must contribute to this wherewithal, including the manufacturer who provides, the air carrier maintenance department which establishes specific procedures and tasks, the air carrier management which is responsible for procurement of the best maintenance facilities and test equipment, and carrier production personnel who must work closely with maintenance to strike a balance between the sometimes conflicting time demands for proper maintenance and the pressures to meet flight schedules. All parties must work together to support the maintenance and inspection team.

Another factor affecting the quality of maintenance and inspection is the extent to which information about operating experience is disseminated through the industry. The physical separation of an engine from the airframe of a DC-10 during takeoff from Chicago several years ago serves as an example here. In this case, the manufacturer had recommended earlier that, when removing and replacing the wing-mounted engine for maintenance purposes, the engine should be removed first in one operation and the pylon removed next in a separate operation. This was a labor intensive activity. The operator, when considering personnel time and costs involved, obviously reviewed the procedure to determine the best and, hopefully, easiest way to accomplish this engine change. The NTSB accident report notes that raising and lowering the engine and the pylon as a single unit reportedly saved 200 man-hours of maintenance time per aircraft. Also, and quite important from a safety standpoint, it reduced the number of disconnects - that is, the hydraulic lines, fuel lines, electrical cables, and wiring - from 79 to 27. In all, there were strong incentives to work with the engine and pylon as a single unit. On the other side, however, moving these two components as a unit was quite a task. The movement of that weight up and down with a forklift, and the precision with which it had to be done, was difficult at best. In retrospect, one can say that the engineering staff should have taken a more detailed look at the advisability of such a procedure and provided an assessment as to the potential for damage in implementing it. However, this was not done.

During the same period of time, another airline was considering this same procedure for changing the engine on its DC-10 aircraft. This airline also decided that movement of the engine and pylon as a single unit would be advantageous because it would save considerable labor costs. Shortly after implementing this procedure, however, they found, somewhat fortuitously, that they had cracked part of the structure at the attach point between the pylon and the wing. Understandably, they immediately stopped using the procedure but they did not advise other DC- 10 operators or the aircraft manufacturer of their experience. Whether they should have done so is debatable. They did not, in any event, have an obligation to apprise other airlines of their experience.

The changing dynamics of the airline industry, in this period of deregulation, seem to have caused a decrease in industry "networking." Old timers in the airline industry contend that in earlier days there was much more frequent dialogue among operators; in other words, a more cooperative grapevine. It would be interesting to speculate about informal means that might have been implemented to spread the word among DC-10 operators and head off the catastrophic accident at Chicago.

Closely allied to the topic of industry networking is that of FAA surveillance. Should the FAA have known of the DC-10 engine experiences? If aware of it, should they have been responsible for seeing that this information was made known immediately to all airlines? For good reason, the Federal Aviation Administration is one step removed from direct maintenance tasks. The FAA, understandably, is reluctant to tell maintenance professionals how to do their jobs. Their surveillance of maintenance and inspection practices is intended to determine whether the organization has a structure which is conducive to accomplishing the required maintenance; whether the people in key positions are qualified; and whether the policies, practices and systems in place are adequate to provide a reasonable assurance that the intent of FAA regulations will be maintained. Whether FAA surveillance should be expanded is a topic for consideration. There are pros and cons.

Finally, there is the matter of communication between airline management and the labor force. During the nearly two-year period before the L-1011 flight from Nassau to Miami started gliding down to the Atlantic, the airline had twelve occurrences of engine oil leaks as a result of improperly installed chip detectors or o-ring seals. Of these twelve, eight involved inflight engine shutdowns and seven necessitated unscheduled landings. Airline senior management, maintenance management, and supervisors were aware of these occurrences, but apparently interpreted them as unrelated mechanic discrepancies rather than a systemic problem. Although minor changes were made in some work cards and procedures, and these incidents were reported upward in the management structure, there appeared to be no flow of information back to the general foreman level. The working maintenance team remained uninformed regarding the magnitude of the chip detector installation problem.

In summary, I submit that across the spectrum from the manufacturer to the working mechanic and inspector, including immediate supervisors and foremen, the engineering staff, top management, and FAA surveillance personnel, everyone needs to take a hard look at the human factor in the maintenance function. Maintenance and inspection involves many very labor intensive tasks which are necessarily susceptible to human error. If we look at the frequency of human performance errors - pilot errors - in commercial and in general aviation, we find that some 60 - 80 percent of these accidents have some human involvement. It is only reasonable to suspect that comparable proportions of human error exist in maintenance and inspection activities. We cannot reduce these errors simply by focusing singly on the person who is doing the work. We must consider in the broadest sense the total environment in which maintenance is done.

DAY-TO-DAY PROBLEMS IN AIR CARRIER MAINTENANCE AND INSPECTION OPERATIONS

Robert T. Lutzinger
Manager of Aircraft Inspection
United Airlines

In the typical inspection department of an airline the game plan, if you will, is accomplishing the Maintenance Plan. The preparation of that Maintenance Plan begins at the time of aircraft construction and the Maintenance Review Board. When the aircraft becomes operational, the airline has the responsibility to implement a Maintenance Plan of greater detail which spells out how they will systematically maintain that airplane in an airworthy fashion through regularly schedules maintenance activities. This plan provides the timeframes within which we must perform certain functions of that aircraft maintenance program. The more comprehensive that program is, the more effective our Maintenance Plan will be and the better our opportunities to avoid incidents and irregularities.

At United Airlines, our typical Maintenance Plan includes the following maintenance opportunities:

<u>Number 1 Checks</u> - Activities requiring compliance for through flights with turn times of less than four and one-half hours.

<u>Number 2 Checks</u> - Activities we have identified as necessary to meet the overall maintenance program for aircraft that lay over four and one-half hours or more.

<u>A Check</u> - This occurs for the 737 aircraft, for example, every 200 hours. This is somewhat more extensive than a walk-around, but the aircraft is not opened up.

<u>B Check</u> - This occurs at about 550 hours and includes opening specific accessible areas of the aircraft. This generally is an overnight activity.

<u>C Check</u> - This occurs essentially on an annual basis or at about 3,000 hours. Access panels are opened and we go into the airplane extensively.

<u>D Check</u> - This occurs about every four years or at 16,000 to 18,000 hours. This check can last from 20 to 30 days. All access areas are opened and detailed work accomplished on the aircraft structure and systems.

At United, the above activities are controlled and initiated with what we term Routine Paper Packages, each task related to a specified level of maintenance. In all, these constitute our game plan. I personally think the United game plan is a good one; however, the charge we have today is to discuss problem areas involved in carrying out the Maintenance Plan and the risks that might be associated with this plan. I will discuss these in terms characteristic to our airline operations.

<u>Fleet Size.</u> The different types of airplanes used by an airline can affect the maintenance program and the related behavior of maintenance inspectors. The ages of the airplanes and the types and various models of engines also can complicate the Maintenance Plan. The more complex the fleet, the more problems one may have with maintaining a qualified and experienced staff of inspectors.

In dealing with a complex fleet, it is particularly important that the routine maintenance package be as effective as possible so that the inspection function does not become a work generator but is a quality verifier. With the age of our aircraft growing daily, it is a quality verifier. With the age of our aircraft growing daily, it is imperative that our Maintenance Plan be continually adjusted so that the plan is the maintenance driver rather that a compilation of non-routine unscheduled maintenance events. As fleet size and complexity grow, the more likely it becomes that the non-routine activities affect the maintenance program. When such an imbalance occurs, it follows that greater risks become part of the inspection process.

Utilization. As the airline industry has grown, seeking ways to maximize the utility of its fleet has become a basic part of corporate strategy. Since maintenance causes aircraft to be on the ground, attention always must be given to minimizing maintenance down time. When United Airlines introduced its 747 fleet, for example, we started a phase check type program. Here, rather than having an aircraft be out of service for two, three, or even six days a year, the required maintenance elements were identified and phased in a planned visit so that we could accomplish these tasks on overnight stops when the airplane was not flying. This reduced the out-of-service time for the 747 fleet and literally saved us, at that time, one equivalent airplane.

Today, we have aircraft that have reached or gone beyond their "economic expected life." With these aircraft, we expect that structural inspections will find more discrepancies and that these aircraft must be dealt with using a somewhat different approach. This means that maintenance personnel must continually identify and make inputs into the Maintenance Plan strategy so that the plan may be adjusted to address these new requirements. If a phase check program allowing only for an eight hour turn is continually found to require 16 hours of work, we will soon have a major problem unless the Maintenance Plan is adjusted and we respond with changes. An ongoing plan review is most important for a maintenance program to be successful and effective.

Facilities and Work Environment. For the most part, the major facilities now used by the larger airlines for maintenance and inspection are quite good. While there may be some outdated facilities with significant environmental problems, I suspect they would be in a minority.

Every effort is made at our maintenance facility to insure a proper and safe work environment. Company representatives meet once a month with the Union Safety Committee and our Safety Department personnel to consider issues concerning quality of the job and quality of the environment. An action list is reviewed which covers topics such as safety of equipment, heating and lighting problems, procedures for use in emergencies, job clothing, disposal of radioactive material, training for particular jobs, and any other matter considered important. As a result, our work environment is kept in as good condition as feasible, considering the work which must be done.

Personally, I have never found lighting conditions or heat/cold problems to be so severe at our location that quality of performance is adversely affected. We have always been able to get around these problems satisfactorily, whether through the use of local lighting, the use of warm clothing, or implementing some other solution. In addition, it is the expectation of an aircraft mechanic that he must, as part of his job, deal with some of these negative environmental elements. Our employees seem to adjust well, and under severe conditions they work to overcome these negative factors.

One problem with facilities for dealing with large jet aircraft concerns those structures necessary to effectively perform inspections on inaccessible parts of the airplane. At United, we have permanent structures around an airplane when it is in for a heavy maintenance check so that our inspectors have opportunities to inspect the aircraft. However, these structures are quite expensive. The cost of this equipment may represent a problem for some operators.

An environmental issue which is becoming an industry problem is dealing with paint stripping. There are many state and local regulations today concerning the use of these chemicals and the required training of people who use them. Because of this, some operators attempt to find better or different ways to accomplish this process.

Training and Experience. The rapid expansion of the airline industry over the past en years has resulted in a need for considerable larger numbers of qualified maintenance and inspection personnel. We have seen a real growth in our staffing requirements and found that the resources are simply not always there. In my opinion, it takes an inspector at an airline such as ours two years to become effective; six years to become efficient.

When an air carrier has a complex fleet, one having a variety of aircraft and engines requiring maintenance, the time required for an inspector to become fully complicate the issue, many of the skills of an inspector will be of the "use it or lost it" type. When dealing with eddy current inspections, magnetic particle inspections, ultrasonic inspections, or radiograph, the risk of performing an inspection improperly grows if the inspector is not performing that task with regularity - use it or lose it!

Skilled maintenance becomes even more important with areas of maintenance such as the Special Inspection Document (SID) Program which we will face more and more as our aircraft grow older. When an airplane reaches the special inspection threshold designated by cycles and hours, it becomes a candidate to have literally hundreds of additional inspections performed. The inspector assigned this task must apply his knowledge and expertise in making very precise technical judgments concerning the discrepancies he is looking for. This is a difficult assignment if the inspector has not done these particular inspections with some regularity. Prior to that special inspection, he might have been on a 747; the week before that on a 727; and the week before that on a 737. Maintenance of the necessary skills, some unique to the special inspection, presents a problem for maintaining skill levels and assignments.

United Airlines recognizes the ongoing training requirement and this year will commit at least five percent of its inspection department for training on a regular basis. This means that some 15 to 17 inspectors will be in classroom training daily increasing their skill levels by engaging in special training experiences.

An aircraft inspector needs not only the formal classroom training, involving the operation of detailed parts and aircraft components, but also must acquire unique skills related to aircraft structures and systems. He must understand exactly that signal on the scope which indicates that a crack has been found, the meaning of those unusual noises that may occur on gear retraction, and the apparent stiffness of that aileron movement when the aircraft control wheel is turned. He must also recognize the significance of those blue water stains on the fuselage when he sees them. He must know that this may represent the possible corrosion and delamination of certain skin laps, even though the Maintenance Plan may not say, "Inspect fuselage for blue water stains." Only experience produces these sensitivities. In an expanding industry, the time required to obtain these experience levels is not available and represents a problem we must learn to deal with.

In order to assist in have desired performance levels maintained for our inspectors, United uses an error feedback process which we call the "C-3." We do not use these C-3 items for disciplinary purposes but instead attempt to employ them in a positive educational program for inspectors in which we point out the kinds of discrepancies being missed during aircraft checks. While this system is not always totally viewed as effective, it does assist in reviewing our process with our employees.

Unions. In a unionized operations, seniority plays a paramount role. By contract, most organized unions require assignments by seniority. This means that the older and more experienced employees often bid for the preferred shift, usually "Days." If the aircraft is down at night for inspection and maintenance, your experience at night is affected. In some instances, the night maintenance opportunity represents the most valuable maintenance time.

As they relate to company operations, unions see themselves as responsible more for "quality of life" issues for their members than for issues relating to quality or effectiveness of operation. Their concern centers on trying to insure a normal like for workers. i.e., proper vacations, appropriate economic reward, better shift work for senior vacations, appropriate economic reward, better shift work for senior workers, and similar matters. They do not give as great attention to workplace issues although, as I noted earlier, the Union Safety Committee does meet once a month with company representatives at United to discuss a variety of safety matters, some of which deal directly with the work-place environment.

The above topics represent some of the principal features of the maintenance and inspection process at United Airlines that I feel impact personnel performance. We recognize that we are in a growth industry; that we operate a mixed and complex fleet; and that our fleet is becoming older.

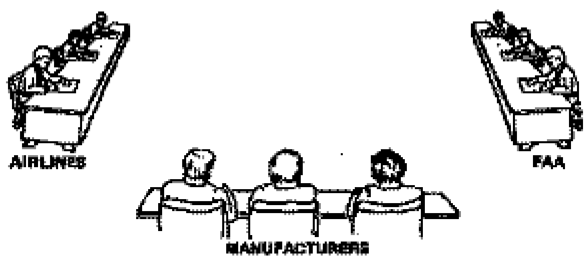
Accordingly, we have increased our in-house training program and are beginning to employ new techniques such as video to inform and train our personnel. We are continually reviewing our Maintenance Plans to be certain that new problems are quickly incorporated into our routine tasks and inspections. We are in the process of developing specialized job fields as we begin to use more sophisticated equipment to meet new maintenance challenges. Finally, we are expanding our networking capabilities with the rest of our industry, in part through our participation in industry-wide activities such as those of the Air Transport Association to enhance our skills and problem solving. The skills we are developing and the skills other airline are developing should be shared. We all have a stake in maintaining the highest quality of maintenance possible.

MAINTENANCE AND INSPECTION FROM THE MANUFACTURER'S POINT OF VIEW

Robert L. Oldani
Manager, Maintenance and Ground Operations
Boeing Commercial Airplanes

The process of establishing and conducting a proper maintenance program to support airline operations has a number of points which hold the possibility for human error. To illustrate this, I would like to review briefly the steps involved in developing an airline maintenance program. Then I will describe some innovations made by Boeing which we feel reduce both the cost of maintenance and the potential for error.

The maintenance process starts with the Maintenance Review Board (MRB). Figure 1 shows that the Maintenance Review Board is composed of representatives of the manufacturer, the Federal Aviation Administration, and the airline that has just purchased the airplane. These representatives work together to develop a minimum maintenance program for that particular airplane. The MRB work lasts for a considerable period of time, in the order of eight to fourteen months, and draws on the expertise of a number of small working groups. These working groups consist of individuals with specific expertise in aircraft maintenance. They review the systems, the structures, the various other aspects of the airplane and based on their experience, determine what should be inspected, when it should be inspected, and how it should be inspected. The end result of this procedure is the issuance of a Maintenance Review Board Report.



DOCUMENTATION

BOEING	FAA	AIRLINE
MAINTENANCE MANUAL (MM) MAINTENANCE PLANNING DATA DOCUMENT (MPD) TASK CARDS	MAINTENANCE REVIEW BOARD REPORT	MAINTENANCE OP SPEC TASK CARDS

Figure 1 Airline scheduled maintenance program.

Three end products are produced by the manufacturer during the MRB, as shown in Figure 1. These are the maintenance tasks; the Maintenance Planning Document (MPD), which tells when and where to accomplish the task; and the task cards, which combine the information of the MPD and the maintenance manual.

The airline operator works from the Maintenance Planning Data document and the maintenance manual to develop their own Maintenance Operations Specifications. This becomes their official maintenance program when approved by the FAA. In addition, the airline also develops its own task cards.

The common area of task card development by the manufacturer and by the airline was considered at Boeing to be part of the MRB in which human error could be involved. Therefore, we developed what we call an Automated Customized Task Card.

Under the old task card system, used until the introduction of the 757/767 aircraft, the task cards told a maintenance man what to do and when to do it. Then he had to go to the maintenance manual to find how to do it. Figure 2 illustrates the operation of the old task card system. Information from the task cards and the maintenance manual is fed to an airline task card writer who prepares task cards for the particular airplane. These customized task cards then go to the mechanic to direct his labor. However, mechanics require more information concerning the exact way in which to perform a task. Therefore, information from the maintenance manual is put into cassettes which then can be used with a microfilm or microfiche reader/printer. Mechanics then stand at the printer and wait to get their instructions as to how to do the job. Hopefully, they get the right printout to match the task card. This is a part of the process in which errors can be made.

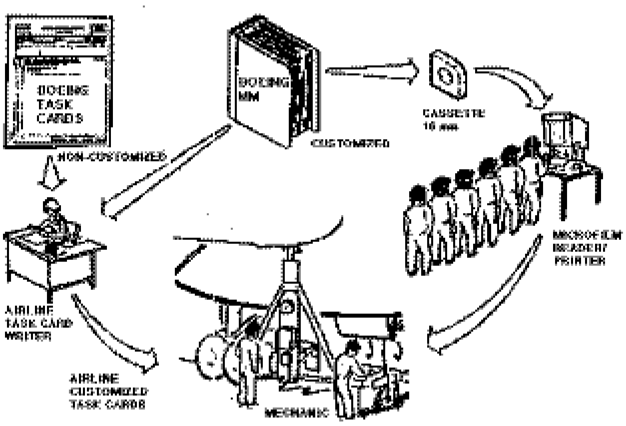


Figure 2 Old method using non-customized task cards.

To expedite the maintenance process and to reduce the possibility of error, Boeing improved on the old system with the development of the "Automated Customized Task Card" method, illustrated in Figure 3. This method eliminates the task card writer and the microfilmer reader/printer from the process entirely. Material from the maintenance manual is computerized and then accessed through use of what we call "hooks" to obtain specific items.

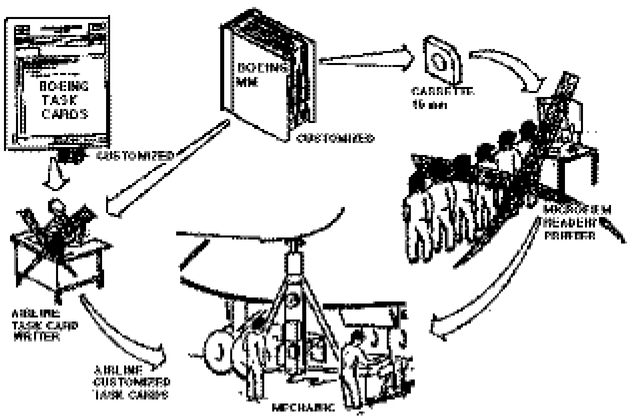
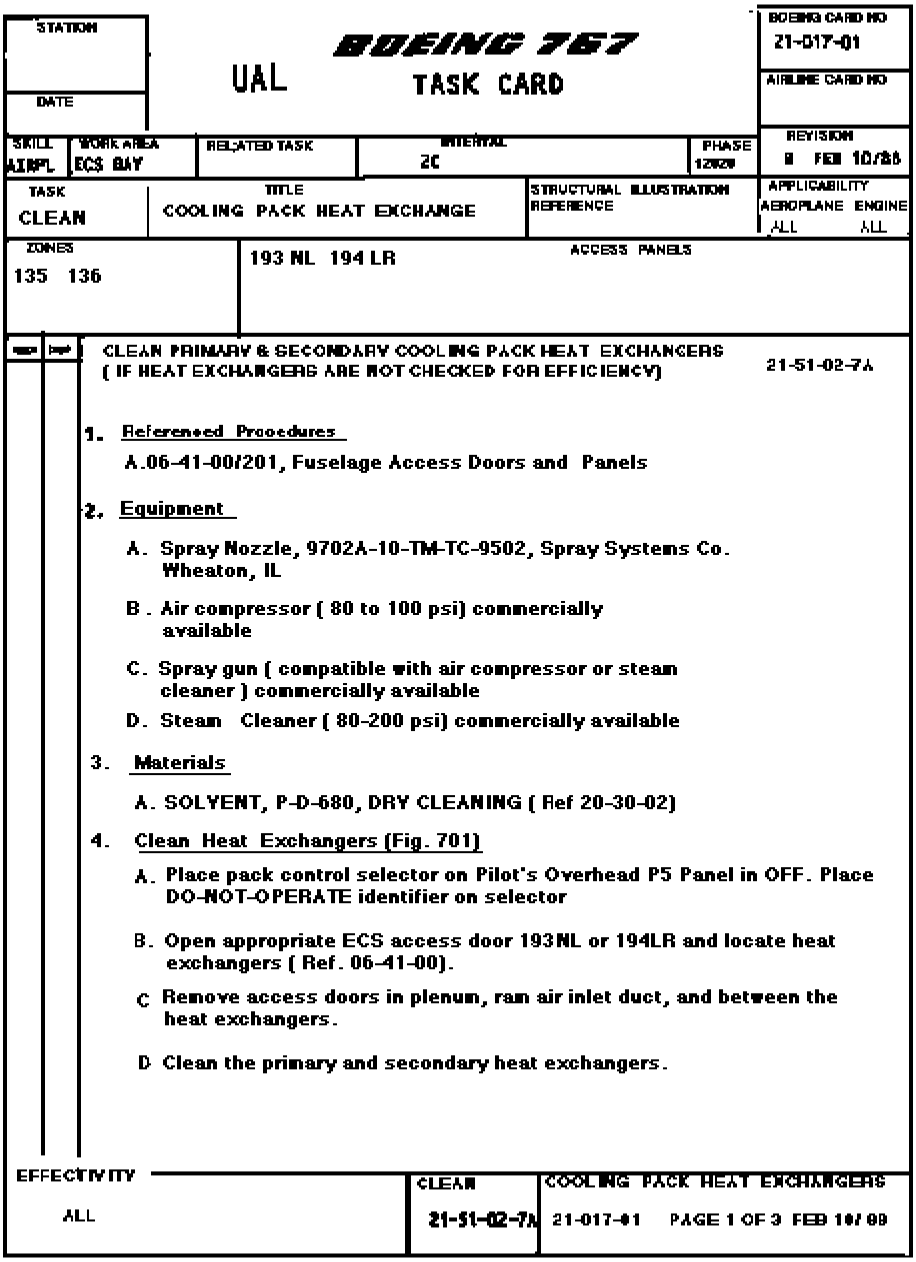


Figure 3 New method using Automated Customized Task Cards.

Under the new system, the maintenance manual is revised on a 60- to 90-day basis. The Customized Task Cards thus are revised on the same basis, which means that the mechanic always is dealing with up-to-date data. In addition, the new task cards can provide all of the needed illustrations.

Figure 4 presents a sample of an Automated Customized Task Card. This task card covers cleaning of a cooling pack/heat exchanger on a 767 aircraft. Figure 5 shows the illustrations accompanying this particular task card. With these new task cards, the mechanic now has everything he needs to properly conduct that particular task. He has the equipment, the material, the procedure, and all of the illustrations, all reflecting the latest changes. From a human factors point of view, we feel this is a considerably better maintenance support program.



STATION

DATE

UAL

BOEING 767

TASK CARD

BOEING CARD NO 21-017-01

AIRLINE CARD NO

SKILL	WORK AREA	RELATED TASK	INTERVAL	PHASE	REVISION
AIRPL	ECS BAY		2C	12020	8 FEB 10/88

TASK	TITLE	STRUCTURAL ILLUSTRATION REFERENCE	APPLICABILITY AEROPLANE	ENGINE
CLEAN	COOLING PACK HEAT EXCHANGE		ALL	ALL

ZONES	ACCESS PANELS
135 136	193 NL 194 LR

CLEAN PRIMARY & SECONDARY COOLING PACK HEAT EXCHANGERS
(IF HEAT EXCHANGERS ARE NOT CHECKED FOR EFFICIENCY) 21-51-02-7A

1. Referenced Procedures

A. 06-41-00/201, Fuselage Access Doors and Panels

2. Equipment

A. Spray Nozzle, 9702A-10-TM-TC-9502, Spray Systems Co. Wheaton, IL

B. Air compressor (80 to 100 psi) commercially available

C. Spray gun (compatible with air compressor or steam cleaner) commercially available

D. Steam Cleaner (80-200 psi) commercially available

3. Materials

A. SOLVENT, P-D-680, DRY CLEANING (Ref 20-30-02)

4. Clean Heat Exchangers (Fig. 701)

A. Place pack control selector on Pilot's Overhead P5 Panel in OFF. Place DO-NOT-OPERATE identifier on selector

B. Open appropriate ECS access door 193NL or 194LR and locate heat exchangers (Ref. 06-41-00).

C Remove access doors in plenum, ram air inlet duct, and between the heat exchangers.

D Clean the primary and secondary heat exchangers.

EFFECTIVITY ALL

CLEAN 21-51-02-7A

COOLING PACK HEAT EXCHANGERS 21-017-01 PAGE 1 OF 3 FEB 10/88

Figure 4 Sample Automated Customized Task Card.

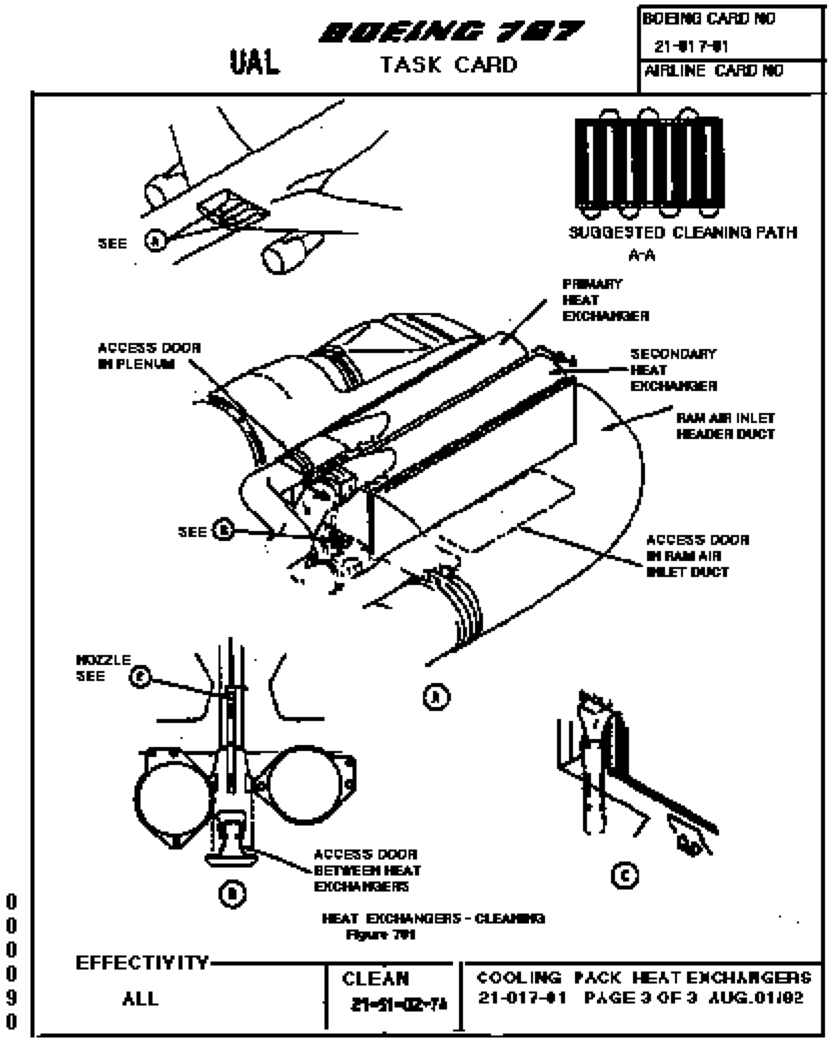


Figure 5 Illustrations accompanying Automated Customized Task Card.

There are a number of benefits with use of the new customized task card system. It reduces the number of airline man-hours expended in writing and revising job cards; it eliminates a mechanic's need to refer to microfilm; it eliminates lines of mechanics waiting at the microfilm reader; and it eliminates errors due to manually transferring and retyping the manufacturer's data. A final benefit is that each airline receives that latest information from the maintenance manual. This eliminates guesswork in identifying applicable maintenance manuals can be complicated, with their particular accession and numbering systems. With the automated system, airlines can easily identify revisions in the maintenance manual affecting their scheduled maintenance.

One airline operator who accepted our system and evaluated it over a one-year period estimated that they saved over $1 million. This was based on eliminating the task writing, eliminating the problem of mechanics waiting to look at microfilm, and generally expediting the labors. Several other airlines do not actually use our task cards to direct maintenance but, rather, use then to determine when we have revised the maintenance manual. Rather than going through the total revision, they just go to the task cards to look for a revised card. They then know the maintenance manual has been changed for that process. Finally, we provide this information on magnetic tapes to some airlines who prefer to develop their own computerized task card systems.

Another area of concern to the airlines is Service Bulletins. These are documents prepared by engineers working at desks in the manufacturer's facility. They can be rather complex, and may use language meaningful only at the engineering level. In order to make Service Bulletins more readable, Boeing is attempting to improve their content by using what we call "simplified English." This is English which we feel can be readily understood by the average mechanic. Again, the purpose is to reduce errors of interpretation.

A final recommendation of mine is that we continue to use whatever means we have - such as this meeting - to review our maintenance problems and to spread work throughout the industry concerning new or improved ways of doing things. If we have a safety situation and have options to resolve the problem, everyone should know about it. We are talking about the total airline fleet.

HUMAN PERFORMANCE IN AIRCRAFT MAINTENANCE: THE ROLE OF AIRCRAFT DESIGN

Anthony E. Majoros, Ph. D.
Engineer Scientist
Douglas Aircraft Company

This presentation describes work being done by the Douglas Aircraft Company concerning human factors in maintainability and design for ease of maintenance. Specific topics are (1) human factors aspects of supplemental inspections, (2) maintainer workload, and (3) maintainer reliability.

Supplemental Inspections

A fundamental truth in design is that provision for supplemental inspections is seldom built in as part of the initial aircraft design. With an aging aircraft fleet, however, supplemental inspections have become and will continue to be a way of life. For the inspector dealing with an aircraft with no design provision for supplemental inspection, definition of the inspection concept may be unnecessarily complex and access to inspection areas may be difficult.

We believe that it is possible to aid the inspector by defining inspection concepts. One way to do this is through use of a computer-generated anthropomorphic mode. Figure 1 shows that manner in which we used such a model to demonstrate two possibilities for inspecting the inner frames of a DC-3 vertical stabilizer. The model is based on anthropometric dimensions taken from Military Standard 1472 and the Navy Crew Assessment of Reach (CAR-4) algorithms.

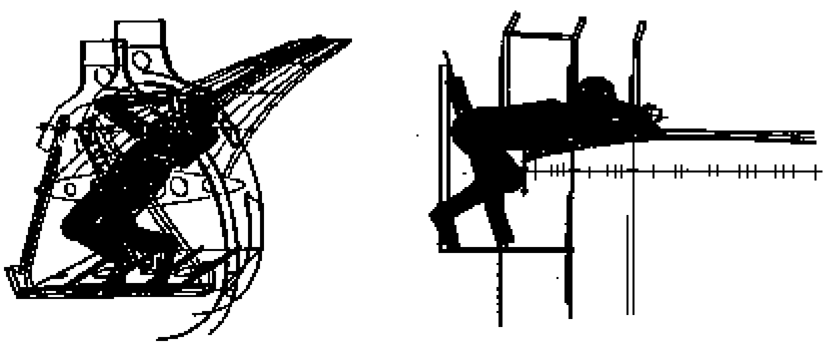


Figure 1 Computer simulated DC-3 vertical stablizer inspection.

We would not recommend that the inspector lie with his back on the horizontal stabilizer as shown on the left in Figure 1. We would recommend instead that the inspector lie with his stomach on the horizontal stabilizer and see the overhead view with a mirror. We compared our simulation of this task with actual attempts to perform the inspection on a DC-3. By personal experience, I can tell you there is good reason not to recommend the procedure shown on the left. It is difficult to get into and out of the position, it is painful, and very little can be seen. Inferences about the difficulties of this inspection made possible with computer simulation compared very well with the actual experience.

In one design evaluation, we considered a maintainer attempting removal of a flight control module from the upper aspect of a vertical stabilizer. The analysis showed that the pull of gravity on that component, weighing about 44 pounds, presented sufficient risk that the maintainer would incorrectly remove the package and so damage the delicate ribs within the vertical stabilizer, that a recommendation was made to mount the flight control module on the outside of the rear spar of the vertical stabilizer and not on the inside. This illustrates consideration of several variables during static simulation of maintainers. One is weight-lifting and carrying limitations, another is maintainer comfort (or pain), another concerns postural difficulties, and a final one is time required to hold posture and to generate force in certain postures. All of this information bears on the ability of the maintainer to perform the operation efficiently and accurately.

There is an emerging belief within the Douglas Aircraft Company that computer-assisted design (CAD) environments represent the way all design will be done in the future. There will be less paper and more electronic models. Within this environment, sophisticated anthropometric models can be use to predict the performance of people in any position within aircraft structures. Ultimately, these anthropomorphic models will show real-time motion characteristics and will have vision and strength capabilities as well.

Maintainer Workload

In aircraft flight operations, excessive levels of workload are considered to be associated with increased error likelihood. We make the same assumption with maintainer workload. We believe that as workload increases beyond certain acceptable levels, the chances of error being made by the maintainer are increased.

We have performed some preliminary work in an attempt to locate aircraft systems during design that we believe are likely sources of unacceptable levels of maintenance error. In Figure 2, ten selected aircraft systems are plotted for maintainability, reliability, and ratio of difficult to easy tasks within the system. Maintainability, specifically mean man-hours to repair (MTTR) is plotted on the left-right axis; reliability, specifically mean time between corrective maintenance actions (MTBM (C)) is plotted on the front-back axis; and the ratio of difficult to easy tasks, specifically the skew of the distribution of task times within a system, is plotted on the up-down axis.

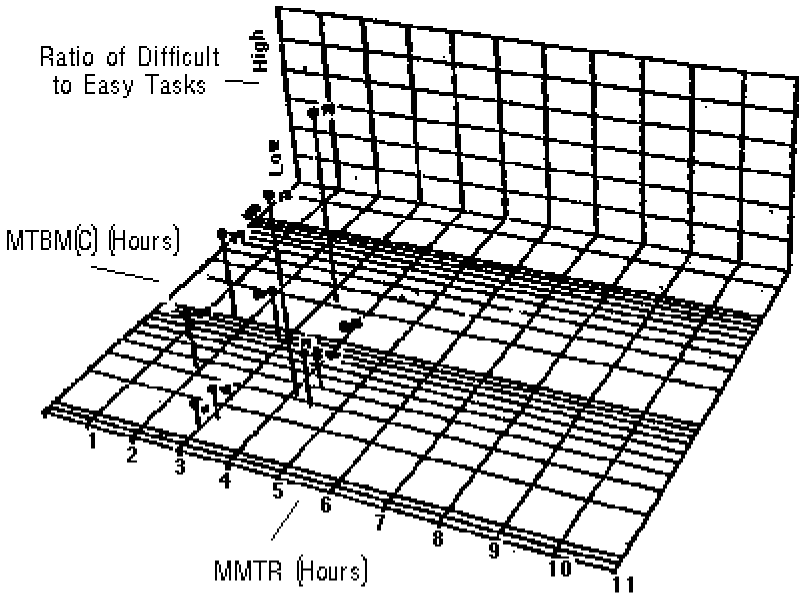


Figure 2 Three-ax graph used to identify systems loaded with tasks requiring many time-consuming steps.

Task times for aircraft systems are generally positively skewed, and the greater the ratio of time-consuming (difficult, with many steps) to fast (easy, with few steps) tasks in the system, the greater the degree of skew. We made the assumption that systems whose tasks times are more skewed offer relatively more opportunities for maintenance error. In the figure, systems with longer stems are more positively skewed. With a graph of three variables, we can determine an aircraft system's availability by plotting the location of the bottom of its stem on the "floor" of the graph in terms of reliability and maintainability, and we can check the system's potential for error by noting the length of the stem.

In Figure 2, flight control (System 14) and independent position determining (System 72) contribute nearly identical burdens to aircraft availability, yet the position determining system offers relatively more opportunities for error. We would conclude that position determining - in the design configuration under study - is a better candidate for human factors attention to maintenance error reduction than flight control.

Note that error rates are not used in the analysis in Figure 2. The three axis graph is used to locate aircraft systems that have a high proportion of time consuming tasks on the assumption that those systems contain more chances for error.

In our review of workload parameters relative to aircraft maintenance, we identified three aspects worthy of in-depth consideration. These are (1) infrequency or novelty of a task or defect, (2) the cognitive complexity of the task or the mental demands the tasks imposes, and (3) the physical and physiological demands of the task. Each of these is reviewed next.

1. Infrequency or Novelty of Task/Defect. One of the rules of inspection and quality assurance is that rare defects are difficult to detect. As you increase the percentage of defects present in a sample, the likelihood of catching a given defect increases.

One way to aid an inspector in dealing with rare events is with procedural checklists that guide the user. To study the potential of checklists go guide the search for uncommon errors, we created three types of checklists for use in an experiment. The experiment required subjects to search for characteristics of a design that could be considered "errors" from the standpoint of maintainability, but the same logic could apply to an inspector checking system for integrity. One checklist contained irrelevant items, a second contained conventional USAF maintainability checklist items that were not specific to any particular aircraft system, and a third contained items written at Douglas Aircraft that were specialized for the system under examination by the subjects. As shown in Figure 3, we found that more errors were determined with the specialized checklist.

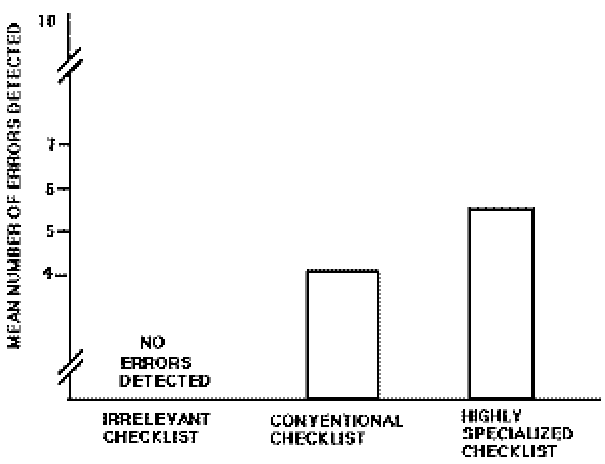


Figure 3 Comparison of conventional vs. improved checklists.

2. Cognitive Complexity of Tasks. Aircraft obviously are complicated systems. Nicholas

Bond, in a recent chapter in the Handbook of Human Factors, makes the observation that, in his opinion, no single person understands everything about certain aircraft systems. He uses the F-18 flight control system as an example, and states that no one is alive who understands it all. Many systems within civil transport aircraft are similar. They are highly complicated and few individuals understand them completely.

One problem with increasingly complicated systems is that the representation, or the mental model of what a person should look for, becomes difficult for a maintainer to hold for a long time. Methods that enhance the representation for that person can do nothing but help. A few years ago, in an attempt to improve this situation an "Advanced Maintenance Information Packet" was developed. In this, maintenance tasks are numbered in a step-by-step sequence, with accompanying graphic presentations. Even the position of the hand relative to where the maintainer would be standing or sitting is shown. Cautions and warnings are put before the action; tools and special equipment are identified before the action begins.

The advanced maintenance information concept was tested with novice mechanics and for what were termed major errors. This would be an incorrect removal and replacing the wrong part. In this test, use of the advanced maintenance information system produced a 55 percent reduction in errors. For minor errors, such as incorrect torque on bolts, there was a 79 percent reduction in error.

One concern about the advanced maintenance information concept was that the many different and necessary illustrations made it prohibitively expensive. This is not the case today. Computer generated graphics, much less expensive to produce, can be used to illustrate maintenance actions.

Another aid in overcoming the cognitive complexity faced by maintainers is through use of expert systems during the design stage. Designs can be more or less maintainable for a number of reasons. If these reasons are incorporated into an expert system, the designer will be able to rapidly evaluate a new design for its maintenance characteristics. The designer should be able to ask the expert system questions such as: "Given this task, a change of a filter requiring two seals in this location of the aircraft, how long will it take to make the change if the filter is in this locations?" This is basic maintainability information and it can be very valuable during the design stage.

3. Physical and Physiological Demands. Another aspect of workload concerns physical and physiological demands placed on the maintainer. Table 1 presents results of a small survey done with operators of Douglas products. As can be seen, weight and access complaints are most frequent among civil aircraft maintainers. Visual lighting problems were next, followed by difficulties with connectors, seals and component installation.

TABLE 1
MAINTENANCE PROBLEM AREAS NOTED IN
SMALL SURVEY OF OPERATORS OF DOUGLAS AIRCRAFT

Access and weight	28%
Visual, lighting	18%
Connectors	16%
Seals	7%
Installation	7%
Others	24%

The Douglas survey was small and informal. More data than we obtained are required. Many questions concerning difficulty of maintenance were not asked in this survey. Such information is needed for designers to understand how to develop a product that maintainers can work on most efficiently.

Designers should be able to reduce physical and physiological demands by attention to placement of components when the structure permits some variation of placement. Figure 4 presents one approach to solve installation questions during design. The figure is a working envelope for removal of a slat lock valve. Spatial coordinates for this envelope were obtained by videotaping the removal of the valve from a wing mockup. Cameras were set above and to the side of the valve location in the mockup.

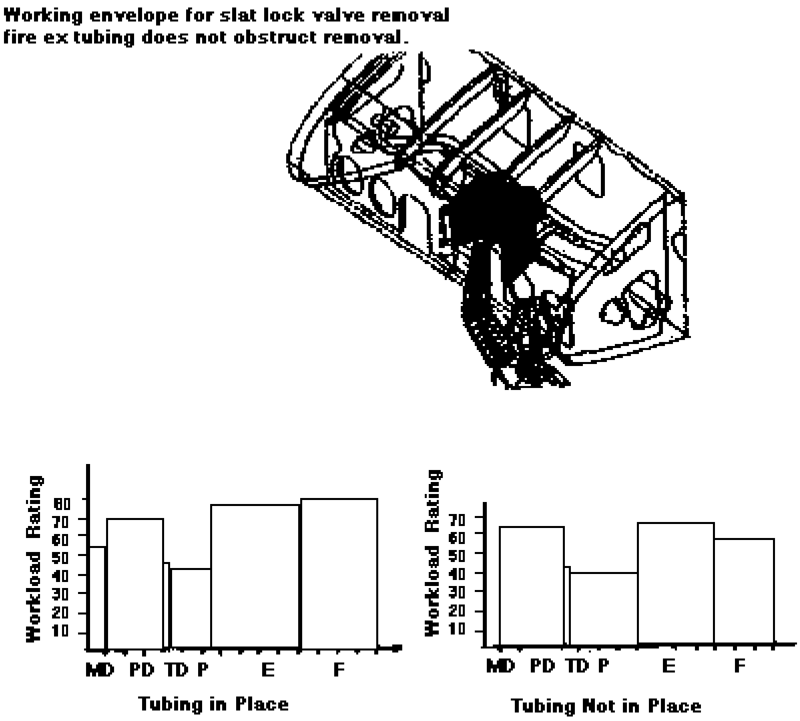


Figure 4 Workload for slat lock valve removal compared with and without fire ex tubing in place.

The working envelope shows the maximum excursions of hands, tools, fasteners, and the valve itself during removal. Two trials were videotaped: removal without any obstruction - which required 12 1/2 minutes - and removal when fire extinguisher tubing obstructed access - which required 16 minutes. We can conclude that if the tubing were routed to avoid obstruction, valve removal would require about 25 percent less time. This study is a first step toward defining required working envelopes for components during design. If equipment is arranged in the aircraft with adequate working envelopes, maintenance workload can be reduced.

We developed workload measures on the above task using the NASA Task Load Index to measure operational workload. This system rates mental demands (MD), physical demands (PD), temporal demand (TD), performance (P), effort (E), and frustration (F). Here we see that effort and frustration are increased by having a design that includes the fire extube below the slot valve. This offers us a chance to understand some sources of error that could head to damage during the performance of the task.

Maintainer Reliability

There is growing interest in maintenance reliability. Reliability concerns errors, departures from procedures, time to complete tasks, and damage or induced maintenance. The goal at the design stage is to aid the mechanic by designing to reduce error likelihood.

Many aspects of maintenance affect error potential. Figure 5 is an example of labeling that led to error. Labels and placards are part of the world that guides inspectors and maintainers to do their job. In this case, one can connect P26 to either J5 or J6 of the adapter. This test is for an aerial refueling boom and in one case (J5) you test the elevator actuator. In the other (J6), you test the aileron actuator on the flying boom. However, mechanics interpreted the labeling to mean "take your choice," but that is not what it meant. This led to many test errors. The role of human factors here is to identify those design variables that lead to error and develop procedures to control them.

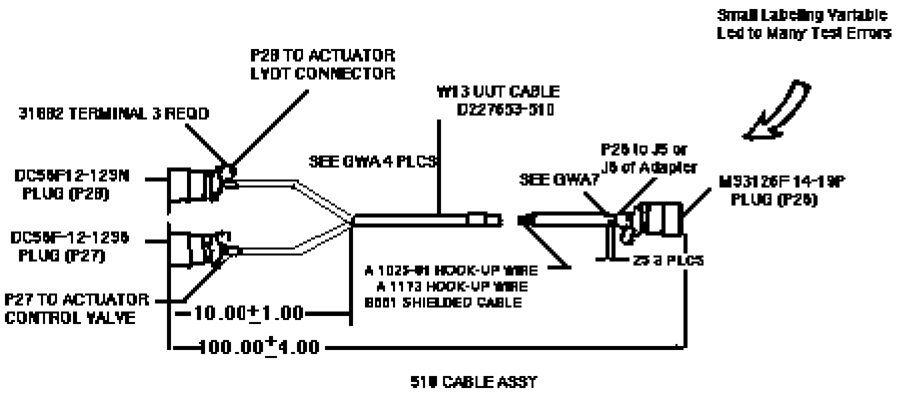


Figure 5 Test set lead and labels leading to maintenance error.

From a manufacturer's standpoint, a number of approaches appear worthwhile in a program to reduce maintenance and inspection error. Briefly, these include:

1. Manufacturers need to team with aircraft operators in the collection of necessary data. What errors are being made; what are the most frequent types; and, perhaps with workload measures, what are the components of error?
2. Inspection concepts must be defined to facilitate inspection as much as possible and ensure best performance.
3. Checklists must be improved.
4. Maintenance aids should be developed for with knowledge representation both in paper form and in expert system form.
5. Aircraft systems should be designed for ease of access.
6. Modelling should be employed to aid in the development of maintenance procedures. Anthropomorphic models are becoming so sophisticated that maintenance procedures could be modeled before an aircraft is built.
7. A research center, or at least a coordinated research effort, is needed where problems can be studied indepth and where concepts can be tested to assess design configurations and their contribution to error. There is no place where regulatory agencies, operators, and manufacturers can team together to examine concepts and to examine the role of environmental variables that are often assumed to play a part in maintenance effectiveness.

Finally, I would offer one comment on use of models. Models hold the illusion of solution, but they are not the solution. They aid in interpretation and/or application of human engineering judgment. They do not replace human engineering judgment.

MAINTENANCE AND INSPECTION ISSUES IN AIR CARRIER OPERATIONS

Robert Doll
Vice President of Technical Services
United Airlines

An important avenue for the coordination of maintenance improvement and the exchange of related information within the airline industry is through the Engineering and Maintenance Council (EMC) of the Air Transport Association. I am the representative of United Airlines to the EMC. My remarks today represent the activities of the EMC and the industry in general rather than a specific United Airlines position.

The ATA Engineering and Maintenance Council recently formed with the FAA and other industry representatives, a steering committee to consider a number of issues raised during the FAA conference on Aging Aircraft held on June 1-3, 1988 in Crystal City, Virginia. The first item on the agenda of the steering committee is to examine the technical problems that underlie the industry's and the public's concern about the manufacture of aging aircraft. The technical issues are structural integrity and corrosion. At this time, there is no industrial standard for corrosion. At this time, there is no industrial standard for corrosion control. Fleet specific task groups have been formed to consider the integration of corrosion control programs with the existing structural inspection program for individual fleet types.

The second major item on the steering committee's agenda is human factors, which, of course, is the topic of this meeting. We anticipate working closely worth the FAA human factors program to ensure that our activities are mutually supportive.

Within the scope of human factors, the issues we have selected as important closely parallel those mentioned earlier today. The first issue is the work environment, and here we are concerned both with the work environment as designed at the time of manufacture and the work environment provided by the operator. The second issue is of design and system maintainability. This is a problem with long range solutions but one which, as we have heard, manufacturers such as Douglas Aircraft are now addressing vigorously. The third issue concerns the preparation and training of an individual to work in a maintenance facility, whether he works as an inspector or as a mechanic. Here we must recognize that we are not talking about clear-cut job entities. A lot of the inspection chores are actually carried out by A&P mechanics.

Next we come to the matter of qualifications, and here we are talking about the basic A&P license. There are questions as to whether we should go to more certification and licensing at higher levels. While there might be advantages, one very practical problem with increased licensing is that it generally leads to a more complex pay structure which, in turn, places a heavier administrative burden on the airlines.

A final issue within our human factors agenda concerns job instruction. How do we instruct an inspector or mechanic to do a specific job? What kind of language do we use? This issue, of course, goes well beyond our internal communications within an airline. It includes the manner in which a Service Bulletin prepared by the manufacturer, or an A.S. prepared by the FAA is written. The A.D., for example, is prepared by an engineer, reviewed by an attorney, sprinkled with "Washingtonese," and then delivered to the airline operator. We have a reasonable chance to interpret it properly in San Francisco, but consider the plight of the maintenance supervisor in Hamburg or Paris, translating to his language.

The third area of inquiry for the steering committee is new technology. One part of this with human factors implications is the use of expert systems. One means of circumventing to some extent the requirement for experience and training is to have an expert system, a computerized means of providing the needed expertise rather than depending on an experienced mechanic. Expert systems, if incorporated properly, can play a very useful role.

New technology also encompasses aircraft systems. Use of composite materials presents a new set of demands for inspection. Such materials are not compatible with some of the existing inspection procedures, one example being the use of eddy currents to explore possible cracks within composited structures. We have to understand these new materials from the point of view of maintainability, repairability, and associated human factors problems.

The last agenda item for the steering committee, and perhaps the most important item, is that of communications. How do we share information? How do we communicate problems? In the maintenance base at United Airlines, we have about 12,000 employees, each one of whom is involved in many information transactions in a single day. How do we manage this information exchange so it best supports our maintenance objectives?

At United, we have made attempts to better manage this information flow and to better understand its dynamics. For example, many years ago we began a fault isolation program to code maintenance problems in order to classify them in a way that we could then run computer analyses.

In a recent "classic" incident, we had an airplane problem which the crew code as "Left brakes binding. Airplane pulls to left on landing." So we went in and replaced the brakes on the left side. The airplane flew again and we got the same report from the crew: "Left brakes binding, Airplane pulls to left." This time we went in more deeply, changing parts in the anti-skid system and some other components. Well, guess what the problem turned out to be? The right brakes didn't work.

Here we have simple maintenance problem which, through neglect of human factors considerations, became a more complex problem. If someone had simply said "The airplane pulls to the left," we probably would have checked both brakes. But someone got one more level into trouble-shooting than was required and the system led us down the wrong path. The issue here, of course, is one of information exchange. How can we insure that the data we receive is translated to information appropriate to our needs in maintenance?

I happen to believe that there is a fairly simple dictionary that could be put together for use in fault isolation that would be easier to learn than a system based on significant number codes. This approach would be put together for use in fault isolation that would be easier to learn than a system based on significant number codes. This approach would be more appropriate for human understanding. Problems would be reported in standard terms commonly used. For example, the report "Airplane pulls left" uses works well known to all. Certainly, humans relate to this better than to a problem described as "001--3002." Then, by use of a standard dictionary of terms, word-processing techniques could be employed with the key words, yielding a higher likelihood of an accurate diagnosis.

Another issue that falls under the scope of communications is the exchange of information among the different players in the industry. There is a need for an improved data base of maintenance information to be shared throughout our industry. As good as some of use think our networking is, I did not know about. The same is probably true for work at Boeing. Ours is a very complex industry. We need an efficient data base that will keep all of us abreast of advances.

Maintenance and inspection programs are build on the premise of commonality - that we have common fleets. In fact, this is not true. United Airlines has nominally 400 airplanes. No two of them are alike. Some are more alike than others, but every one of our maintenance systems is based on the assumption that they are common and that we are going to find the differences. This can lead to serious consequences when an error is made.

If I assume all aircraft are different and then look for the commonality, I don't have the same problem if I miss a commonality as I do if I assume they are common and then miss a difference. In terms of human factors, we are creating an error prone process by starting with a bad assumption.

Another problem in our industry is that in the past our audits, including those conducted by the FAA and those conducted eternally by an airline, accept a 95 percent performance level or above as okay. By comparison, segments of the manufacturing industry decided some time ago that anything less than 100 percent quality as a target only leads to problems. Why should one ignore five mistakes in 100 and consider that good performance?

In maintenance operations, we must come to realize that we are the ultimate example of a zero-defects industry. Statistics describing the low incidence of mechanically related accidents should not provide any measure of comfort. When you look at an accident classified as "pilot error," you frequently find a mechanical problem somewhere along the line of causal events leading to the accident. The L-1011 accident which occurred in the Florida everglades many years ago is an excellent example. In this case, crew members were distracted from the flight regime by the failure of a landing gear light to illuminate when the nose gear was lowered. Trying to evaluate the problem took the full attention of the flight deck crew, during which time the low altitude alarm system was accidentally disengaged and the aircraft gradually descended into the swamp.

We obviously cannot accept any level of defect in maintenance. It is just not good business. Every airline operator and every manufacturer has a stake in 100 percent safety. Every commercial carrier must have total dedication to safety. I want every airline to spend the same money on maintenance that I spend and to be as safe as I'm safe.

Somehow this part of the industry (the least common denominator) must be brought up to the same level of commitment as the rest of the operators. This is one issue being examined now by the industry steering committee. The question is "What do we do as an industry to ensure that we have 100 percent quality performance on an industry-wide basis?"

To meet a standard of 100 percent quality performance, we must design our systems so that we do not build errors into the system. In particular, we must build systems that allow aircraft inspectors and aircraft mechanics to do their jobs efficiently and to make their full contribution to aviation safety. The air carrier industry, both as individual operators and through industry-wide activities such as the aging aircraft program, is searching for means to manage human error during aircraft maintenance and inspection and to make ours truly a zero-defects industry.

INSPECTION AND MAINTENANCE ISSUES IN COMMUTER AIR CARRIER OPERATIONS

Norman S. Grubb
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Introduction

The commuter air carrier industry of this country and the world has experienced a very volatile and rapid growth over recent years from the "Mom and Pop" entrepreneur operations of ten years ago with a few aircraft to the large corporate regional air carriers of today. Large fleets of sophisticated and new generation aircraft cover route structures over large segments of the United States. This explosive growth has brought with it a unique challenge in the human aspects needed to support the sophistication of the industry. (NOTE: The following remarks represent input from four commuter air carriers).

Thesis

It is our contention that the human elements of the equation have lagged behind and not kept pace with the technologies of today's new generation aircraft, coupled with the market demands of the commuter industry. I say this because of the many human factors issues that we see in today's workplace. These factors span the industry from the manufacturer of the equipment, to the regulatory agencies, to the mechanic on the job.

Issues

Let us examine these issues and discuss their impact on the production of a safe and reliable product.

1. Sophistication of the new generation commuter aircraft vs. the "old school."
2. Training.
3. Manufacturer support.
4. Frictions between AP Mechanics and Quality Control Inspectors.
5. Clock-card employee turnover and experience level.
6. Management turnover and competency as it affects the man on the job.

7. Aircraft utilization vs. aircraft maintenance ground time.
8. Fatigue.
9. Morale/job satisfaction.
10. Drug/alcohol dependency.

Sophistication of New Generation Commuter Aircraft vs. the Old School

The technology of the new generation aircraft with the more extensive use of microprocessors, integrated circuits, and advanced avionics has surpassed the know-how of the majority of AP Mechanics and Inspectors.

The AP School curriculum has not kept pace with advances in the industry. The "dope and fabric" days are over and yet this subject, as well as "woodworking," is still taught in AP Schools. Needless to say, the A&P curriculum is totally inadequate and a drastic overhaul of what we are teaching in the AP Schools is badly needed to prepare mechanics for the "high tech" commuter aircraft of today and tomorrow.

Some of the more technically-trained and capable employees are the avionics technicians who have gone through an FAA-approved avionics school. These people are virtually ignored in the traditional FAA organizational structure. For example, an Avionics Manager cannot be yet an old-timer can be Director of Maintenance strictly with an AP license, and understand very little about today's high tech aircraft. An avionics technician can graduate from an FAA avionics school, but there is no license that allows the technician to work on the aircraft or sign-off his own work. An avionics technician must obtain a repairman's certificate in radio and instrument repair before he can sign-off his work. An SP mechanic can be taken from the ranks and trained in-house in a few months and be doing work and signing off work that the trained avionics technician cannot do until he gets an airman's certificate requiring as much time as the FAA Administrator deems necessary. This can be up to 18 months of practical experience in the specific job category, and then this certificate is not transferable to another employer (FAR 65.101). Again, this is a deficiency in today's school system for qualifying our technicians.

Training

In view of the inadequate training of today's AP in school, new hires are not ready for systems training on the commuter aircraft. After an initial indoctrination program, the new hire is put to work on the floor with an experienced mechanic for aircraft familiarization a month or two before systems training can be meaningful and absorbed by the mechanic.

Manufacturer Support

The manufacturers of today's new generation aircraft have rushed the product to market before full technical support is developed. Maintenance manuals leave much to be desired in terms of wear limits, damage limits, repair schemes and adequate or accurate wiring diagrams. As situations occur, the operators find themselves going back to the manufacturer frequently for repair limits, repair limits, repair schemes and other relief, and this information is forthcoming after the information is developed by the engineers and approved by the DER/DAR (Designated Engineering Representative/Designated Airworthiness Representative). In the meantime, an aircraft is AOG ("Aircraft on Ground"). The operator is caught between not having adequate manual information for the aircraft and not being able to make subjective judgments in violation of the FAR's as interpreted by the Federal Aviation Administration. The industry needs some latitude in making judgment calls by mature and experienced maintenance personnel.

Friction Between AP Mechanics and Quality Control Inspectors

In my opinion, this issue has the most effect on people in the maintenance and inspection category in terms of mental and physical strains of the job. Maintenance people have the pressure of getting the aircraft to the gate on time, and inspectors have the pressure of making certain the aircraft is airworthy before it leaves maintenance for revenue service. This raises many questions between the two groups as to what is airworthy and what isn't, and on what basis is the determination made? This situation causes an adversarial relationship between the inspectors and the mechanics and supervisors. Maintenance people think the inspectors do not feel responsible for getting the aircraft out on time and that they continue to write-up items and are "nitpicking." Maintenance is dedicated to putting out a safe aircraft, but on many occasions, the inspectors do not consider the aircraft airworthy by the strict definition or interpretation of the FAR's. The more experienced maintenance people feel they should be able to make subjective judgments and that the less experienced inspectors are looking for objective judgments or decisions only - in other works, they want to go strictly "by the book." I'm sure this is an old story to all of you; nevertheless, this causes mental and physical strain on both the maintenance group and the inspectors.

In the Shop atmosphere however, where there is not a gate time to meet, an adversarial relationship does not exist between the mechanics, supervisor and inspectors. In fact, maintenance welcomes the inspection group in the Shop atmosphere and sees them as a help rather than a hindrance. It appears the pressure of the gate time makes the difference.

Clock-Card Employee Turnover and Experience Level

The commuter industry has experienced an extremely high turnover due to the major air carriers' expansion and need for mechanics and inspectors. Since the commuters then have to fill the ranks from AP School, the military, or from Fixed-Base Operators (FBO's), there is a large percentage of inexperienced mechanics, particularly on a type aircraft. This makes both the inspectors' job and the supervisors' job more difficult, and it does result in less efficient operations, since not as much work is accomplished and more mistakes are make that must be corrected.

Management Turnover and Competence As It Affects the Man on the Job

With the rapid expansion of the industry, there has been an increasing demand for experienced and competent management to fill the many positions that have become available. As a result, there has been considerable movement of managers from operator to operator and many managers in their present positions have not had longevity in that position with the particular company. The workforce sees instability in management and in the policies and procedures that ensue. Also, a lot of the administrative work falls on the lower-level supervisors as the learning process of the new manager takes place. This allows less time for the supervisor to spend with the mechanics or inspectors on the job.

The second part of the increased need for management is that a number of young people have been promoted from within to authoritative positions and these people are relatively inexperienced in management. They are good people and have great potential, but many time they make management decisions based on their ego rather than on sound managerial judgment. This tendency of a new manager to show his authority rather than consult with the more experienced often results in poor decisions, particularly in the handling of personnel.

Thus, in a rapidly-expanding industry, whether you promote form within or hire from outside, there is a maturing period for the manager which has a direct effect on the workforce.

Aircraft Utilization vs. Aircraft Maintenance Ground Time

This is a never-ending battle and maintenance usually loses as a result of the marketplace and cost-effectiveness pressures that prevail in most commuter operations. To meet your competition, higher aircraft utilization is necessary and more maintenance has to be squeezed into fewer hours of ground time at the maintenance base. It is not unusual for an RON aircraft to arrive at midnight with a run-up time of 5:00 a.m. to meet a departure at 6:00 a.m. This time constraint does put pressure on the maintenance and inspection groups, as well as causes friction between these two groups, which I have addressed as a separate issue.

Fatigue

The high turnover in the mechanics' ranks due to mechanics moving up to major carriers results in the hiring of young mechanics who are often just out of school and starting families. These mechanics, working at starting wages, find it difficult to make ends meet and often require second jobs. In "burning the candle at both ends," these mechanics become tired and are obviously less effective and more prone to making mistakes.

At other times, there are situations when the hiring rate has not kept up with the turnover and there is a shortage of mechanics. This leads to overtime and longer than normal hours and, again, contributes to the fatigue of an employee and the associated vulnerability.

The night schedule required for RON maintenance of airline aircraft is a factor in fatigue also, particularly for newer employees who are not used to the night routine. The mechanic has to do his business during the day and often goes to work tired as a result. When a mechanic is tired, that is when he takes shortcuts in doing his job.

Morale/Job Satisfaction

Basically people want to feel appreciated and want to feel good about themselves and the job they are doing. When a mechanic doesn't like what he's doing, or doesn't feel good about his job, his work suffers and this is not necessarily a conscious effort on the employee's part. When the mechanic does not have his heart in the work, that is when details will be overlooked and oversights will occur. Good morale of the workforce can make the difference, and many things, of course, go into making good moral, but, in my opinion, some of the more important are: (1) letting the troops know when a job has been well done; (2) maintaining a clean, well-kept and good-appearing workplace or environment; (3) having all the necessary tools and equipment and having them in good repair; and (4) communicate, communicate, communicate!

Drug/Alcohol Dependency

What can I say that hasn't already been said about drugs and alcohol problems in our society today? However, in our industry, this problem must have particular emphasis as the lives of so many people are at stake. I am proud to say that Henson Airlines has mandatory drug-testing in the hiring process and drug-testing of individuals involved in any incident or accident. However, the entire industry needs mandatory drug-testing of the workforce. This should be a top priority.

I can honestly say that I have not personally seen any evidence of drugs or alcohol use or abuse in our workforce. However, we must remain alert and always be on the lookout for the problem. Our experience has been that less than one percent of mechanic applicants have been turned down for employment as a result of positive drug-testing results.

Thank you.

HUMAN FACTORS IN AIRCRAFT MAINTENANCE AND INSPECTION ROTORCRAFT MAINTENANCE AND INSPECTION

James T. Moran
Air Safety Investigator

Aerospatiale Helicopter Corporation

Introduction

Several years ago, Harry Reasoner made a rather tongue-in-cheek comparison between pilots who fly fixed-wing aircraft and pilots who fly rotary-wing aircraft. The paraphrased statement indicated that fixed-wing pilots were extroverted, happy-go-lucky, bright-eyed people who could not understand who people actually paid money to have them perform their day-to-day duties; while on the other hand, helicopter pilots were beady-eyed, neurotic little people who know that if a catastrophic failure of some sort has not already happened, it is about to. This is due to the fact that rotor-wing aircraft are viewed by the pilots and maintenance personnel as 3,000 pieces of metal fatigue surrounding an oil leak, and these combined pieces don't really fly, but rather beat the air into submission.

Due to the different environments that the helicopters operator in (i.e., high vibration levels, high torque levels, corrosive environments), a higher level of diligence is required by maintenance personnel.

Standardization of Inspection, Maintenance and Repair Manuals

Maintenance and inspection manuals come in a wide variety of shapes, sizes and formats. Although the majority of manufacturers have gone to the ATA Specification 100 Type System, there are still gaping differences in the way material is presented to the mechanic. Although the ATA System provides mechanics a standard format for finding material in maintenance manuals, once that material is found its presentation differs greatly among manufacturers.

A standardization of language used in manuals is becoming increasingly necessary as the rotary-wing aircraft on the market attain greater degrees of sophistication. For example, turbine temperatures are expressed on different aircraft as: EGT, T4, T5, TIT and TOT. Although the areas of pick-up for these temperatures differ slightly among engines, all of the figures produce the same information. The same confusion applies to the nomenclature of turbine sections of the same engines are referred to as either N2, NTL, NF, N OR NP. Admittedly, there are some differences in the operations between a free-turbine engine and a fixed-shaft engine. However, the number of different names outweigh the differences by far.

Licensing of Mechanics

In discussions with some of the larger helicopter operators in the United States, it has been observed that as the sophistication of aircraft becomes greater, the possibility exists that the necessity of "type rating" mechanics in different aircraft will arise. Although presently operators, in conjunction with insurance companies, limit the duties of certain mechanics to their experience level, there is no regulation pertaining to this. At the very least, consideration should be given to making it mandatory that aircraft above certain weight limits and complexities require factory-trained mechanics to perform the needed maintenance. This also applies to the level of maintenance which should be allowed to be performed on different type aircraft. An A&P mechanic with an Overhaul Manual and no training can be very dangerous. Attempts are presently being made by the manufacturers to contain such activities. However, lack of regulation in this area makes the job difficult.

Consideration should be given to bringing the FAA Regulations more in line with the Canadian Aviation Regulations which require licensing by aircraft type for mechanics, even after they have been to an approved manufacturer's maintenance school.

Initial Airframe and Powerplant Mechanic Training

Under present day standards, there are no requirements for an A&P School to provide a potential mechanic edith any training in rotorcraft maintenance. This means that a mechanic in today's market can conceivably finish his license requirements never having been any closer to a helicopter than seeing Airwolf on television.

In has long been known that schools teach the requirements for the FAA test, and the test borders on being antiquated. There presently are sections of the initial training which deal with woodwork, welding, fabric skin repair and radial engines, which the mechanics will never see once they finish the curriculum they are enrolled in. Perhaps maintenance schools should take a cue from flight schools, which divide training into different phases. First phase would be initial entry level maintenance on all aircraft to cover standards and practices and other topics described in AC 43.13-1A. Later phases of training could be devoted to either rotorcraft or the more advanced maintenance techniques required by the air transport industry. Having additional certifications such as these stamped on a mechanic's license would make him more valuable to the operators of different aircraft and put the mechanics in a better position to obtain gainful employment.

Dynamic Components and Service Life Limited Parts in Rotary Wing Aircraft

Certain parts in aircraft, to include the dynamic components in the rotor head, tail rotor, drive trains, and gearboxes, are "service life limited" should never be confused with "time before overhaul," a term used in the fixed-wing market mostly connected with fixed-wing powerplants and components. A properly maintained helicopter should have separate logs and "serviceable" cards for all life-limited parts. Over the years, many catastrophic accidents have been attributed to having aircraft parts reinstalled that have reached their useful fatigue life, been "overhauled," and returned to service. Having your alternator go out on a Beech Bonanza while in flight is "disturbing." The loss of a main rotor blade in flight could add a new dimension to that term.

Constant vigilance by mechanics and supervisors is becoming more and more necessary with today's generation of helicopters. Small things like following the Standards and Practices sections of maintenance manuals, and giving particular attention to the corrosion protection sections of the aircraft inspection and repair manual can go a long way in reducing the accident rate, which has already been substantially reduced over the past ten years.

Perhaps some day we can improve rotary wing maintenance to the point where our "beady-eyed, neurotic little pilots" become the "extroverted, happy-go-lucky" ones they once were.

NONDESTRUCTIVE INSPECTION EQUIPMENT AND PROCEDURES

George Ansley
NDT Specialist, Service Engineering Department
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This presentation describes the inspection techniques known variously as nondestructive testing (NDT), nondestructive testing (NDT), nondestructive inspection (NDI), and nondestructive examination (NDE). The principal methods used today to support nondestructive testing include:

- X-ray. These procedures have been in use for roughly 50 years. X-ray can detect anomalies in metal just as in bone during medical examinations.
- Ultrasonics. Alterations in patterns of reflected sound waves are used to pinpoint structural faults. Technically, this is the most difficult NDT method.
- Eddy Current. This is an electronic inspection method in which disturbances in an eddy current indicate a metal fault. Probably 90 percent of the NDT inspections made today use this procedure.
- Penetrant. In this procedure, a dye is applied to the metal and then examined with different lighting sources for indications of unusual stress patterns. This is a well-known inspection procedure.
- Magnetic Particle. This procedure is limited to the inspection of steels that can be

magnetized and is commonly used in overhaul situations where parts are taken from the airplane, completely disassembled, and inspected.

The above are referred to generically as methods, i.e., eddy current method. When these methods are presented in specific written instructions for aircraft inspection they are referred to as procedures.

The primary method of aircraft examination is by visual inspection. This remains the best inspection method, with possibly 95 percent of an aircraft being inspected visually. NDT procedures are used to supplement the visual inspection and, in general, are used in lieu of a costly tear-down process in which much hardware is removed to get to the structure requiring inspection. NDT procedures are effective and also control costs. Finally, NDT procedures can be used for reliable detection of smaller defects than could be found visually.

Figure 1 illustrates the use of a nondestructive inspection. Some years ago we did a tear-down inspection of an older airplane and found small cracks in the lower wing surface spanwise splice stringer. This stringer goes through the fuel tank, so the first visual evidence of such a crack would be a noticeable fuel leak on the underwing surface. Other than the surface inspection, the only other visual option consists of draining the tank, climbing inside, scraping sealant, and performing a visual check there of each of the 7,000 fasteners. It is our position that such an inspection simply is impossible. A nondestructive procedure must be used.

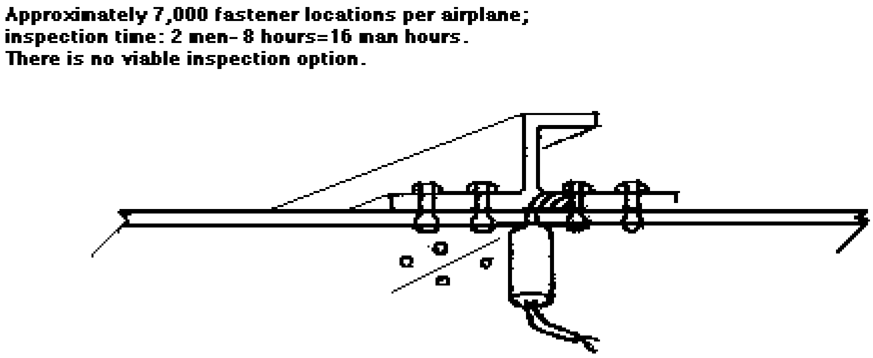

Figure 1 Example of low frequency eddy current inspection of lower wing surface span-wise splice stringer.

The NDT inspection used for the splice stringer consists of centering an eddy current probe in place and sliding it slowly the full length of the wing to detect possible cracks in the underlying member. Inspection time for the 7,000 fasteners is approximately 16 man-hours. Obviously, the NDT procedure is superior to a visual inspection. However, it comes with its own problems. Since this is a lower wing surface, typically one man holds the eddy current equipment while the other applies the probe to the aircraft while standing on a short ladder. The inspector thus is leaning back while looking straight up. Their is quite uncomfortable and can only be tolerated for short periods of time. However, in our mind, this inspection procedure is mandatory. There is no viable option.

The basic eddy current inspection in use today is illustrated in Figure 2. This shows the high frequency eddy current probe inside a fastener. Generally, the inspection in use today is illustrated in Figure 2. This shows the high frequency eddy current probe inside a fastener. Generally, the inspection probe is calibrated against a test base with a thirty-thousandth inch notch. If a crack of this extent is found during the inspection of a fastener hole, the hole is drilled and repaired. For the remaining holes, we assume smaller cracks are present even though the required eddy current inspection shows nothing. We then oversize each of these good holes about 1/16 the of an inch and refasten the structure with oversize bolts. This procedure is called out in many of the Service

Bulletins we have issued.

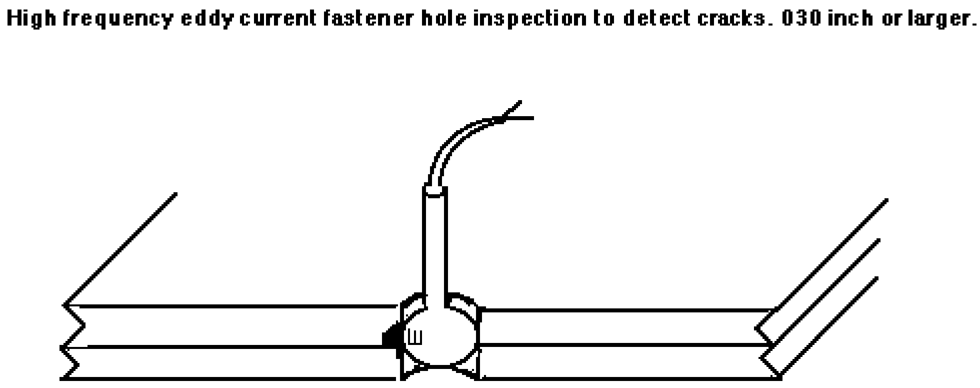

Figure 2 Examples of non-destructive inspection to support structural repair or modification

NDI Procedure Development

The Boeing Company maintains a well-equipped NDT laboratory, with an extensive investment in equipment, which is used to study NDT procedures and to validate the inspection requirements we describe in Service Bulletins. In a sense, we work for the airlines as we try to develop the most practical and effective options to visual inspection in maintenance programs. For the most part, the procedures we develop are considered mandatory since the alternative, taking the airplane apart to examine internal systems visually, generally is not feasible.

The NDT laboratory also considers field conditions when developing an inspection procedure. For example, some eddy current and ultrasonic instruments provide the readout on an oscilloscope rather than a meter. This works fine in the laboratory. However, we deal with airlines all over the world, a great many of which operate in the tropics. For an outside inspection or in a hangar without doors, the sunlight simply is too bright for an oscilloscope to be used. Therefore, we look to alternate procedures or equipment that will be effective in the various environments in which they will be uses.

We also take into account cost of equipment to the airlines and training requirements imposed on inspectors. For example, when the FAA made the first low frequency eddy current inspection mandatory, we conducted a school for inspectors to insure that these inspections would be conducted properly. While the equipment and training does present an additional cost burden to airlines, there appears to be no alternative.

Much laboratory work is concerned with establishing procedures and standards for critical crack detection. We know that a crack grows slowly as metal fatigues, and that as the crack gets larger its rate of growth increases. Our Stress Department develops information on crack size versus aircraft landing cycles. In how many cycles does the crack go critical? From these data we establish inspection intervals, as shown in Figure 3. Our Service Bulletin philosophy is that we want two opportunities to detect that crack before it reaches critical size.

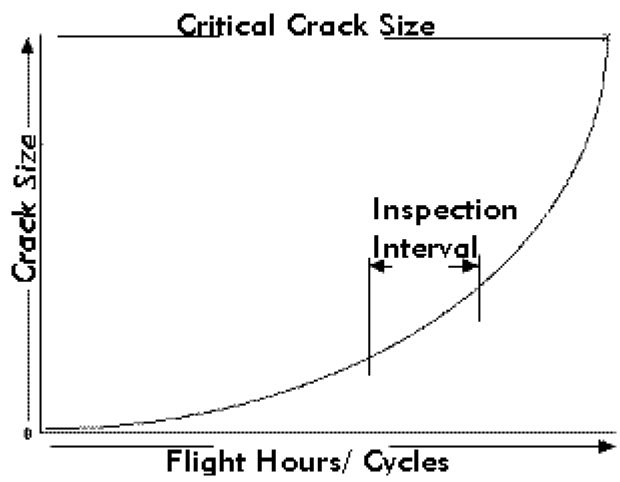

Figure 3 Establishment of NDI inspection intervals to ensure detection before cracks become critical.

We also consider inspection options from an airline's point of view. If I can allow for a larger defect in a Service Bulletin, the inspection will be easier technically, a less expensive piece of equipment can be used, and the inspector might not require as much training. The disadvantage, however, is that the inspection interval must be shorter. For instance, the inspection might have to be made every six months. This is inconvenient since the airplane is not available for scheduled maintenance that often. Therefore, we can stretch the inspection interval by dealing with a smaller defect size. In turn, this may require special instrumentation and training. The inspection itself might be slow and tedious. These are difficult tradeoffs to consider.

Lap Splice Inspections

Considerable attention has been given recently to the 737 aircraft because of cracks discovered in the fuselage lap splice. At the splice, fuselage skins are thin, each of them only thirty-six thousandths of an inch. Because of these thin skins, the base of the countersink for a rivet tends to be a knife-edge, which is a poor fatigue detail. To counteract this, the aircraft were constructed with a cold bond system using epoxy over a thin layer of dacron or glass cloth as a means of using epoxy over a thin layer of dacron or glass cloth as a means of distributing the load. The bonding shares the load with the fastener and picks up enough of the load so that a fatigue crack should never develop.

We found with older airplanes that over a period of time, in the order of five years, the bonding material begins to deteriorate with moisture and you begin to lose the load-carrying capability that the bond gave you. Fatigue cracks then can form in the upper row of fasteners, as shown in Figure 4.

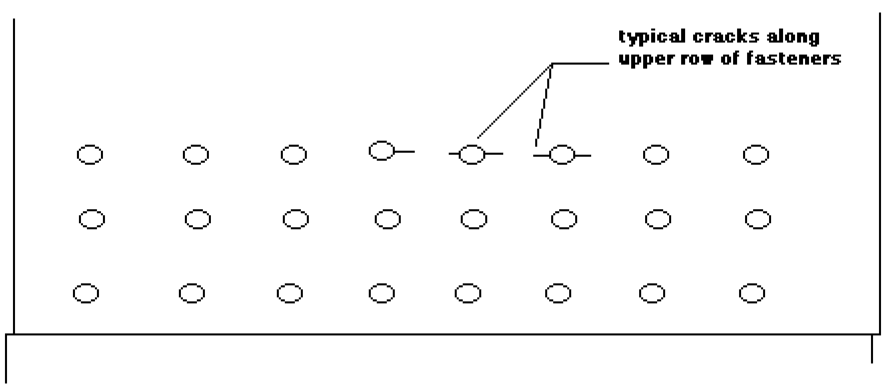

Figure 4 737 aircraft fuselage lap splice inspection.

Because of the potential for crack formation, there now is a mandatory eddy current inspection of the top row of fasteners in the 737 airplane. The required area covers 659 inches, or 55 feet, of lap. Being roughly one inch apart, there are 659 fasteners in each lap and four laps to be inspected.

The inspection is mandatory. However, there are various techniques for conducting an eddy current inspection. These include:

- Pencil probe/template
- Pencil probe/oversize template
- Rotating probe
- Sliding probe
- Freehand pencil probe

All of the above are variations on a theme. To illustrate their use, I will describe those frequently employed at this time.

Use of the pencil probe/template technique is shown in Figure 5. The inspector visually centers the template on the fasteners, then takes the pencil probe and scans the fastener looking for a telltale which of the needle on his eddy current display instrument. The inspector must center the template before he can move the pencil probe. While working, he holds the instrument in one hand, scans using the pencil probe with the other, and watches the meter. Since this must be done for every fastener, this can be a laborious inspection.

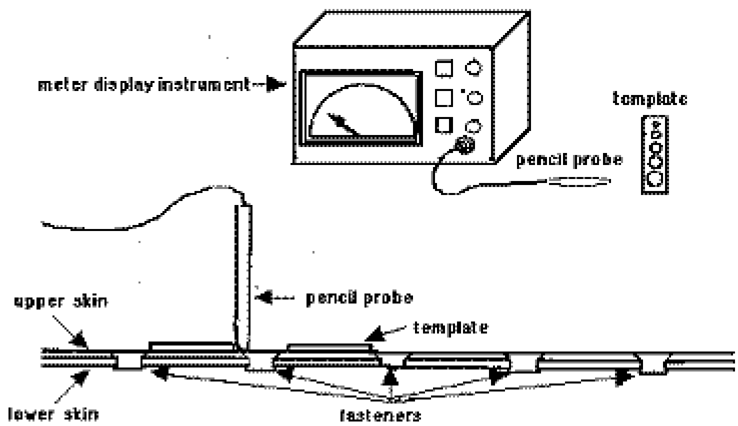

Figure 5 737 aircraft lap splice eddy current crack inspection using pencil probe/template techniques.

Figure 6 shows the key characteristics of the pencil probe/template technique. Detectable crack size is forty thousandths of an inch from the shank. Since 6 to 8 hours are required per lap, approximately 24 to 32 hours is required to do one airplane.

Detectable Crack Size	0.040 Inch From Shank
Estimated Inspection Time	6-8 Hours Per Lap
Required Equipment	Meter Display Instrument, Pencil Probe, and Circle Template
Inspection Advantages and Limitations	* Sensitive to Very Small Cracks -Permits Economic Rework * Very Tedious * Detects Cracks in All Directions

Figure 6 Inspection parameters for 737 aircraft eddy current crack inspections using pencil probe/template technique.

With use of an oversize template, as seen in Figure 7, inspection time can be reduced to 3 to 4 hours per lap. However, detectable crack size increases to 90 thousandths of an inch. So we have shortened the hours but reduced the sensitivity of the technique.

Detectable Crack Size	0.090 Inch From Shank
Estimated Inspection Time	3-4 Hours Per Lap
Required Equipment	Meter Display Instrument, Pencil Probe and Circle Template
Inspection Advantages and Limitations	* Detects Cracks in All Directions

Figure 7 Inspection parameters for 737 aircraft eddy current crack inspections using pencil probe/oversize template technique.

Figures 8, 9, 10, 11, 12, and 13 show the techniques and characteristics for the sliding probe, the rotating probe, and the freehand pencil probe systems. Note that inspection time can be reduced to one to two hours per lap with the freehand pencil probe system. However, detectable crack size is only two-tenths of an inch. A summary of characteristics for all of these eddy current crack inspection techniques is presented in Figure 14.

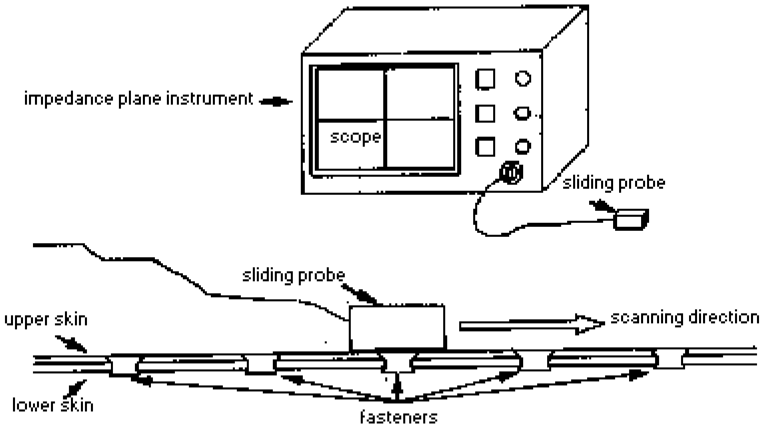

Figure 8 737 aircraft lap splice eddy current inspection using sliding probe technique.

Detectable Crack Size	0.090 Inch From Shank
Estimated Inspection Time	2-3 Hours Per Lap
Required Equipment	Impedance Plane Scope Instrument and Nortec SPO 3806 Sliding Probe
Inspection Advantages and Limitations	* Requires Only One Scanning Direction * Maximum Probe Off-Center +/- 0.050 Inch * Detects Cracks- 45 Degrees to + 45 Degrees From Fastener Line * Oversize Fasteners May Give Crack Indications

Figure 9 Inspection parameters for 737 aircraft eddy current crack inspections using Sliding Probe Technique.

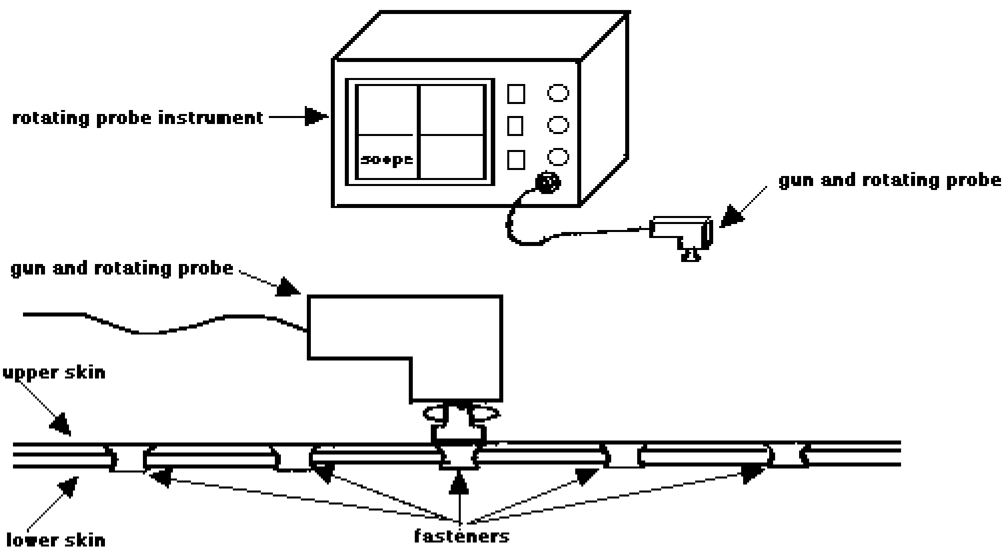

Figure 10 737 aircraft lap splice eddy current crack inspection using rotating probe technique

Detectable Crack Size	0.065 Inch From Shank
Estimated Inspection Time	2-3 Hours Per Lap
Required Equipment	Rotating Probe Instrument and Rotating Probe
Inspection Advantages and Limitations	* Detects Cracks in All Directions * Oversize Fasteners May Give Crack Indications

Figure 11 Inspection parameters for 737 aircraft eddy current crack inspections using rotating probe technique.

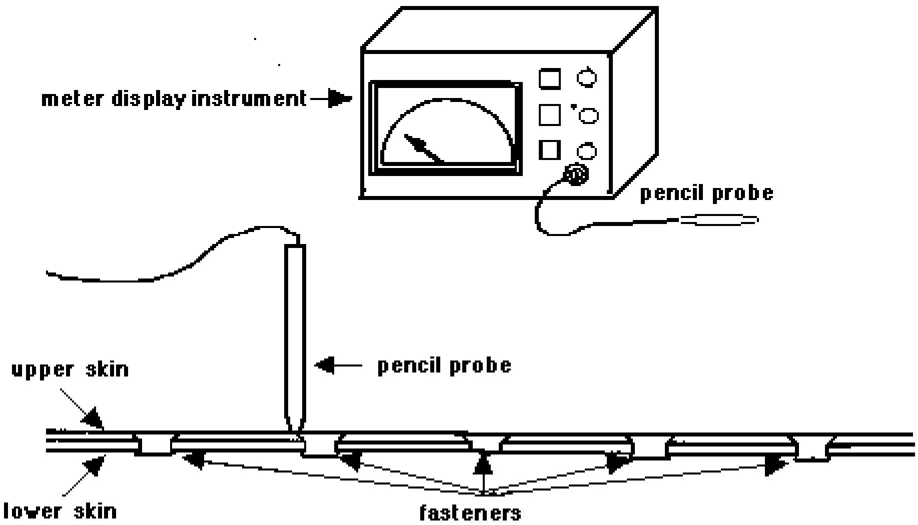

Figure 12 737 aircraft lap splice eddy current crack inspection using free-hand pencil probe technique.

Detectable Crack Size	0.20 Inch From Shank
Estimated Inspection Time	1-2 Hours Per Lap
Required Equipment	Meter Display Instrument and Pencil Probe
Inspection Advantages and Limitations	* Detects Cracks -45 Degrees to +45 Degrees From Fastener Line

Figure 13 Inspection parameters for 737 aircraft eddy current crack inspections using full-hand pencil probe technique.

Technique	Detectable Crack Size From Shank	Estimated Inspection Time	Equipment Required
Pencil Probe/Template	0.040 Inch	6-8 Hours Per Lap	Meter Display Instrument
Pencil Probe/Oversize Template	0.090 Inch	3-4 Hours Per Lap	Meter Display Instrument
Rotating Probe	0.065 Inch	2-3 Hours Per Lap	Rotating Probe Instrument
Sliding Probe	0.090 Inch	2-3 Hours Per Lap	Impedance Plane Instrument
Free-Hand Pencil Probe	0.200 Inch	1-2 Hours Per Lap	Meter Display Instrument

Figure 14 Summary of technique for 737 aircraft lap splice eddy current crack inspections.

There is a wide variety of excellent NDT equipment available "off the shelf" today. The NDT instrument manufacturers react rapidly to industry needs and are actively developing new equipment to support airframe manufacturers and the airlines.

In general, the advances in NDT technology and application of NDT procedures have exceeded the availability of qualified NDT personnel. Our biggest need is for skilled, trained, and experienced inspectors. The instrument manufacturers have outdistanced the supply of trained personnel to use these instruments. This is a problem we must address.

IMPROVED INFORMATION FOR MAINTENANCE PERSONNEL

Robert C. Johnson
Chief, Combat Logistics Branch
USAF Human Resources Laboratory

The Air Force has been working on the problem of providing proper technical information to maintenance personnel for many years. Our problem in this respect is not all that different from that of the commercial airlines. We both are concerned with the development of procedures and systems to support and enhance the performance of aircraft mechanics and inspectors.

A significant Air Force activity in this field began about 20 years ago with the Job Performance Aids (JPA) program. This program literally redefined the technical information that Air Force maintenance personnel used to repair airplanes. Before this, technical data were found in reading level, far above most of our mechanics' ability to read it. Related information was scattered throughout a volume and possibly throughout several volumes. A mechanic had to have many books in order to follow a procedure. Procedures themselves were not clearly identified. Illustrations supporting the procedure also were scattered throughout the books. Studies run to examine the performance of maintenance personnel at that time estimated that about one-third of a mechanics' total time was spent in finding the proper information. In all, there was ample justification to begin the JPA program.

Even as job performance aids come into increasing use, the amount of maintenance data necessary to support a given airplane continues to grow. The number of pages of technical order data required to support four Air Force aircraft over a forty-year period is shown in Figure 1. During this time span, the number of pages of maintenance documentation has doubled approximately seven times.

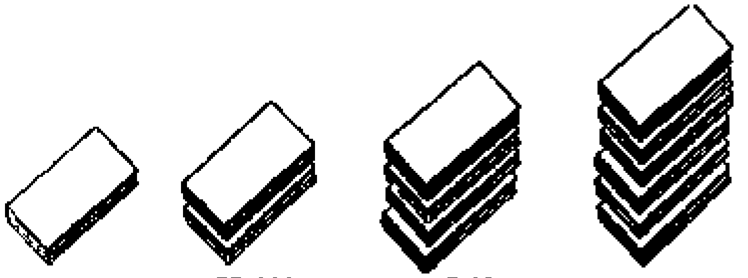

Figure 1 Pages of technical order data required for four Air Force aircraft

The voluminous maintenance documentation lends itself naturally to an automation process. Indeed, it is quite possible to automate technical data and print it out in stacks of IBM paper as one desires. While this would serve the purposes of automation, it would not serve the user's purpose of maintaining performance. For automation to be successful, it must be accomplished in a manner that supports user requirements.

Once the Air Force was committed to automation, the first step was to determine the requirements for technical information to support effective job performance. A number of guiding principles were followed in the approach to automation. First, as noted, the user;s requirements had to be kept in mind at all times during the design process. It was clear that we could not take existing technical data, process it through the computer, print it out, and expect improved performance. Second, the system should employ an effective technical order content/format approach to be consistent with existing systems. A radical departure form conventional documentation would not be effective. Third, usable controls and displays should be provided to the operator attempting to access the technical data and then employ it for his purposes. Finally, user acceptance was deemed to be critical. Even though all human factors issues might be addressed, user acceptance would not be guaranteed. User acceptance is a variable in itself.

In an automation program, there are three areas of primary concern. In the Air Force program, as seen in Figure 2, issues of computer-aided authoring of materials is primarily a contractor effort. Issues of automated publication and distribution are handled through the Air Force Logistics Command. The part of the effort I am concerned with, as conducted through the Human Resources Laboratory, concerns electronic delivery of maintenance information. This is delivery to the hands-on level, whether to support performance in maintenance conducted at the flight line.

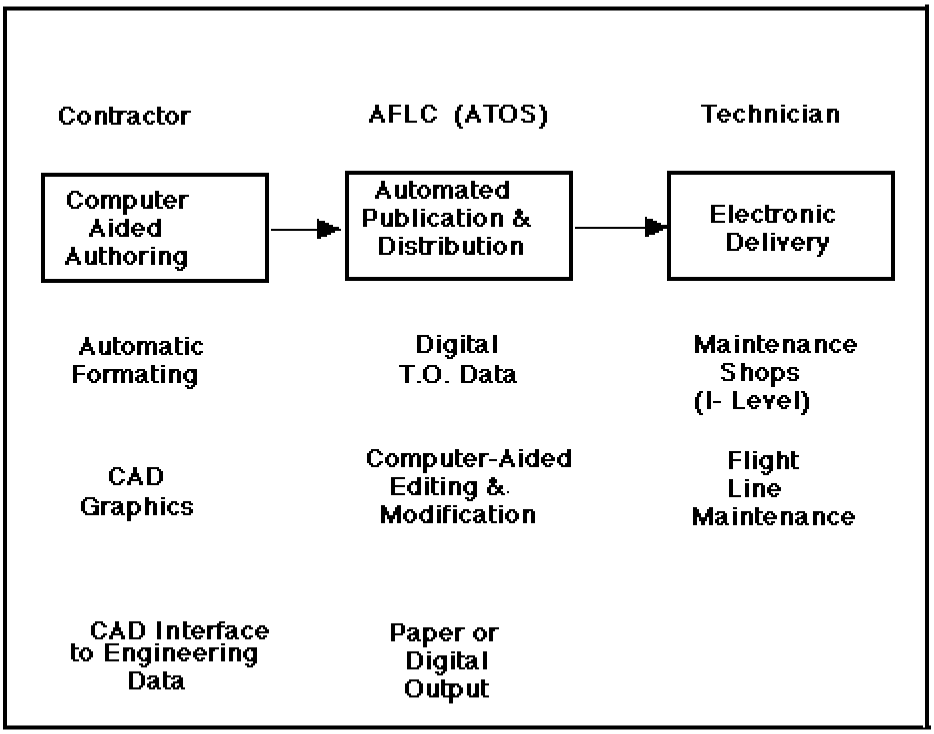

Figure 2 Areas of responsibility in Air Force integrated technical data system.

A major issue in the delivery of automated maintenance information is that such information precisely match the needs of the user. However, we in the Air Force, as do you in airline operations, have a range of experience in our mechanics and inspectors. On one hand, we have exceptionally experienced people who have performed certain tasks hundreds of times and do not actually need technical data at all, except that Air Force doctrine says that they will use it. On the other hand, we have new personnel who need step-by-step detail to support their performance. In our program, maintenance personnel are separated into three tracks according to their needs. Figure 3 illustrates the levels of detail provided through the automated maintenance program to support a technician operation in each of these three tracks.

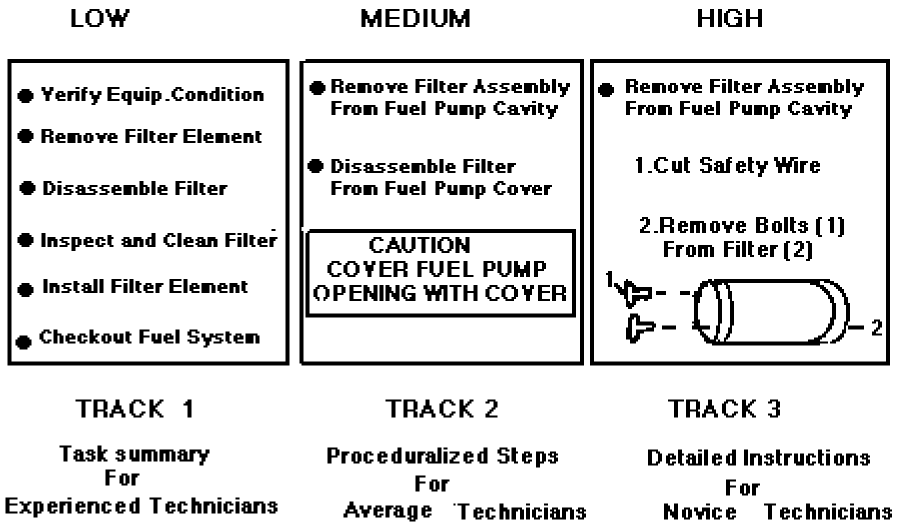

Figure 3 Different levels of detail in maintenance instruction to support technicians with different experience levels.

In 1979 I prepared a concept paper describing an Integrated Maintenance Information System (IMIS) which has subsequently turned into a major Air Force and DoD project. It was clear at that time that maintenance personnel needed more than simply the data describing disassembly and assembly of components. The needed technical information of many kinds: training data, management information data, built-in test data on the airplane, flight parameters, supply information, and possibly access to historical information. In the course of a day, a maintenance man might have to interact with virtually all of these data systems at least once and possibly more. In this case, the maintenance man would be dealing with five or six different systems with different protocols, different software, different displays, and possibly conflicting information. No one would provide him with precisely the information he needed.

The purpose of the Integrated Maintenance Information System was to provide one device that would allow a technician to interact with all data systems as if they were one. Software integration would be the key feature of the new IMIS system. At this time, we are well on our way to proving the IMIS concept and demonstrating the system in operation. The technical data to support IMIS are available. System components have been evaluated in three field tests using intermediate or shop-level automated technical data. Figure 4 shows the major topics of concern over the period from 1985 to 1991.

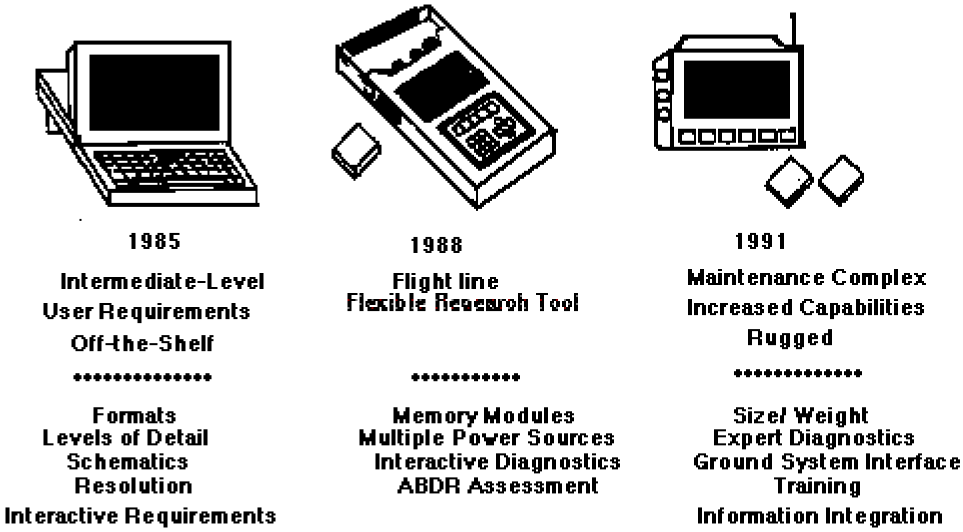

Figure 4 Three phases of the Air Force Integrated Maintenance Information System.

The principal end product of IMIS is a portable computer which will plug into the maintenance bus on one of our airplanes and download at the flight line the built-in test data necessary to troubleshoot the airplane. All automated systems on the airplane can be checked without climbing into the cockpit. Following this, the same portable computer plugs into a keyboard and turns into a maintenance workstation that allows the technician to interact with ground systems, with airborne systems, and with the range of data bases necessary to support his performance.

In February 1989, we plan to plug the portable IMIS computer into an F-16 aircraft and try the system on the flight line. We will have integration of step-by-step diagnostic procedures with supporting technical data, the two major elements of IMIS. All IMIS software will be integrated in late 1991, with the full IMIS system available in early 1992. Figure 5 illustrates the operation of the IMIS information network at that time.

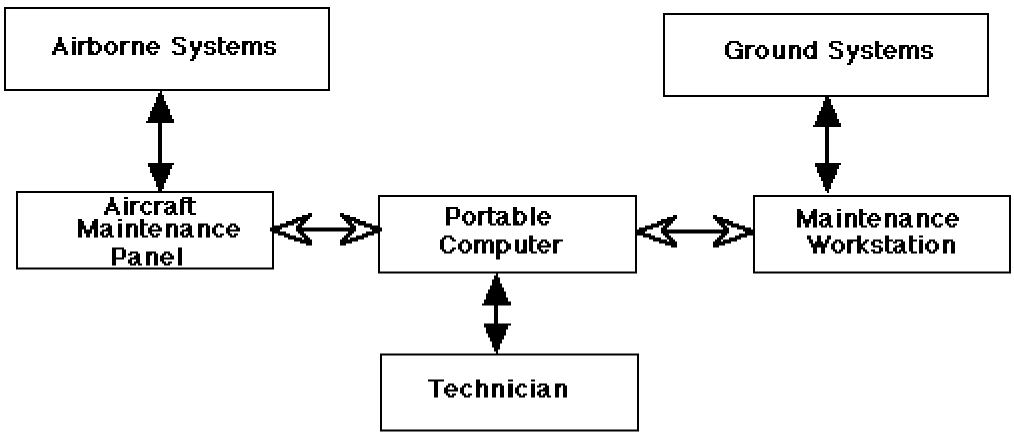

Figure 5 Operations of Integrated Maintenance Information System Network.

There remain a number of associated technologies requiring work by us to develop the IMIS system to its full potential. Some of these are (1) interactive diagnostic technology, (2) computer hardware technology, (3) data base development issues, and (4) problems of flight line operation. One of particular interest, however, is maintenance aiding technology, as shown in Table 1. For example, the size of the computer screen is a matter of genuine concern.

TABLE 1
EXAMPLE OF ONE TECHNOLOGY REQUIRING WORK TO SUPPORT DEVELOPMENT OF THE INTEGRATED MAINTENANCE INFORMATION SYSTEM

Maintenance Aiding Technology	Presenting Data on Small Screen
Content	
Formats	
Man/Machine Interaction Techniques	
Presenting Schematics	
Enhancing Performance	
Levels of detail	
Highlight signal flow, etc.	
Computations	
Field Test	

Much of our information is presented in the form of schematics which, to be readable, are physically larger than the screen. We are working intensively with the problem of small screen presentations but, although we have made progress, we do not have the necessary answers as yet. We also are continuing to work on problems of man-machine interaction, although we feel this is an advanced technology at this time. We still need to know, however, precise levels of detail to use for a technician at a given level of training performing a specific task. We also need to understand proper procedures to highlight signal flow through a schematic and it illustrate required computations. Finally, there is more work to be done on defining optimum procedures for field testing a system such as IMIS so that the test provides all information to support ongoing improvements.

While the Air Force has a specific military mission, its requirement for quality aircraft maintenance information that we have developed over the years can prove useful for the nation's civilian aviation industry, so much the better.

Strengths and Problems in Maintenance Training Programs

Richard Hlavenka
Division Chairman
Tarrant County Junior College

This presentation describes the manner in which training for aviation maintenance is being conducted in colleges at this time and the way we relate to the different segments of the aviation industry. I would also like to dispel certain misconceptions about our training programs. Finally, I would like to discuss some human factors pertaining to the scope of maintenance training today.

Perhaps the best way to introduce the topic of maintenance training is to describe briefly the program at Tarrant/Fort Worth Municipal Airport, some three miles from the main campus. The school operates on a semester system, with two semesters each year plus a single summer session. Students who enter our program fall into three basic groups. First, there are those who are studying to enter the field of aviation maintenance but who have no prior experience. These students typically have been out of high school from one to ten years. Second, we have those who already involved in aviation and are looking to upgrade their skills. In some cases, these are individuals who feel the airframe and power plant mechanics license will allow them to moave to a better position at their present employment. Finally, we have those individuals with unique reasons for being in the program. For example, some are professionals who own aircraft and want to understand their airplane better and possibly do some part of their own maintenance. Of these three groups, the largest number are those seriously interested in entering aviation maintenance as a profession.

Tarrant County Junior College is similar to the other 140 or so FAA approved and certified airframe and power plant mechanic program requires approximately two years to complete the core curriculum. During this time, a student becomes fully qualified to take the FAA examination. We also offer the student an option to continue into a two year Associate Degree program. Here we offer addition academic courses, usually in the areas of mathematics, science, and communications. Beginning this year, we will also include a cours in human relations and a course in speech. It is estimated that over 90 percent of those graduating from the core two-year program continue on and are awarded the Associated of Applied Science Degree.

For the past several years, the majority of our students ahve been employed by the major airlines immediately upon graduation. In the past two years, most have gone to work for American and Delta. We are proud of the fact that, for the first time in the Dallas/Fort Worth area, American Airlines has started hiring our graduates and putting them directly on the floor with other mechanics. Thus, while we recognize an ongoing need for certain improvements within the program, we do feel that this certainly illustrates our program's effectiveness.

Within Part 147, there is considerable flexibility as to the way in which a school can cover required topics. For example, we are still required to teach dope and fabric techniques, even though the number of fabric covered aircraft in the national inventory certainly is limited today. However, Part 147 does not specify whether this topic requires one hour or 500 hours of training. In our particular program, we offer 24 hours of dope and fabric procedures. In this time, we teach students of the need for the procedure, how it is performed, and problems incurred with it's use.

One problem we faced until recently concerned getting students into the program who were academically qualified. About four years ago, we were experiencing approzimately a 30 percent drop-out rate among students who entered the first semester of our aviation maintenance program. This caused us some concern, particularly since our enrollment is limited and we were having to turn away students each semester as we started that year's program. In order to improve this situation, we established academic entrance standards. All students now are required to take placement tests in mathematics, reading, and English prior to entering aviation maintenance training. We now have a drop-out rate of five percent or less in the first semester of our program.

Academic instruction is continued after the student enter his maintenance training. Mathematics is continued through basic trigonometric functions. Other courses emphasize writing and communication. Upon completion of the program, our average student probably is reading at the 14 year level. We consider this skill quite important since he is required to make logbook entries, to complete Form accurately the working in Airworthiness Directives.

Turning to the problems in aviation maintenance training today, we come back to Part 147. While I have previously identified it as a strength, it also had it's weaknesses. One problem that must be solved, and is currently being worked on, is that the document basically has not changed considerably during the last 20 years; Part 147 must reflect these changes. It is suggested that those of you with concerns about Part 147 make them known to the FAA as input to the study now in progress.

When changes are made to Part 147, consideration should be given to time requirements. At the moment, the FAA requiers that students ahve at least 1900 hours of training. Our program offers 1965 hours during an intensive two-year program in which students have a total of only six weeks of free time. If Part 147 is extended to require more hours, this automatically means that schools must extend their programs. I believe this will have an economic ripple effect al through the aviation industry. At the present time, for one price an employer can buy a product - an individual - with basic entry level skills and knowledge. This individual knows how to perform aircraft maintenance, how to interpret technical manuals, and how to work on his own. If his training is extended and his skills enhanced, however desirable these may be the price of the package may well increase. This in turn would impact aviation maintenance costs in areas where operators are looking at close profit margins.

One means of dealing with the above issue could be to develop certain post-graduate packages. These specialized programs could be added to the core program and be elective. This would be a way of dealing with topics such as helicopter maintenance and repair of advanced electronics systems.

Finally, there is another topic I offer for consideration. Table 1 shows a typical core curriculum for an aviation maintenance program. This is basically the FAA curriculum and I would like to point out one thing about it. There is nothing in it that relates to human factors or human relations. With this curriculum, we produce an individual who is strictly limited to the maintenance phase of aviation.

Table 1. Typical Core Curriculum for an Aviation Maintenance Program.

GENERAL AVIATION MAINTENANCE COURSES (17Hours)	
AER 1313	Background for Aircraft Science
AER 1323	Advanced Aircraft Science
AER 1344	Ground Operation and Servicing
AER 1364	Materials and Processes
AER 1383	Basic Electricity
AIRFRAME COURSES (29 Hours)	
AER 1333	Assembly and Rigging
AER 1335	Sheet Metal Structures
AER 1356	Airframe Electrical Systems
AER 1372	Aircraft Landing Gear Systems
AER 1374	Hydraulic, Pneumatic and Fuel Systems
AER 1392	Aircraft Covering and Finishing
AER 1402	Welding
AER 1403	Utility Systems
AER 1412	Airframe Inspection and Review
POWERPLANT COURSES (26 Hours)	
AER 2412	Turbine Engines
AER 2425	Powerplant Fuel Systems
AER 2434	Propellers
AER 2442	Powerplant Lubrication Systems
AER 2456	Reciprocating Engines Overhaul
AER 2465	Powerplant Electrical Systems
AER 2472	Powerplant Inspection and Review

It is my belief that the Part 147 core curriculum, and the profession in general, could be improved by adding some topics related to employee/employer relations. Areas of coverage could include professional ethics, professional communications, and personal commitment to one's job. I believe these to be areas that are vitally important to the aviaiton maintenance technician of the 1980's and 1990's.

In an expansion of Part 147, we could without great effort include newer areas of coverage such as topics concerned with "glass cockpit," etc.If we are going to do that, however, I still recommend that we include coverage of human relations topics as suggested. By doing this, we will produce a better and safer mechanic who will not only be a person who can do the job well, but also be a person who will understand the responsibilities that go along with that job.

The Human Operator as an Inspector: Aided and Unaided

Colin G. Drury, Ph.D.
Professor of Industrial Engineering
SUNY, Buffalo

The thrust of this presentation is toward human factors in inspection, a key element within the broader field of industrial maintenance. The objective is to point out human factors concerns in the inspection process and, in particular, to illustrate how the human inspector can be viewed as a quantitatively defined technical system.

The term "human factors" can be considered synonymous with "ergonomics," which has been defined as the science of "flitting the job to the person to enhance human efficiency and well-being." There are specific techniques to be used in fitting the job to the person. The first activity is a systems analysis in which the objective, or end product, of the system is clearly defined. The role of the human as one component within the system also is specified, to the extent feasible, at this point. Once the role of the human has been spelled out in general terms, a task analysis is conducted. This task analysis feeds back into system design in that hardware changes may be necessary at this point to begin to fit the job requirements to the human ergonomically. This same task analysis also becomes the basis for development of selection criteria and the establishment of a training program.

The human as a system component has specific capabilities and weaknesses. Humans are incredibly flexible and constitute possibly the best general purpose device ever built. Humans can do almost anything reasonably well. However, the error rate in human performance can be high. An individual asked to perform some critical task over and over and do it exactly right every time generally will be able to do so. We have exceeded his capability in terms of reliable performance. In human factors design terms, this means it is a mistake to design a system in which 100 percent reliability is required of the human operator.

To ensure proper system design, much specific information concerning human capabilities must be obtained. Some of this comes from the field of psychology, where considerable work has been done in defining human information processing capabilities. How are data obtained, interpreted, manipulated, and acted on? The field of anatomy provides information concerning body size, reach characteristics, and other anthropometric qualities. The field of physiology, finally, provides data concerning physiological limitations for energetic and sustained activities.

One characteristic of the human component which separates it from the machine is the manner in which it fails. When seriously overloaded, a machine component will tend to fail suddenly. It will simply break. On the other hand, humans exhibit what is called "graceful degradation" where they begin to disregard things considered less important and concentrate only on the central elements of the task. By so doing, a human can maintain a significant measure of system performance beyond the point where a totally machine system will fail. However, overall performance reliability will be impaired during this period.

Reliability of human performance is a key element to be addressed during a human factors analysis. A machine, when working perfectly, generally will exhibit reliability many times better than that of a human. The object, however, is to match the human and the machine components together so that overall system reliability can be improved over that achievable independently with either component.

Much of the study of human reliability in industrial settings has centered on the inspection process, whether simple unaided inspection or that in which various devices are used to "aid" the process. Inspection can be part of production, where it provides a quality control over the production process. It can also be part of maintenance, where it serve to guide attention to components in need of replacement or repair. In the aviation industry, inspection for maintenance is of greatest concern at this moment.

In the inspection process, where we are trying to detect something, there are two things that can go wrong. A Type 1 error occurs when a good item is identified incorrectly as faulty. This is the false alarm problem, or the false replacement of a part. A Type 2 error occurs when a faulty item is missed. A Type 1 error is costly because it results in an unnecessary economic burden. A Type 2 error generally is of greater concern since it can lead to more serious trouble later as a result of the faulty part.

In aviation, the problem is one of trying to detect a fault at an early stage rather than simply trying to detect one. However, the earlier we try to detect a fault, the more the fault looks like a fault-free item. In other words, the signal/noise ratio it very low, making detection much more difficult. Under these circumstances, we can define the percentage of Type 1 errors (E1) and Type 2 errors (E2). Performance then can be specified in terms of E1 and E2 plus "T," which is the time to do the job. An assessment of job performance then becomes a matter of examining the relationship between these three quantities.

Table 1 presents a model used in the study of industrial inspection. It is called a first-fault inspection model. While not entirely relevant to aviation inspections, it does illustrate the logic of the inspection process.

TABLE 1
PRINCIPAL STEPS IN FIRST-FAULT INSPECTION MODEL DEVELOPED FOR INDUSTRIAL INSPECTION

1. Present pre-selected items for inspection
2. Search each item to locate possible faults ("flaws")
3. Decide whether each flaw is sufficiently bad to be classified as a fault
4. Take the appropriate action of acceptance or rejecion

In the fault inspection process, an item is presented to an inspector who fixates some small area, either with direct vision or with some tool, and decides whether a flaw is present. Then, as shown in step 3, the inspector decides whether the flaw is sufficiently bed to be classified as a fault. Finally, he recommends the appropriate action of acceptance or rejection. Figure 1 shows the logic of inspection in flow chart forms.

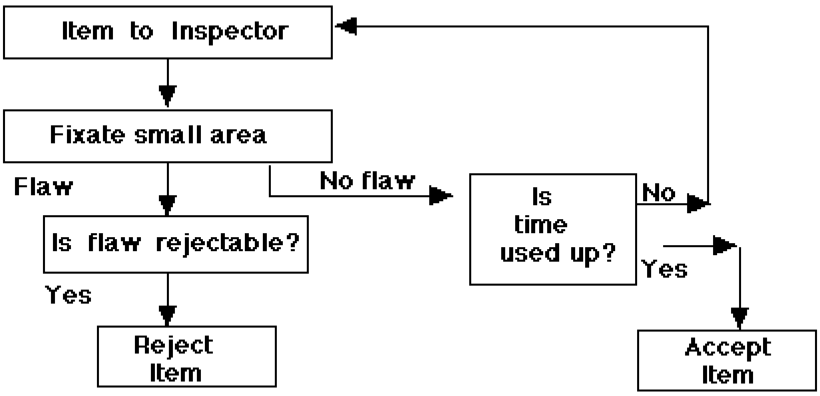

Figure 1 Flow Chart depicting the process of inspection.

The fault inspection model of Figure 1 can lead to interesting conclusions concerning the inspection process. First, to commit a Type 1 error, the rejection of a good item, one must make two errors. The inspector first must find a flaw that is not actually severe enough for rejection and then must make an incorrect fault classification decision.

To make a Type 2 error, acceptance of a faulty item, the inspector can make either one of two errors in parallel. The inspector can either fail to find the flaw or he can find it and make the wrong classification decision. Thus, everything else being equal, one would expect many more Type 2 errors (defects being accepted) than Type 1 errors (good items being rejected). So immediately we do not expect E1 and E2 probabilities to be equal.

Of the four tasks presented in Table 1, the first and last are relatively reliable operations. If the system is designed well, these two should not represent a problem. The other two, the search and the decision-making phases of inspection, are points where there is a high chance for human error. Therefore, attention will be centered on these phases.

The search phase of visual inspection can be influenced by several factors. For example, Figure 2 shows the reduction in visual performance during a test in which a known flaw was presented at different eccentricities, or angle from the line of central vision. Results show a steady decrease in search effectiveness as the flaw is moved away from direct vision. At 20 degrees off axis, subjects could identify a defect with a 10-minute visual angle size. At 40 degrees off-axis, the detectable size increased to 20 minutes. While this is for one type of target, comparable results can be found for other sizes and for different conditions of illumination. The important point is to recognize that any detection task which requires peripheral vision will be less efficient than one relying completely on central vision.

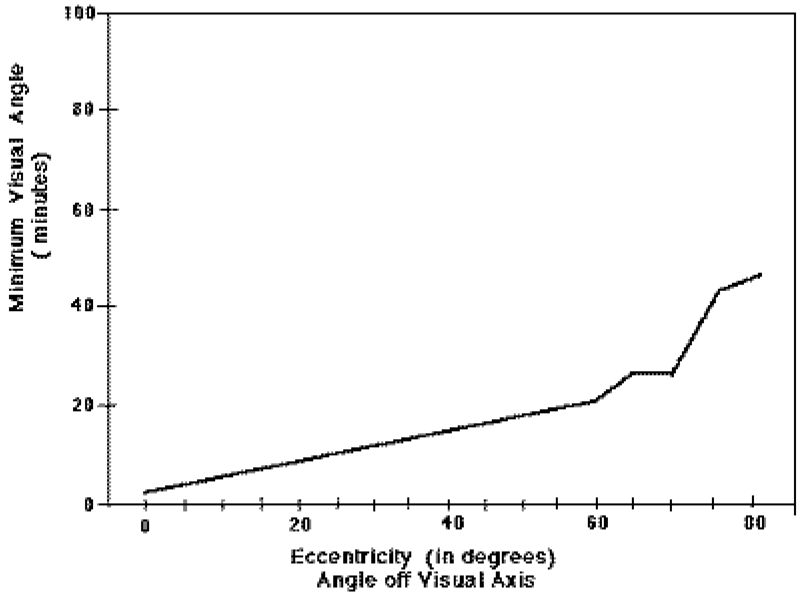

Figure 2 Decrease in visual acuity as target is moved from line of direct vision.

In studying visual detection, a human factors engineer is concerned with visual lobe, that is, the area around the line of sight within which a fault can be detected. Factors affecting lobe size include the size of the target, or fault; the amount of light placed on the target, and in turn the eye; and the contrast between the target and it's background. All of these variables may be manipulated in an effort to increase the visual lobe size and hence either reduce the time required to do the job or reduce the errors made during job performance.

Another factor with a dramatic effect on visual search performance is search time, as shown in Figure 3. These results show that, when a difficult-to-detect target is used, a search time of two seconds will result in only 20 percent of the faults being identified. If the search time is increased to six seconds, 80 percent of the faults can be found. This is a direct speed/accuracy tradeoff curve. When longer search time is allowed, more faults will be identified. Note also in Figure 3 that making the fault easier to detect (larger visual lobe size) gives 100 percent detection at two seconds per item.

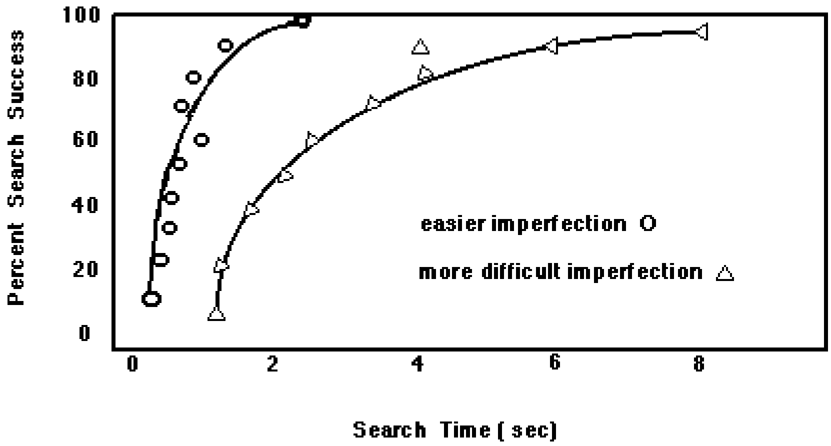

Figure 3 Cumulative probability of detecting two different imperfections.

An examination of the decision-making task also reveals some interesting features. Here there are two aspects of performance, as noted earlier. Figure 4 plots these two aspects, i.e., the percentage of faulty items being rejected (100-E2); the percentage of good items being accepted (100-E1). In Figure 4, perfect performance is represented in the top left corner. At this point, 100 percent of good items are accepted and 100 percent of faulty items are rejected, the ultimate goal of the inspection process. Figure 4 shows the results taken from seven inspectors in an industrial operation. The data point at the bottom shows an inspector who is accepting over 90 percent of the good items but is finding only 25 percent of the faults. On the other hand, the inspector at the top is finding 80 percent of the defects but, unfortunately, is rejecting almost 50 percent of the good items.

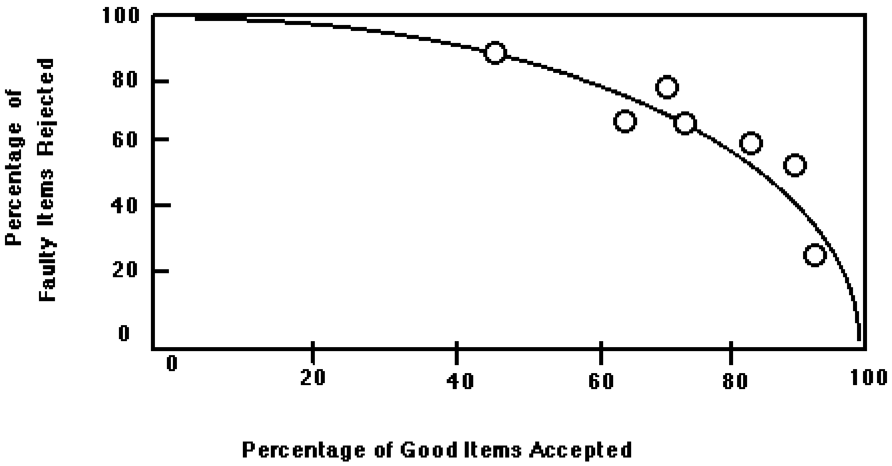

Figure 4 Performance of seven inspectors in an industrial operation.

The results in Figure 4 tell us something about the decision criteria used by inspectors. The individual at the bottom is using a criterion which says "Unless something is really bad, I'm not going to report it." The person at the top, on the other hand, is using a criterion which says "I am going to report the slightest flaw I can see." Neither criterion is acceptable. Improved training for on-line inspectors is required.

Improved training is only one requirement dictated by Figure 4. The real need is to move all points on the curve toward the upper left corner. Use of signal-detection theory is of value in deciding how to proceed. Basically, this tells us that the signal-to-noise ratio must be increased. What makes the curve so bad is that there is considerable noise mixed with the signals. Achieving an increase in signal to noise can be a difficult matter, but there are many ways one can make improvements in that direction.

Signal detection theory tells us that detection criteria can be expressed mathematically, to show that two factors influence the inspector's choice of criterion. One is related to the prior probability of a signal being a real signal. The more a person expects to see a signal, the more likely he is to call any aberration a signal. So, as the probability of a signal increases, inspectors modify their criteria. Secondly, the inspector's perceived costs of error and rewards for good performance affect the criteria. As the costs and payoffs balance towards either acceptance or rejection, inspectors modify their criteria appropriately.

A major concern in maintenance inspection is the time pressure. Figure 5 illustrates the effect on inspection performance of increasing inspection time. Here, inspection time was increased by a factor of one, two, and three times the normal. With this increase, the probability of rejecting a faulty item increases. More and more faults are found. Not all are found because the line does not level at 100 percent. It's final level depends on the decision performance. At this point all search is complete and the inspector is now into decision, so that the curve is decision limited. On the left side of the curve, the search has not been completed, so it is search limited.

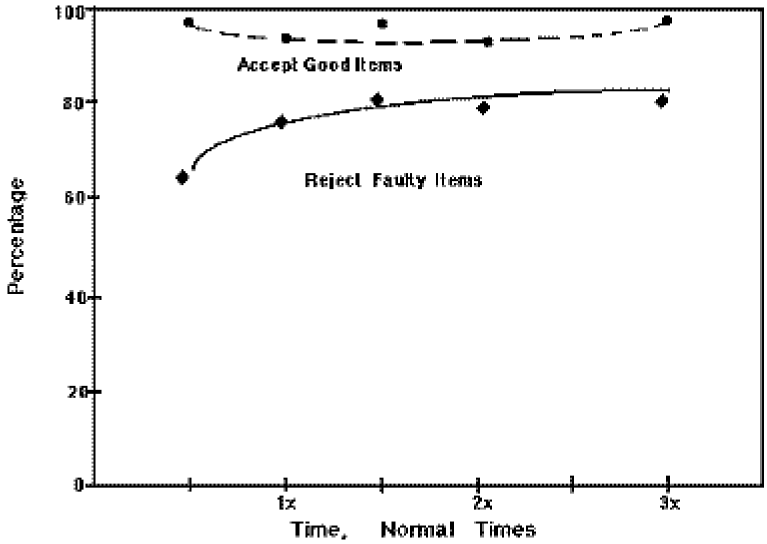

Figure 5 Effect on inspection performance of increasing inspection time.

The upper curve of Figure 5, the probability of accepting a good item, shows a marginal decrease in performance with increased time. This simply means that as individuals are given more time to search, they are more likely to be successful in finding something, whether a real fault or not a real fault. More false alarms are produced with excessive search time.

The above data illustrate some features of inspection theory. Search theory and signal detection theory together offer guidance concerning ways to improve the inspection process. A number have been mentioned. Target/background contrast can be increased. Search time can be adjusted optimally. Operators can be trained to use appropriate search criteria. Defect size, unfortunately, is a variable not subject to manipulation, although the size of an acceptable defect can be varied.

Another feature which can be varied is the feedback given an inspector concerning his success. Figure 6 shows performance on a task where, as marked, a change in feedback to inspectors was made. They were simply provided more rapid feedback to inspectors was made. They were simply provided more rapid feedback to inspectors was made. They were simply provided more rapid feedback as to how well they were doing. This made a significant change in their discrimination of flaws and effectively halved the number of errors. For a given false alarm rate, it halved the number of misses. For a given miss rate, it halved the false alarm rate. Their performance was essentially doubled by providing more rapidly. This makes sense when one realizes that without rapid feedback, the inspection loop is open for longer periods of time and increased errors can occur without the inspector being aware of them.

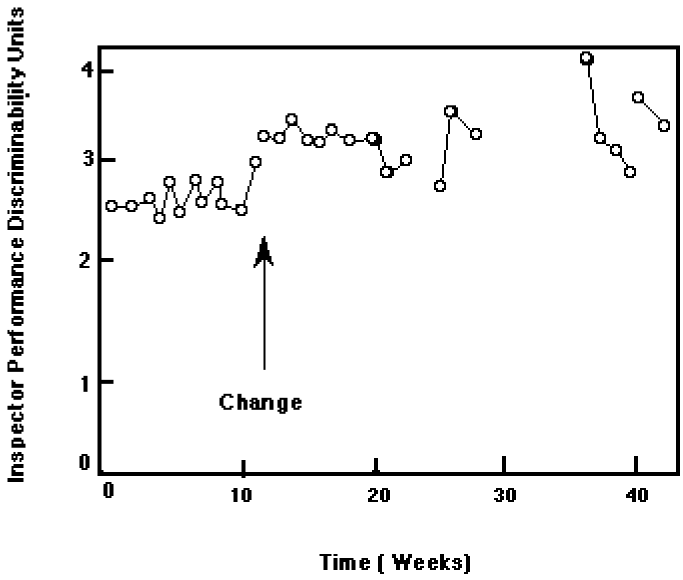

Figure 6 Effect of providing more rapid feedback on inspector performance.

In summary, human factors has grown into a scientific discipline in which the role of the human operator in an industrial system can be examined in terms of well-developed models and mathematical relationships. Improvements in aircraft maintenance and inspection can be achieved with proper application of tested human factors procedures for performance enhancement.

VIGILANCE AND INSPECTION PERFORMANCE

Earl L. Wiener, Ph.D.
Professor, Department of Management Science and Industrial Engineering
University of Miami

Vigilant behavior initially was studied as a problem in it's own right. In time, however, a bridge was made between the world of vigilant behavior and that of inspection performance. Certainly, what we have learned through the years about human vigilance will be of value as we consider problems in the inspection of systems and materials.

Vigilance research shows the human to be a poor monitor. Yet this same research illustrates opportunities for management intervention to improve vigilance. Human factors engineers can contribute to this improvement through their understanding of vigilance and it's relation to inspection.

The routes of formal vigilance research can be traced to wartime experiences during World War II. AT that time, the British Coastal Command was flying long anti-submarine patrols over the Bay of Biscay, searching by radar for surfaced German submarines. These missions were long, lasting for over 10 hours. During these missions, a navigator or a pilot on occasion would walk past the radar operator's position, look at the radarscope, and reach over the operator's shoulder to say, "Hey, there's one right there." The person least qualified to detect radar targets, who happened to be just passing by, spotted radar signals that had not been seen by the radar operator.

Problems of radar detection became so severe that a laboratory investigation was begun at the Medical Research Council under Dr. Norman Mackworth. These studies demonstrated that the longer operators were on patrol, the less likely it was that they could detect a submarine. This was one of the first finding of vigilance research.

Vigilance refers to the likelihood that a human will respond to a signal, so vigilance can be defined operationally in terms of probability. Vigilance differs from an inspection task in that it is event driven; the signal occurs in real time in the real world. You either see the submarine now or it is gone. With inspection, you frequently have an opportunity to go over the inspection a second time.

Another characteristic of a vigilance task is that the signal is subtle; it is hard to detect. Another way of saying this is that the signal-to-noise ratio is low. Also, there generally is a low signal rate. Targets do not appear frequently. Finally, there is temporal uncertainty. This, of course, makes the task unpredictable. We do not know if a signal will appear in so many seconds or in so many minutes.

There is a short test which can be used to demonstrate some of the issues in vigilance. Done properly, the following sentence is projected on a screen for 15 seconds:

FINISHED FILES ARE THE RESULT OF YEARS OF SCIENTIFIC STUDY COMBINED WITH THE EXPERIENCE OF MANY YEARS

Subjects are asked, during their 15 seconds of viewing, to count the number of times the letter "F" appears. In any group, most people will guess three. Others will guess four or five. Very few will answer with the correct number, which is six.

The above test shows that the human is not a good inspector. The problem here is a basic one in cognitive psychology. Apparently, since humans pronounce "OF" as "OV," the "F" is frequently missed. The humans serves as an information processor and, in this case, tends to distort the information. In any event, the monitoring and inspection process certainly is subject to error.

Vigilance performance inevitably shows a decrement through time. In one study involving a 48-minute vigil, probability of detection dropped from just below 80 percent in the initial sages to approximately 60 percent at the conclusion. This illustrates the rather dramatic decrease in performance effectiveness that can occur for a pure vigilance task.

The same study measured performance of subjects on two consecutive days. No significant difference was found. There was no evidence of a practice effect on the vigilance task. This is not to say that subjects cannot be trained for vigilance, but practice alone is not sufficient. In other studies, subjects have been run for many days and, as here, no practice effect has been found.

Another feature of vigilant performance concerns the signal/rate effect. In another study, again conducted for 48 minutes, subjects saw either 16,32, or 48 signals occur during that period. There was a dramatic increase in the rate of detection of these events as a function of whether 16, 32, or 48 signal events were produced during the test period. The more frequently a signal occurs, the higher the probability of detection for any given signal. If you have low probability of the appearance of a signal event, then you will have low probability of detecting that event when it does occur. This clearly has implications for aircraft inspection. Rare faults will be most difficult to detect.

All of the above factors can operate to produce vigilance decrement. The dynamics of vigilance, and vigilance decrement, can be illustrated by an experiment in which adaptive training was used. As a subject's performance improved, the task was made more difficult in proportion. As performance then decreased, the task was made easier. The object's was to produce a constant level of performance. In this study, by continuing to adjust task difficulty, an essentially constant target detection rate of 75 percent was achieved. In terms of aircraft maintenance, this means that if you want a constant detection rate in an inspection task, over a period of time the flaws would have to become larger and larger to be detected at a constant rate.

Figure 1 shows some of the forces impinging on the human inspector which might be viewed as opportunities for management intervention in any program to increase detection probabilities. At the top we see a block containing specifications, photographs, standards, training, and past experience of the operator. These are the variables which directly affect the judgement of the inspector. When an inspector looks at a rivet on an airplane or a pattern appearing on an eddy current scope, he is comparing what he sees to a stored experience. Experience and training can be manipulated to improve performance.

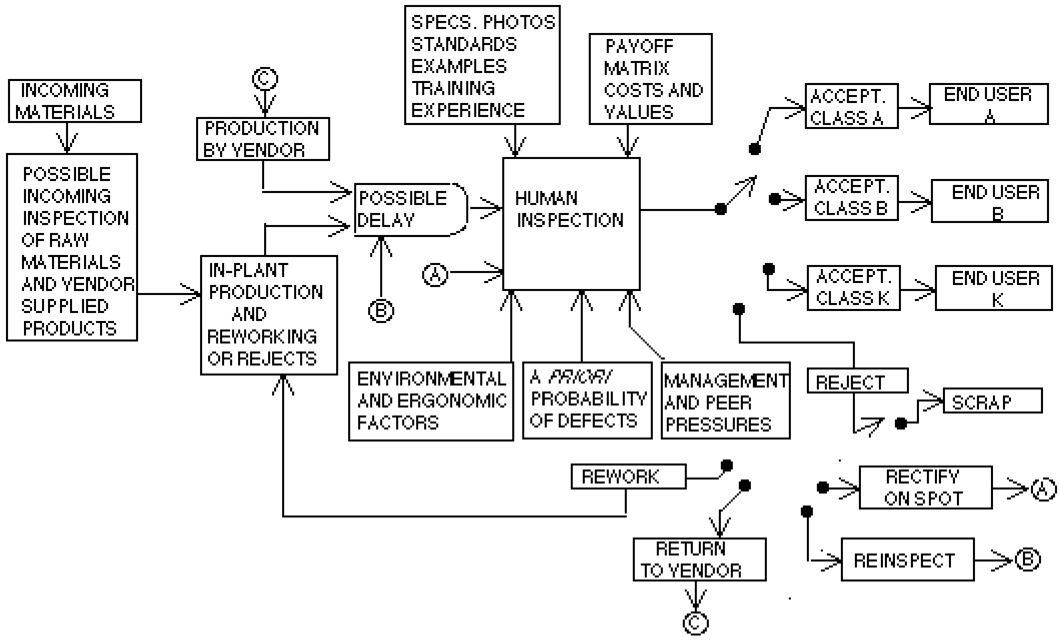

Figure 1 Production, inspection and disposition of items with K acceptance categories (classifications) and one rejection category. Upon rejection, numerous courses of action are available. (From Weiner, 1984).

In studying inspection performance, the consequences, or payoffs, of inspection decisions should be considered. Figure 2 shows the case in which inspection decisions can be classified in a 2x2 matrix. While some industrial processes call for a 2xn matrix, the 2x2 appears most appropriate for aviation inspection. In Figure 2, there are only two classes in which each event can be categorized. There also are only two response opportunities on the part of an inspector. He can either accept or reject an item. If he accepts an effective item, he has made a correct decision. Likewise, if rejects a defective item, he is correct.

	State of Product	
Inspector Decision	Effective	Defective
Accept	Correct	Type 2 Error Omissive Error
Reject	Type 1 Error Commissive Error	Correct

Figure 2 Categorization of inspector decisions

Now let us examine the incorrect decisions, as shown in Figure 2. These are the Type 1 and Type 2 errors mentioned in Dr. Drury's paper. If the product is effective and the decision is made to reject, the inspector has made a Type 1 error - a commissive error. This has a value or cost, here referred to as VRE - the value of rejecting an effective product. In aviation, these are the unnecessary removals of aircraft parts or unnecessary redrilling of rivets.

If the item is defective, and the inspector fails to detect it, he has made a Type 2 error - an omissive error. This also has an attached cost or value. In aviation, these are the errors of considerable consequence. This is where a defective part goes undetected and remains in the aircraft. The ultimate consequences can be quite costly.

In one instance, a company producing a medical product considered the cost of Type 2 errors (missing a defective product) to be so high that the inspection process was adjusted to make such an error almost impossible. However, the adjustment greatly increased Type 1 errors. They now are rejecting 50 percent of all products. One-half of everything manufactured is thrown away prior to use. For them, this cost tradeoff appears appropriate.

In another study of inspector performance, more rational results were obtained. In this study, 39 inspectors each examined 1,000 solder connections into which 20 defects had been inserted. There were thus a total of 39,000 inspections conducted. Table 1 shows that of the 780 defective parts, 646 were correctly rejected. On this basis, the success rate was 83 percent. For the 38,220 effective components, 25 were falsely rejected. We see the probability of false rejection to be less than one in one-thousand. This is excellent inspection performance.

TABLE 1
RESULTS OF AN INSPECTION OF 39,000 PARTS SHOWING TYPE 1 AND TYPE 2 ERRORS

Inspector's Action	Defective	Effective	Total
Accept	134 (Type 2)	38,195	38,329
Reject	646	25 (Type 1)	671
Total	780	38,220	39,000

Data from Jacobson (1952)

In summary, what is known about human vigilance? Man is a poor monitor. Where vigilance is required over time, a vigilance decrement is almost inevitable. Man starts off as an imperfect monitor and the situation only gets worse.

There is a signal rate effect on vigilance. If the rate of appearance of a signal is low, the probability of detecting it is lowered. In aviation this means that the higher the quality of the product, the owner the signal event rate, and therefore the lower the probability of detection of a fault.

Selection of individuals to perform monitoring tasks does not work well. Selection by categories particularly is ineffective. Men versus women or old versus young are not good variables in determining who makes a good inspector.

Training, if well structured, can make a difference in vigilance performance. Practice alone, however, is not effective. The practice must take place within a well defined training effort.

Finally, let me review briefly the available intervention strategies and indicate for each what I consider the probability of producing improvement with that strategy. These are:

> Job Redesign = High. Here we can consider such matters as conspicuity of the signal; increasing the signal-to-noise ratio, if possible; length of inspection periods; social atmosphere and the general work environment; and feed-forward and feed-back mechanisms which are providing information to the inspector both before and after performance.
>
> Training = High. Any improvements which can be introduced for the workforce or for the promise of performance benefits.
>
> Selection = Poor. There is little probability of significant payoff here.

In all of the above, there is of course no magic solution. No single step will result in a dramatic improvement in vigilance or maintenance performance. However, appropriate application of known human factors principles, with continuing review of the problems encountered, should result in a steady and definable improvement.

References

Jacobson, H.J. A study of inspector accuracy. Industrial Quality Control, 1952, 9, 16-25.

Weiner, E.L. Vigilance and inspection. In J.S. Warm (Ed), Sustained attention in human performance. New York: John Wiley & Sons Ltd., 1984.

Human Performance Issues in Nondestructive Testing

Douglas H. Harris, Ph. D.
Chairman
Anacapa Sciences, Inc.

Human performance plays a vital role in all inspection and tests. In some cases such as visual inspections, the importance of human performance is obvious. But even when technically sophisticated equipment is employed, the outcome is highly dependent on human control actions, observations, analyses, and interpretations. The primary consequences of inadequate performance are missed defects and false reports; and the costs that accompany these errors.

Human-Performance Framework

A variety of techniques are available for the inspection of aircraft engine and airframe structures. Visual, eddy-current, ultrasonic, radiographic, magnetic particle, and penetrate testing methods are used (Hagemaier, 1988). However, the types of human actions and the sequence in which these actions are performed are comparable among these various techniques. The typical sequence of actions is shown in Figure 1.

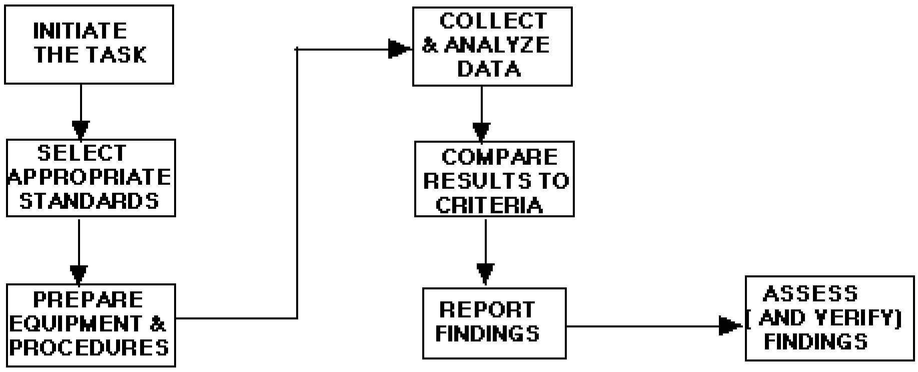

Figure 1 Types of actions and typical action sequence for inspections and tests.

The model illustrated in Figure 2 shows the relationships that exist among the various factors that con influence human performance in conducting any task or action required for the successful completion of an inspection or test. As shown, any action will always require the input of information through one or more sensory channel (visual, auditory, tactile, etc.) to produce a required outcome. Poor performance often occurs with tasks that do not provide an adequate match between information input and action output. For example, information that is incomplete, not timely, ambiguous, or irrelevant will lead to incorrect or delayed actions. Information presented in a form not compatible with the mode of the action can also lead to inadequate performance.

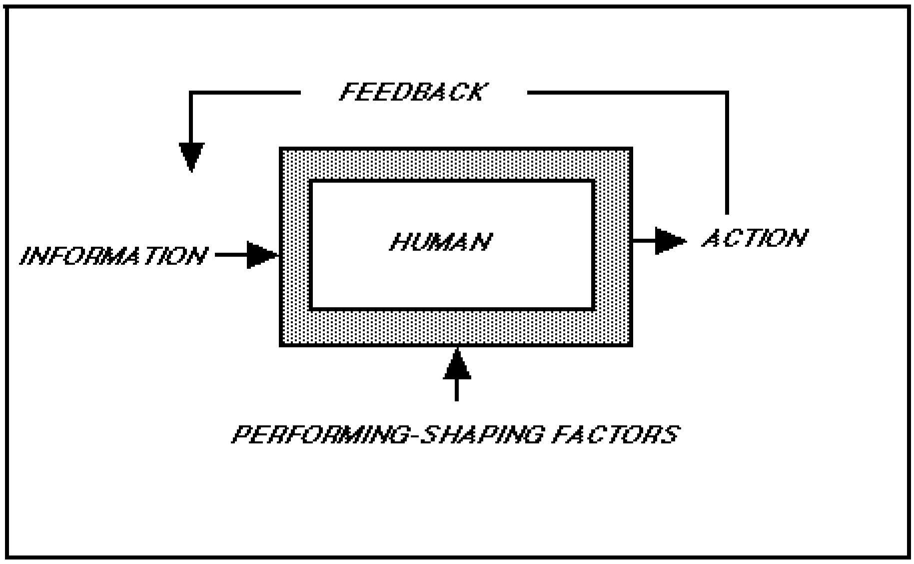

Figure 2 Model of human performance.

To attain and maintain satisfactory levels of performance, feedback is needed on the outcomes of actions taken. Feedback must be complete, relevant, and timely to be effective. However, feedback requirements are highly dependent on the nature of the task or action. For example, feedback of the result of pressing a button during the calibration of an ultrasonic tester must be nearly instantaneous and must be provided each time the button is pressed. On the other hand, feedback on the accuracy of flaw characterization might be effective even if delayed in time and not provided after each characterization.

The information-action-feedback loop is dictated by the design of the equipment and procedures employed in the inspection or test. Consequently, improvement of human performance by addressing inadequacies in this loop must necessarily lead to design changes in equipment and procedures.

The final category illustrated in Figure 2, performance-shaping factors, are those influences that are outside the information-action-feedback loop of the task. They include the following:

- Environmental conditions
- Communications
- Time effects (vigilance, fatigue, stress)
- Organizational structure and support
- Knowledge and skills
- Personal work habits and attitudes

The actions shown in Figure 1 can be combined in a matrix with the human-performance factors shown in Figure 2 to provide a framework for addressing human performance issues in inspection and testing. The resulting framework, provided in Figure 3, suggests that each of four types of performance factors can be examined for each of the seven inspection or test actions.

PERFORMANCE FACTORS	INSPECTION AND TEST ACTIONS						
	INITIATE	SELECT STDS	PREPARE	COLLECT	COMPARE	REPORT	ASSESS/VERIFY
INFORMATION INPUT							
ACTION OUTPUT							
FEEDBACK							
PERFORMANCE- SHAPING							

Figure 3 Framework of human-performance issues in inspection and testing.

Human Performance Issues in Eddy-Current and Ultrasonic Testing

Human performance issues in eddy-current and ultrasonic testing were studies recently with the framework described above (Harris, 1988). The context of the study was eddy-current and ultrasonic examination of the structural integrity of nuclear power plant components. The inspection technologies examined were similar to those employed in inspections of aircraft structures. Information was obtained from the following types of sources:

- Industry procedural reference documents
- Training materials - coursebooks, guides, worksheets
- Research reports and related documents
- Interviews with subject-matter experts and job incumbents
- First-hand observations of task performance.

The study identified numerous human-performance issues in eddy-current and ultrasonic testing, and produced the following nine recommendations for improving human performance on these types of tests.

Develop Guidelines for Operator-Control Interface Design

In the design of new eddy-current and ultrasonic inspection systems, the application of human-factors principles and techniques has not kept pace with the introduction of new technology. New, computer-based inspection and testing systems are cumbersome to set up and operate, require excessive manipulation to get the job done, require control actions not logically organized, and rely excessively on human short-term memory. Because a large body of human-factors information now exists to guide the design of human-computer systems, a handbook of selected information should be developed to guide designers of inspection systems. The handbook would contain human-factors principles, data, and techniques specifically applicable to the design of the operator-system control interface for computer-based inspection and testing systems. Application of the handbook could help produce more effective future systems, reducing the time and expense required for performance of inspection tasks.

Analyze Eddy-Current Performance Data

Little information has been generated, to date, on eddy-current testing performance from systematic studies capable of producing scientifically valid, statistically significant results. Consequently, research is needed to answer some very fundamental questions such as the following: For each of the various damage mechanisms encountered, what are the expected rates of alternative inspection outcomes - correct calls, false calls, and missed detections? How is each inspection outcome for each damage mechanism influenced by structure type, geometry, location, and extraneous variables? What is the relative reliability of different cues used for detection and characterization of different types of flaws? Answers to the question posed can point to the specific aspects of eddy-current testing where improvements in system design, inspection strategies and procedures, analyst training and qualification, and inspection organization are likely to have the greatest payoff.

Assess Eddy-Current Information-Integration and Signal Interpretation Strategies

Eddy-current testing requires the analyst to integrate a substantial amount of information to provide the context for signal pattern recognition and interpretation. What is the most effective way to organize and integrate relevant information in support of signal interpretation? What data integration and signal interpretation procedures are most amenable to computer aiding? Alternative data-integration and pattern-recognition strategies and methods should be developed and experimentally evaluated. Alternatives would incorporate applicable human-factors principles (from previous related research) as well as techniques found to be employed by successful inspectors. The research results would identify and define any significant differences among alternative strategies and methods of information integration and signal interpretation, generate the basis for guidelines for more effective eddy-current inspection strategies and methods, and provide criteria for the design of future eddy-current testing systems.

Develop More Effective Eddy-Current Display Designs

The principal displays employed for eddy-current flaw detection and characterization are variations of meter, oscilloscope, and strip-chart type displays. These displays originated with, and have been little changed since, the initial use of analog systems. The geometric forms (signals) presented on these displays typically do not relate directly to the physical characteristics of what is being inspected, but rather to the characteristics of an induced electric current. Therefore, the information contained in the displayed signals must be mentally transformed by the analyst for purposes of flaw detection and characterization. Such mental transformations are likely sources of inspection errors because they add complexity and ambiguity to the task. They also consume valuable inspection time and effort. The availability of digital signal processing and display technology now provides the opportunity to explore display formats other than those previously dictated by analog technology. Displays that are more representative and directly-interpretable could increase the accuracy of inspections and reduce inspection cost. Costs could be reduced by minimizing inspection time and, with increased accuracy, by reducing the need for redundant inspections and the time required for the resolution of conflicting results.

Research Automatic Eddy-Current Signal Screening and Analysis

Recently, systems have been developed and employed for the automatic screening of eddy-current data by means of computers equipped with detection-rule based programs. The systems are designed to screen the data for signals of potential flows which are, then, analyzed by an experienced analyst. Research and development work is also being conducted on computer-based systems designed to both detect and characterize flaws. Automatic screening and analysis raise some sensitive human-factors issues: What guideline and techniques are required to assure that the screening criteria selected will produce the desired results? What is the most effective form of interaction among analyst and stem? What steps will be required to gain acceptance for the system, among those who have the ultimate decision-making authority for structural integrity? A human-factors study effort should address the above questions in parallel and in close coordination with system research and development efforts. The effort would be mainly analytical, reviewing and applying appropriate data and principles to answer the issues raised. The answers obtained would help assure the success of increased levels of automation in eddy-current inspection systems.

Collect and Analyze Ultrasonic Performance Data

Round-robin studies of ultrasonic inspections, in which each of a sample of inspectors inspects each of a sample of welds, have shown that inspection accuracy is typically much lower than expected. However, these studies have produced little insight into who inspection accuracy is no better than it is, or specifically what might be done to redesign the task or instrumentation to produce better results. Specifically, answers are required to the following questions: What task and procedural variables correlate, positively and negatively, with inspection accuracy? What signal-interpretation strategies are most successful? What signal-interpretation strategies are most successful? What logical steps are correlated with the different inspection outcomes - correct call, false report, missed flaw - for different flaw types? Performance data should ebb collected and analyzed to answer these types of questions. Results could identify improvements required in inspection procedures, instrumentation, and training.

Reduce the Complexity of Manual Ultrasonic Detection of IGSCC

A substantial amount of evidence suggests that ultrasonic detection of intergranular stress-corrosion cracking (IGSCC) by manual methods, as the task is presently designed and under the conditions in which the task is typically performed, is too complex to produce reliable results. IGSCC is the type of cracking that results from the continuing effects of structural stress combined with the corrosive effects of environmental elements, and is often referred to simply as "metal fatigue." The research question is how to increase the accuracy and reliability of ultrasonic inspection by reducing the burden and complexity of the task. Preliminary analyses and observations suggest that, although a major breakthrough is not likely, the cumulative effect of many small changes in task design - instrumentation and procedures - should be developed through detailed task analysis and application of human-factors design principles. The recent availability of microprocessor technology for ultrasonic inspection, in particular, provides new opportunities for increasing the compatibility between inspector capabilities and task design.

Define Optimal Strategies for Ultrasonic Testing

There appears to be no single, agreed-upon, best strategy (or strategies) currently employed for the ultrasonic detection and discrimination of flaws. A relatively large number of possible overall strategies exist because many options are available to select from - inspection parameter, inspection techniques, scanning patterns, discrimination logic, and others. For any type of application, a model strategy should be constructed from the collective experience and judgment of a sample of senior, experienced inspectors. The model would specify the analytical sequences used, the emphasis to be given to different variables, the techniques and cues to be employed, and the reasons for each. Inspector trainees could then be provided an optimal strategy, based on the collective insights and experience of senior inspectors, as part of their instruction in the ultrasonic inspection. As a consequence, they could more quickly attain the confidence and proficiency required for this difficult task.

Assess Human-Factors Issues in Enhanced Automated Scanning and Data Recording for Ultrasonic Testing

The development and employment of automated scanning and data recording techniques have overcome important performance problems in some applications of ultrasonic inspection. However, management resistance to automated scanning and recording exists because these methods are often perceived to require more time and money than manual methods. As a consequence, future research and development efforts will undoubtedly be directed toward increasing the efficiency of scanning and reducing the costs of inspections, raising new issues related to the human-system interface. Research on these issues should be conducted in parallel with, and in close liaison with, research conducted in support of the development of advanced ultrasonic inspection systems. Addressing human-factors issues during the development process will assure that advanced ultrasonic inspection systems produce accurate, reliable, and efficient inspector performance. As has been demonstrated in many successful system development efforts, these issues are best addressed as an integral part of the design effort.

Develop Methods of Sustaining the Effectiveness of Ultrasonic Testing Performance

One of the most powerful factors to influence performance on any task is feedback - information provided to the performer of a task about the effectiveness of task performance. Ultrasonic inspection presents a particularly difficult feedback problem because information needed for feedback is typically not available. For example, if a crack is missed, the error might not be discovered until a later inspection or a structural failure occurs. At that time, even if the information finds it's way back, the inspector who missed the defect may be long gone. Moreover, some inspection outcomes receive more attention than others and thus add potential bias to the process. For example, any reported defect (whether correct or not). In spite of the inherent difficulties in providing feedback on this task, are there cost-effective innovations that can be introduced to take better advantage of this powerful means of sustaining accurate inspection performance? If feedback cannot be enhanced in a practical manner, are there other approaches that can be substituted? One possibility is application of the concept of feed-forward, analogous to procedures employed in the calibration of equipment, for fine-tuning an inspector's detection and discrimination skills prior to a series of inspections. Alternative feedback and feedforward techniques for sustaining effective ultrasonic inspection performance should be developed and evaluated.

Conclusion

Eddy-current and ultrasonic inspections are two of the principal techniques available for the nondestructive examination of aircraft engine and airframe structures. Although each of these techniques can applied by means of technically sophisticated equipment, inspection results are highly dependent on human control actions, observations, analyses, and interpretations. Consequently, substantial potential payoff in the cost-effectiveness of the application of these techniques to aircraft inspections can be realized through improvements in human performance. This paper identified nine human performance issues in eddy-current and ultrasonic inspection, and provided a recommended approach to addressing each of them.

References

Hagemaier, Donald J. Cost benefits of nondestructive testing in aircraft maintenance. Materials Evaluation, September 1988, 46, 1272-1284.

Harris, Douglas H. Human performance in nondestructive inspections and functional tests (EPRI Report NP-6052). Palo Alto, California: Electric Power Research Institute, October 1988.

Appendix B: Meeting Agenda

Human Factors Issues in Aircraft Maintenance and Inspection

12 - 13 October 1988

Old Colony Inn

FEDERAL AVIATION ADMINISTRATION

Washington, D.C.

Wednesday, 12 October 1988

Ballroom A

7:30 a.m. Registration

INTRODUCTION/ORIENTATION

8:30 a.m. Meeting Welcome *Anthony J. Broderick* **Federal Aviation Administration**

Meeting Background and Objectives *William T. Shepherd, Ph.D* **Federal Aviation Administration**

Aircraft Maintenance Parameters *James F. Parker, Jr., Ph.D.* **BioTechnology, Inc.**

FAA Regulatory Requirements for Aircraft Maintenance and Inspection *Raymond E. Ramakis* **Federal Aviation Administration**

10:00 a.m. Break

THE PROBLEM

10:15 a.m. Maintenance and Inspection Issues in Aircraft Accidents/Incidents *Barry Trotter* **National Transportation Safety Board**

James W. Danaher

National Transportation Safety Board

Day-to-Day Problems in Air Carrier Maintenance and Inspection Operations *Robert Lutzinger* **United Airlines**

12:00 noon Lunch Martin Room

MANUFACTURER PERSPECTIVE

1:00 p.m. Maintenance and Inspection from the Manufacturer's Point of View *Robert Oldani* **Boeing Commercial Airplanes**

Human Performance in Aircraft Maintenance: The Role of Aircraft Design *Anthony Majoros, Ph.D.* **Douglas Aircraft Company**

Wednesday, 12 October 1988 - Continued

Ballroom A

2:30 p.m. Break

INDUSTRY PERSPECTIVE

2:45 p.m. Maintenance and Inspection Issues in Air Carrier Operations *Robert Doll* **United Airlines**

Computer Air Carrier Maintenance and Inspection *Norman S. Grubb* **Henson Airlines**

Rotorcraft Maintenance and Inspection *James Moran* **Aerospatiale Helicopter Corporation**

MAINTENANCE AND INSPECTION TECHNOLOGY

Nondestructive Inspection Equipment and Procedures *George Ansley* **Boeing Commercial Airplanes**

5:00 p.m. Adjourn

5:00 p.m.-7:00 p.m. Reception - Martin Room

Thursday, 13 October 1988

Ballroom A

MAINTENANCE AND INSPECTION TECHNOLOGY

8:30 a.m. Improved Information for Maintenance Personnel *Robert C. Johnson* **USAF Human Resources Laboratory**

TRAINING ISSUES

Strength and Problems in Maintenance Training Programs *Richard Hlavenka* **Tarrant County Junior College**

10:00 a.m. Break

Thursday, 13 October 1988 - Continued

Ballroom A

HUMAN FACTORS TECHNOLOGY

10:15 a.m. The Human Operator as an Inspector: Aided and Unaided *Colin G. Drury, Ph.D.* **SUNY, Buffalo**

Vigilance and Inspection Performance *Earl L. Wiener, Ph.D.* **University of Miami**

11:45 a.m. Lunch (On Own)

1:15 p.m. Human Performance in Non-Destructive Inspection Processes *Douglas H. Harris, Ph.D.* **Anacapa Sciences, Inc.**

2:00 p.m. Break

SUMMARY SESSION

2:15 p.m. Development of Summary Statements and Recommendations

4:30 p.m. Adjourn

Appendix C: Meeting Attendees

First Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection October 1989

MEETING ATTENDEES

Allen, Robert, Manager, Continued Airworthiness Staff Federal Aviation Administration, Washington, DC 20591

Ansley, George, NDT Specialist, Service Engineering Department Boeing Company, Seattle, WA 98124

Austin, Frank H., Jr., M.D., Human Factors Specialist Federal Aviation Administration, Washington, DC 20591

Baer, Judith, Editor, Ops Update Helicopter Association International, Alexandria, VA 22314

Broderick, Anthony J., Associate Administrator for Regulation and Certification Federal Aviation Administration, Washington, DC 20591

Christensen, Diane G., General Manager BioTechnology, Inc., Falls Church, VA 22042

Cook, Robert D., Assistant Manager, Accident Investigation Federal Aviation Administration, Washington, DC 20591

Danaher, James W., Chief, Human Performance Division National Transportation Safety Board, Washington, DC 20594

Doll, Robert, Vice President of Technical Services United Airlines, San Francisco, CA 94128

Drury, Colin G., Ph.D., Professor of Industrial Engineering SUNY Buffalo, Amherst, NY 14260

Easton, Locke, Aerospace Engineer Federal Aviation Administration, Burlington, MA 01803

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Oldani, Robert L., Manager, Maintenance and Ground Operations Boeing Commercial Airplanes, Seattle, WA 98124

Palmerton, William, Aviation Safety Inspector Federal Aviation Administration, Kansas City, MO 64106

Parker, James F., Ph.D., President BioTechnology, Inc., Falls Church, VA 22042

Pickrel, Evan, Consultant to the Federal Aviation Administration, Alexandria, VA 22309

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Meeting 2: Information Exchange and Communications (1989)

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

Report of a Meeting

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Foreword

Maintenance procedures to support world-wide air transport are being given considerable attention today. The growth of air transportation since the 1978 deregulation of the industry has caused demand for new carrier aircraft to exceed production. Under these conditions, older aircraft must remain in the operating fleet for many years, often beyond the anticipated retirement date established when these aircraft were designed. To ensure continuing highest levels of safety, maintenance of this aging carrier fleet must be rigorous. Indeed, aircraft inspection and maintenance must be effectively error-free operations.

The Federal Aviation Administration (FAA), aircraft manufacturers, and airline operators all are commited to achieving the highest standards in aircraft maintenance. However, the quality of maintenance ultimately depends directly on the performance of maintenance personnel. The FAA recognizes the need to establish a proper working environment for maintenance personnel and to understand those features of this environment which either enhance or degrade the performance of maintenance technicians.

The FAA is conducting a series of meetings to address Human Factors Issues in Aircraft Maintenance and Inspection. At the first meeting, in December 1988, "communications" was identified as an important issue underlying effectiveness and proficiency at all levels of maintenance. The meeting convened here, the second in the FAA series, addresses "information exchange and communications." All segments of the aviation maintenance community are represented through those speaking and those in attendance. The contribution of each of you to a program of continuing improvement in aviation maintenance is greatly appreciated.

William T. Shepherd, Ph.D.

Federal Aviation Administration

Executive Summary

The Federal Aviation Administration sponsored a two-day meeting in December 1989 as part of a continuing program to address issues of human factors and personnel performance in aviation maintenance and inspection. Presentations were given by some 15 individuals representing the full spectrum of interests in commercial aviation. Presentations also covered related efforts from other fields and new technologies having possible application to aviation maintenance. Each presentation, as well as the following question-and-answer period, was recorded for transcription and study.

The focus of the December meeting was on issues of "information exchange and communications." An earlier FAA meeting identified communication, in all its forms, as being of great importance in aviation maintenance and a matter in need of attention. The primary goal of the present meeting was to consider means of ensuring that the exchange of information within the industry responsible for the maintenance of the U.S. air carrier fleet is accurate, efficient, and responsive to the particular needs of this industry.

Recommendations presented to the Federal Aviation Administration are summarized as:

1. The movement toward a central data base to support aviation maintenance should be expedited as feasible. The Service Difficulty Reports data base maintained by the Federal Aviation Administration is a beginning, although this data base is not truly responsive to air carrier needs at this time. In continuing work toward a central data base, the FAA should consider carefully the strong initiatives made by other agencies such as the U.S. Nuclear Regulatory Commission.

2. The exchange of maintenance information will be improved significantly with greater standardization and consistency in the development and presentation of technical data. Data standardization projects should be encouraged.

3. Efforts to develop a Simplified English are excellent. However, care should be taken to avoid multiple versions of Simplified English.

4. The time required for transmission of much maintenance information is unsatisfactory. New and improved systems of electronic transmission should be developed. A fully responsive data system will require that all transmissions of maintenance information, particularly those with safety implications, be done electronically.

5. Safety analyses and trend analyses using the FAA Service Difficulty Reporting System must be improved to provide needed information more rapidly. Software should be developed to allow trend analyses for industry upon request, with rapid distribution of trend results.

6. The format for presentation of maintenance information is important, whether the presentation is in paper or electronic form. The FAA should consider the development and publication of a brief document containing an explicit list of guidelines for the preparation of maintenance manual-type information. The maintenance industry itself should consider incorporation of relevant parts of the electronic presentation technologies being developed by the U.S. Air Force in its Integrated Maintenance Information System.

7. The Federal Aviation Administration and the Air Transport Association both have programs considering information exchange in aircraft maintenance and inspection. Coordination between these programs is excellent. Anyone interested in the topic of information exchange should be familiar with each of these programs.

8. Traditional topics in human factors such as (1) use of visual displays, (2) information processing, (3) performance measurement, (4) feedback requirements, and (5) decision making were given little reference during this meeting. However, one can assume that each of these topics plays some role in determining maintenance efficiency. As the FAA Human Factors Program proceeds and more direct human factors data are developed, findings of these efforts should be incorporated into new procedures and systems to improve information

exchange in aviation maintenance.

Introduction

The Federal Aviation Administration (FAA) sponsored a two-day meeting in December 1989 to address issues of human factors and personnel performance in aviation maintenance and inspection. At this meeting, particular attention was given to "information exchange and communications" in maintenance operations. Presentations were given by some 15 individuals representing the full spectrum of interests in commercial aviation. Presentations also covered related efforts from other fields and new technologies having possible application to aviation maintenance. Each presentation, as well as the following question-and-answer period, was recorded for transcription and study.

The broad objectives of the meeting were to (1) develop an improved understanding of the role of communications in aviation maintenance, (2) identify specific problems of communication, and (3) review new procedures and technologies which might improve the exchange of maintenance information. An elaboration of the objectives of the Federal Aviation Administration in sponsoring a meeting such as this is described in the two presentations immediately following.

"Conclusions and Recommendations" of the meeting are presented just after the FAA Meeting Welcome and Meeting Objectives. These Conclusions and Recommendations are based on a "summing up" session held at the end of the meeting plus a careful review of the transcripts of each presentation. Recommendations have been reviewed for intent and for accuracy by each of the presenters.

An edited version of each presentation, taken for the most part from the tape transcripts, is presented as Appendix A.

Meeting Welcome

Anthony J. Broderick
Associate Administrator for Regulation and Certification
Federal Aviation Administration

I would like to welcome all attendees to the Second FAA Meeting on Human Factors Issues in Aircraft Maintenance and Inspection. I particularly appreciate your attendance in view of the snowstorm we are having just now.

I was able to address this group at last year's meeting and, at the conclusion, made one strong recommendation to Dr. Shepherd. This recommendation was that more of these meetings be held and that they be at frequent intervals. I am pleased to see that this recommendation is being followed and that human factors meetings will become frequent and regular events. I think that it is very difficult to overstate the value of getting people together in a relatively informal setting such as this to discuss problems of common interest from the perspectives of different disciplines.

The topic of today's meeting is "communications and information exchange" because this was identified as a crucial factor at last year's meeting. Communication ties the maintenance operation together and, in fact, is the thread that runs through aviation safety from any point of view. Personally, I am concerned about whether our approaches to communication and information exchange are really working well today. Are we making best use of existing knowledge and technology? In point of fact, I should say that I am convinced that we are not making the best use of new technologies. That being the case, as the aviation fleet grows and the industry expands, how will we meet our communications needs in the 1990's and into the next century?

Anyone who reads the Airworthiness Directive and the associated Service Bulletins for the cargo door on the Boeing 747 airplane will be convinced that we need help with communications. Aircraft systems are growing much more complex and maintenance needs are growing exponentially. We talk today about mechanical, electromechanical, and hydromechanical components. We also have fly-by-wire systems and soon perhaps will have fly-by-light, with all the computers and complex interfaces associated with such equipment. On top of this, inspection and maintenance problems for air carrier aircraft that are aging present special information problems.

A major issue concerns the interface with the person we must address. Repair and service details for all of these airplanes and systems have to be communicated to maintenance organizations in a timely manner and, above all, in an understandable manner. We must make good use of the experience that we have gathered, the mistakes we have made in civil aviation, and draw on progress made in the military and space fields. As I said earlier, for those who have not done so, it will be interesting to read an actual Airworthiness Directive and the Service Bulletin that goes with it. Pick one at random, read it, and you will be convinced that we need to do a better job.

Much maintenance documentation today looks like it was written by a lawyer. The reason for this is that it was. The process that the Federal Aviation Administration and aircraft manufacturers go through in writing an Airworthiness Directive requires a legal review. While the legal review serves useful purposes, it can introduce problems. For example, words like "proscribed" appear. How many people working in aircraft maintenance understand the difference between something being "prescribed" and something being "proscribed?" I would venture to say that not a high percentage do. This is of real importance when you consider the kind of accuracy we want in aviation maintenance. We hear about this all the time from airline operators. It is up to us in the FAA and to us in industry to do something about this problem. The attendees at this meeting can be very helpful by giving us some direction as to the best things for us to do to improve this situation.

Maintenance information must be understandable. Maintenance information also must be easily accessible. If it is not, people just aren't going to look for it. It is not a responsible act to place critical maintenance information into thick binders and assume that this information will get to the people who need it. If it does, it is likely to be torn out of the book and become so dirty that one cannot read it. We have an obligation not only to deliver messages, but to deliver them in a usable form and in a user friendly manner. Of the many new technologies available today, certainly some can be adapted for problems of the shop floor. These technologies should become standard rather than unusual in maintenance operations.

The fact that we need to implement new information transfer technology in maintenance does not mean that we need to move away from personal relationships. At one time, maintenance staffs were relatively small and so was the fleet size. It was possible for a given mechanic to work on a particular airplane enough to actually understand its history and to have a real sense of the problems with that aircraft. The advantages to this are such that at least one airline, in Japan, is reinstituting a program to reconnect aviation personnel with specific airplanes.

Today, maintenance operations for U.S. and international airlines are big and specialized. Maintenance for a given airplane may be done at many places. Implementation of communications and database technology will provide an opportunity for maintenance personnel to be more closely coupled with the aircraft they maintain. There is no reason this cannot be done, in concept, with the computer technology available today.

Current technologies can give maintenance workers access to training, technical, and procedural information without a need for tons of paper and can present this information in a way more interesting to those who must use it. The repair histories of individual airplanes can be followed and needed information quickly provided. All of this can be done today and, indeed, some airlines are beginning to do it. A system that lets a worker know the status of the airplane he or she has worked on will increase his or her personal involvement with the process. It seems to us that this sense of personal vesting in an airplane and its status would be of benefit for the worker. In turn, the increased worker involvement should be of benefit for the airline. Finally, this tracking technology would be of value for us in the FAA to support our Service Difficulty Reporting System. Since the benefits seem so obvious, and the technologies are available, it is time for us to work together to bring these maintenance communication technologies online within the next decade.

The adoption of advanced communication technologies, procedures, and philosophies has the commitment of the Federal Aviation Administration and, I believe, the senior management in U.S. airlines. What we need to do now is build some momentum behind the program. Over the next two days, you who are attending this meeting will be discussing issues of information exchange, hearing presentations, and, I hope, beginning to build that momentum. By so doing, you will be making a valuable contribution to the entire aviation maintenance community.

Finally, I would like to note that I recognize the difficulty many of you have in taking time from your busy schedules to attend these meetings. I appreciate your interest and your efforts and urge you to continue working with us as we strive to build an aviation maintenance system suitable for the demands of the 21st century. Thank you.

Meeting Objectives

William T. Shepherd, Ph.D.
Federal Aviation Administration

The Federal Aviation Administration is sponsoring today's meeting as part of a broad effort to enhance communications between the FAA and industry as well as among different groups concerned with human factors and personnel issues in aircraft maintenance and inspection. Our Human Factors R&D Program within the FAA requires a continuing flow of information from the outside world if the program is to be effective. The FAA has held a number of meetings concerning maintenance and inspection, including one last year which specifically addressed human factors issues - a meeting attended by many of you here today. These meetings are a key part of our communications process and we plan to continue them into the future.

An important part of the communications process is the identification of human factors R&D requirements. We want you to tell us what you think we should be doing in FAA. What kinds of problems should we address in our R&D program? For our program to be successful, we must target the R&D activity toward industry needs. That is where the payoff will be. To this end, all of the presenters in the program, with one exception, are from outside the FAA.

The catalyst for the FAA's current program dealing with aircraft maintenance and inspection was the Aloha Airlines accident in April 1988. Shortly after this accident, the FAA convened an international conference at which human factors were identified as a crucial issue underlying effective maintenance and inspection. 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. At this international conference, the FAA Office of Aviation Medicine was assigned responsibility for the development and management of a research program concerning human factors in aircraft maintenance and inspection.

As one of our first activities, in October 1988 we held our first human factors conference with a wide spectrum of industry, Government, and academic interests in attendance. The purpose of the meeting was to develop a listing of human factors issues and to establish priorities whereby these issues might be addressed by our R&D program.

In developing the Human Factors Research Program, we believed that a major accomplishment would be to provide compendiums of information that would be useful to various aspects of the aviation maintenance industry. We hope to provide information of value to those involved in maintenance training, people responsible for establishing and monitoring workplace conditions, and those who prepare written documents to support maintenance work.

As another goal, we want to identify experts who can help industry and the FAA incorporate proper human factors concepts in their activities. Target groups for our R&D activity include aircraft designers, individuals working in the manufacturing environment; manufacturers themselves; air carriers and their maintenance operations; repair stations; and of course our own people within the FAA.

A number of research topics for our R&D effort have been identified, many developed through our first conference held last year. At that meeting, information transfer/communication was identified as the most important issue facing the aviation maintenance community. Training also is a crucial issue and is one which requires careful review if we are to develop a training strategy which best supports present maintenance needs. As a start toward optimum working environments for maintenance personnel, we are sending people to various air carrier maintenance sites and looking at environmental parameters such as lighting, noise level, and other factors which might be either helpful or detrimental to the process. Other topics of concern for our program include the kinds of equipment and job performance aids required for maintenance and inspection as well as studies of vigilance and variables which might lead to boredom and complacency on the job.

A number of initiatives already are underway as we build our research program. As part of the FAA's aging fleet evaluation program, we send a human factors specialist on each site visit and use that as an opportunity to collect information concerning work environments and working conditions. We also are sending research teams to conduct task analyses of maintenance activities at different air carriers. To date the teams have visited Pan Am facilities at Kennedy and Miami airports. A number of other visits are planned both for air carriers and for repair stations.

Another activity just starting is a study of the application of intelligent tutoring systems and computer-based instruction in maintenance training. These interactive technologies have developed considerably in recent years and now may be of real value as systems to improve the effectiveness of maintenance training.

We plan to use the findings of our various research activities to develop an information source, a handbook available to industry and others concerned with maintenance. At this time we do not know exactly the contents of this handbook or the form which it might take. Ultimately it might be a printed handbook supported by such things as video tutorials and other types of machine oriented media. But, again, I want to emphasize that our product is going to be information.

While we do not have a firm set of chapters for the Human Factors Handbook at this time, some chapters that we anticipate might be included will cover:

Information transfer/communications

Work environment

Selection/training

Equipment/job performance aids

Inspection methods

Human limits

Problems of vigilance/boredom/complacency

Reliability of NDI activities

Just as the present meeting focuses on matters of "information exchange and communications," we plan another meeting for June 1990 which will focus on "training issues." At that time we will discuss some of the initiatives I have just described, such as intelligent tutoring systems, computer-based instruction, and other new training techniques. The June conference will be held under auspices of the FAA Technical Center in Atlantic City, New Jersey. Detailed information concerning this meeting will be available in the near future.

The Human Factors Research Program I have just described is organized as shown in Figure 1. The top of this figure indicates that we are seeking input from industry, the Federal Government, and any others who can contribute. Within the Government, we plan to deal not just with FAA facilities but to include the Department of Defense (DoD), the National Aeronautics and Space Administration (NASA), and others such as the Nuclear Regulatory Commission (NRC), with expertise and information of value. Private sector groups, such as professional and technical societies as well as academic institutions, also will be invited to contribute. We also will use our own in-house activity at the Civil Aeromedical Institute (CAMI) in Oklahoma City, Oklahoma. Behavioral scientists from CAMI will be responsible for the aging fleet evaluation visits. We also expect to have the NASA Ames Research Center as well as others connected with the Space Shuttle program as contributors. Finally, there are of course the industry people who are most conversant with the issues of aviation maintenance and its problems.

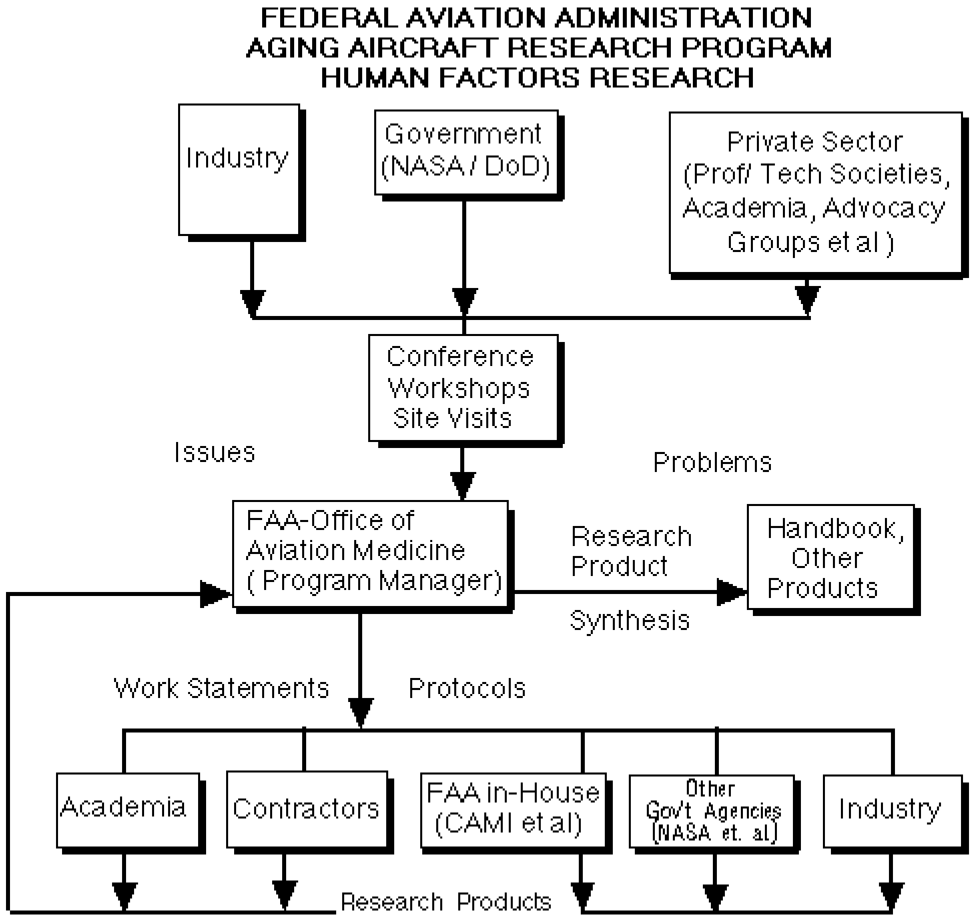

Figure 1

The Human Factors Research Program will draw on all of the above sources as we prepare our handbook and other information products. Within the next year, I hope that we can begin to make some of these products available to industry and thereby contribute to aviation safety through improvements in the efficiency and effectiveness of aircraft maintenance and inspection.

Conclusions and Recommendations

The exchange of information within the industry responsible for the maintenance of the U.S. air carrier fleet must be accurate, efficient, and responsive to the particular needs of this industry. Since deregulation of the airlines in 1978, the industry has grown rapidly and has become more diverse. New aircraft types have been added to the fleet, with many coming from foreign manufacturers. Older aircraft, which in former years would have been retired after 10 or 15 years of service, are being kept in use. As a consequence, there is a new problem facing the maintenance community, that of the "aging aircraft." All of these factors place new and growing demands on aircraft maintenance organizations and on communication systems to support their efforts.

Attendees at this two-day meeting represent all segments within the air carrier industry, including regulators, manufacturers, and operators. During the two days, attention was given exclusively to issues of information exchange and communications. Recommendations for improvement were offered during formal presentations, during ensuing discussions, and during a final "summing up" period. The following recommendations represent a grouping of attendee suggestions according to broad topics, with specific recommendations included within each topic.

Management of Maintenance Data

The documentation required for maintenance of the U.S. air carrier fleet is voluminous and is growing. This documentation supports a triad consisting of the Federal Aviation Administration, aircraft manufacturers, and airline operators. The flow of data within this triad is complex and multi-directional. Manufacturers require feedback from operators to determine acceptability and reliability of their product and its components. Airlines require product support information from the manufacturer. The FAA requires data from both the airlines and the manufacturers concerning product reliability and safety issues to support its industry surveillance role. The Air Transport Association (ATA) plays an important role by coordinating the flow of data among the three triad members.

The sheer volume of maintenance documentation is impressive. To illustrate one type of this documentation, Boeing maintains some 1,126 active manuals for 5,300 airplanes and 425 operators. At these levels, the management of all forms of maintenance documentation -- notices, directives, manuals, etc. -- becomes very challenging. For these data to serve their intended purposes fully, a carefully planned and operated data management system is essential. This system should include the collection, analysis, dissemination, and storage of technical information supporting aircraft maintenance.

Database Development.

A central data base for maintenance information would have many values. It would serve as a central repository, thereby making maintenance information equally available to those in both large and small aviation operations. It would offer immediate accessibility to information needed on an urgent basis. Also, and of considerable importance, a central data base, containing information from all segments of aviation, could support a variety of safety studies and analyses of safety trends.

Aircraft manufacturers and airline operators maintain a number of computerized data bases to support their individual needs. The closest to a national data base is that maintained by the Federal Aviation Administration which contains Service Difficulty Reports. These reports are required of airlines and detail events which occur in-flight or on the ground prior to flight. While the SDR data base generally supports the needs of the FAA, it is not particularly useful for the airline industry. By the time SDR reports become available, those airline operators with a particular interest in a problem have learned of the issue through an informal and more expeditious system. Also, the output at present is somewhat weakened as it is non-specific. A user needs to be able to query the SDR data base for specific information rather than having to peruse an enormous print-out. If the central SDR data base of the FAA is to achieve its full potential, it must be expanded and improved to a point where the informal data exchange system no longer is needed and where airline or aircraft-specific information can be obtained.

An improvement program for the SDR data base also should consider issues of data capture and data consistency. At this time, a problem indication below the legal reporting threshold may be lost. Thus, (1) the next inspection must rediscover the problem, if it can, and (2) other interested parties are unaware of the problem. In addition, there is a measure of inconsistency in the way in which operators interpret SDR data reporting requirements.

The need for an efficient database structure by the airline maintenance community has its parallels in the nuclear power industry. Under the auspices of the U.S. Nuclear Regulatory Commission, considerable progress has been made in the development of data bases to support nuclear power operations. One such data base, the Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR), contains data concerning both equipment and personnel and deals with both operations and maintenance. This system contains raw data describing both equipment and personnel performance and probabilistic data describing error likelihood under specified circumstances. The logic and procedures used in developing the NUCLARR data base could be of considerable value in any expansion of the FAA SDR data base.

Recommendations

1. The movement toward a central data base to support aviation maintenance should be expedited as feasible. The Air Transport Association, operating through its Improved Airworthiness Communications Systems Committee, has as one goal using information within the FAA Service Difficulty Reporting System to create an analysis loop for the airline industry geared specifically toward maintenance needs. This is a valuable initiative.

Certain requirements and cautions are in order in the development of a central data base. Access must be immediate and available to all individuals and organizations concerned with aviation maintenance. Data should be in a form so that safety and trend analyses can be done quickly and without major data transformation. The data base should include human factors data describing human reliability in various maintenance activities. Finally, developers of the data base should always be cognizant of a basic law presented by one of the meeting attendees: "The effectiveness of a maintenance program is in direct proportion to how well the mechanic accomplishes his task -- independent of the associated computer system." The data base must be oriented to the needs of maintenance personnel and not to the underlying computer system.

2. The FAA should examine in detail the logic and procedures used by the U.S. Nuclear Regulatory Commission in its development of the NUCLARR data base. Insights obtained by doing this could be of considerable value in an expansion of the FAA Service Difficulty Reporting System. This is particularly true concerning the manner in which human performance data are entered and procedures for establishing probabilistic descriptions of human reliability.

Quality of Maintenance Data

Maintenance data must be usable for all maintenance personnel, whether they be managers planning for a "heavy check," or mechanics doing a flight-line repair of a hydraulic system. Maintenance information also must maintain a consistent format as it proceeds through the system. Data generated by a manufacturer to describe a maintenance action should not be changed in format or meaning as it works its way to the mechanic on the floor.

The preparation of maintenance documentation takes place at many points in the maintenance system and involves many individuals of varying backgrounds and skills. At the manufacturer, engineers and documentation specialists prepare Service Bulletins, changes to the Manual, and other messages for airline operators. Working with the Federal Aviation Administration, Airworthiness Directives are prepared. Since ADs require a legal review, lawyers now are involved in the writing process. As a result, according to one operator undoubtedly reflecting an industry consensus, "Airworthiness Directives are not always clear-cut and easy to understand."

One approach being taken to improving the readability and understanding of technical documents is the development of "Simplified English." Interest has been expressed by manufacturers, operators, and the FAA in the development of a limited vocabulary for technical writers and engineers which is accepted through the industry. A standardized language would do much to remove elements of confusion from technical documentation. In an example provided by Boeing, a "hatch" is always a hatch. Technical writers and engineers cannot refer to it as a "door," a "panel," a "limited access area," or any of the many other designations. Under all circumstances, access is through a "hatch."

Boeing Commercial Airplanes is using a limited and standard vocabulary developed by AECMA for its documentation activities. Other organizations are pursuing a similar approach. At Boeing, the Writing Guide includes an artificial intelligence unit which, in addition to checking spelling, also reviews writing rules and saves an engineer from having to do this review. This is a real step forward in the improvement of maintenance documentation and the quality of maintenance data elements.

Recommendations

1. While "established" ways exist for the preparation of most maintenance documentation, there are no standards. In recognition of this, the Communications Committee of the Air Transport Association has, as one long- term objective, the development of a standardized technical data system. Such a system offers much in terms of improving communications and maintaining a high level of reliability in maintenance operations. The FAA should support the development of this system and consider specific projects to develop and evaluate standardization procedures.
2. A number of initiatives are underway to establish a Simplified English for use with maintenance documents. Aircraft manufacturers have done some of this; research sponsored by the Air Force has prepared other lists. The FAA, possibly working through the ATA Communications Committee, should give impetus to the development of a single Simplified English. This list then could be distributed through the U.S. industry and also through foreign manufacturers, where it would be quite helpful. In any event, every effort should be made to avoid multiple versions of Simplified English.

Transmission Efficiency

Maintenance information must move swiftly through the system if it is to serve its purpose fully. Delays in generating or transmitting maintenance documents impact maintenance performance and reduce effectiveness. Several speakers commented on the length of time required to get technical data to an operator. If a Designated Engineering Representative decides that a change in technical data is necessary, an average of about six months is required for the changes to be made and the information then sent to the operator using the aircraft. Once at the operator level, there is another delay before the manufacturer's information can be incorporated into his manuals.

Another problem relating to delays in processing of information concerns the Service Difficulty Report data base maintained by the FAA. The purpose of the SDR system is to collect information concerning aircraft difficulties on an industry- wide basis and then analyze this information as a basis for appropriate corrective action. However, these analyses proceed too slowly to serve their avowed purpose. By the time an analysis of significant SDR findings is completed, the industry is aware of the problem and has taken corrective action. The value of the SDR system could be increased significantly if it could work in a more timely manner.

Recommendations

1. New procedures to improve the flow of maintenance information must be developed. Needed information should be prepared expeditiously and transferred by electronic means. At this time, some 37 airlines obtain their maintenance manuals, or some portion of these manuals, on magnetic tape from Boeing. This is a beginning toward a complete electronic system. However, a truly satisfactory system will require that all tramsmissions of maintenance information, particularly those with safety implications, be done electronically. Movement in this direction should be encouraged.
2. The Service Difficulty Reporting System must provide needed information more rapidly. This is particularly true for analyses which show maintenance trends. Software should be developed for the SDR data base which will perform a fixed number of commonly required trend analyses upon request, with rapid distribution of trend results.

Maintenance Manuals

The printed manual has been the mainstay for aviation maintenance for years. While the format has changed little through time, the manuals have gotten bigger and more cumbersome to work with. While manuals serve a worthwhile purpose as a repository for data and as a reference source, they are not particularly useful for flight-line support. As a result, manufacturers and operators have turned to alternate systems such as Automated Work Cards and electronically generated copies of relevant portions of manuals. ATA has developed an automated Aircraft Maintenance Task Oriented Support System (AMTOSS) in which each task and subtask has a unique number identifier. Through use of this coding, an operator can collect all appropriate and related tasks described in different parts of the manual into one grouping. He can then build a basic work package.

The maintenance manual concept has been taken a significant step forward by the Air Force in the development of the Integrated Maintenance Information System (IMIS). This system integrates diagnostic and maintenance information and presents it to technicians at the flight line through a portable maintenance aid with a hypertext user interface. With this system, there is no need for a maintenance manual. All technical data, diagnostic rules, aircraft-specific information, etc. are presented as requested by the technician.

Another approach moving away from the traditional maintenance manual concept is the On-Board Maintenance Information System (OMIS) being explored by Boeing. This system will provide all required data to support ramp and flight line maintenance on a given airplane. OMIS also will carry information concerning the maintenance history of the airplane on which work is being done. All necessary information for maintenance needs will be provided.

Recommendations

1. The movement toward electronic maintenance information systems represents a significant advance and should be fostered by whatever means feasible. However, the rules for effective presentation of information remain the same, whether the presentation is in paper or electronic form. The FAA should consider the development and publication of a brief document containing an explicit list of guidelines for the preparation of maintenance manual-type information. This document should be based on the guidelines discussed at this meeting and should be distributed to aircraft manufacturers and interested documentation specialists for review and coordination with recent ATA requirements.

Coordination with Air Transport Association

The Air Transport Association formed the Airworthiness Assurance Task Force to address problems of the aging airliner fleet. Within this Task Force is the Improved Airworthiness Communications Systems Committee. This Committee, which includes representatives from the Federal Aviation Administration, has been concerned with many of the same items addressed as Conclusions and Recommendations here. For example, one goal of this Committee is to develop a standardized technical data system. Another goal is to address the role of human factors in aircraft maintenance. As one can see, the goals of the ATA Committee and those of this meeting are closely allied.

Recommendations

1. The FAA Program on Human Factors and the ATA Committee on Communications maintain close coordination. Others interested in specific topics addressed in this meeting should contact the ATA Communications Committee to learn of its agenda and its conclusions to date.

Human Factors

Topics of interest at this meeting focused on maintenance data, technical documentation and industry communications procedures. While human factors are very much a part of each of these topics, little reference was made to some of the more traditional areas of interest within human factors, such as:

Use of visual displays

Information processing

Performance measurement

Feedback requirements

Decisionmaking

The extent to which topics such as these affect maintenance performance and are related to maintenance communications is not known. One can assume that each topic represents a variable underlying maintenance proficiency.

As reported at this meeting task analyses are being performed for an array of maintenance actions as part of the FAA Human Factors Program. At the conclusion of these studies, considerable information will be available concerning the role and influence of traditional human factors variables in maintenance performance.

Recommendations

1. Results of the Human Factors Task Analyses should be reviewed as studies are completed to assess the manner in which any of the recommendations presented here should be modified or expanded to incorporate the new findings.

Appendix A: Meeting Presentations

FAA Overview of Maintenance-Related Information Exchange

Dennis Piotrowski
Federal Aviation Administration

Human factors issues in information exchange were with us long before the Aloha accident. In all of our aircraft development programs, both industry and the Federal Aviation Administration have faced real problems in establishing communication channels among the various groups working in the development programs and in deciding the kinds of information to be distributed through these channels. For example, in the YC-15 flight test program, data-link channels were established between the Long Beach manufacturing facility and the Yuma Flight Test Center. This allowed aircraft design engineers to obtain quickly information that came from the flight test vehicles and to ask questions directly of the flight test crew concerning results of each test. At the same time, we were conducting a flight training program for Kuwait in which information generated concerning flight characteristics and aircraft maintenance needed to be passed to a foreign flight and maintenance team. In all of this, we became quite sensitive to issues of information exchange and communication.

Lessons learned in programs such as those I just mentioned have been of value to the FAA as we try to maintain an effective communication network with the aviation maintenance community. Before we look at the FAA communications system, however, I should call attention to the many different groups with which we must communicate. Ours is by no means a single-channel system. Information concerning an airplane and its maintenance requirements must be transmitted to those with inspection authority, aircraft manufacturers, airline operators, maintenance personnel, pilots, those in the training establishment and many others. With the international flavor of aviation today, the list becomes even longer. The back-and-forth requirements of communication within and between these groups generate any number of unique communications issues.

The communications system used by the FAA for a specific airplane begins with a single piece of paper called a Standard Airworthiness Certificate. This signifies that the airplane conforms to its engineered type design and that it is safe for operation or it is airworthy. At this point, we are trying to communicate the status of a product with a single piece of paper.

When the Airworthiness Certificate is issued, it is supported by the aircraft Maintenance Plan (Instructions for Continued Airworthiness). The Maintenance Plan is developed through the activities of groups from the manufacturer, operators, and the FAA. All of these individuals work together within the Aircraft Evaluation Group (AEG) and through a Maintenance Review Board (MRB) to develop the first maintenance program. This program specifies recommended maintenance intervals and other aspects of the program needed to provide a full maintenance capability from the first day of commercial use.

The Maintenance Plan is supported by appropriate Federal Aviation Regulations which communicate the minimum standards for design and operation of the aircraft. Additions or changes to the Federal Aviation Regulations involve a complex process in which a proposed new rule is published by the FAA for review by the industry or any others with an interest in that topic. After about a two-year period of review, discussions, and revisions, the new rule may become effective. At this time we then need to communicate this change to all impacted parties.

Frequently the FAA determines that more detailed information must be provided to support a Federal Aviation Regulation and, in turn, communicated to industry. The resulting publication is called an Advisory Circular and generally is used to illustrate one means of compliance with the rule. A considerable amount of work and, frequently, a number of public meetings go into the development of an Advisory Circular. To ensure the broadest audience for advisory circulars, they often are published in the Federal Register.

Advisory circulars are directed primarily at industry. However, we also have a need to communicate this type of information to our own employees within the FAA. We need to inform them concerning the policy or provide guidance for implementing an Advisory Circular, for example, from an FAA inspector's standpoint. This information is provided in the form of FAA Orders or Handbooks which are distributed in an effort to have all individuals work from a common information base and to implement the FAA rules in a standardized manner across the country.

The FAA also uses other communication documents called action notices, or just notices, to communicate with its employees when handbooks or more formal orders are not appropriate. In some instances, a simple telephone call is sufficient to ensure that FAA policy is being implemented on a uniform basis.

Another communications problem faced by the FAA is that of communicating to the operating and maintenance communities the technical status of an airplane as it may change during its period of service. In order to support such communications, we collect considerable information from manufacturers and also from users through the Service Difficulty Reporting System. From the information we receive, we can do trend analyses to pinpoint a possible adverse trend with an aircraft or one of its components.

As one means of disseminating trends or describing possible problems to FAA personnel, we frequently use another communication tool called Alerts, which is put out in Advisory Circular form, AC4316. Alerts are distributed through a mailing list maintained at Oklahoma City and are directed to aircraft inspectors, repair stations, and others interested in overseeing and accomplishing aircraft maintenance. Alerts represent a compilation of all of the trends that we see. It is our belief that maintenance actions will be improved if maintenance personnel understand these trends.

Also in an attempt to deal with the changing status of an airplane, manufacturers often put out Service Bulletins. Such bulletins address a problem that requires attention or correction and identify a recommended means for dealing with the problem.

Closely allied with the direct interest of the FAA in communications are programs to identify the knowledge, skills, and abilities required by different personnel to perform their jobs. At this time, a significant program is development of job task analyses for the various positions of FAA Aviation Safety Inspector. Results of this effort will provide a better understanding of the requirements of these jobs and the materials needed to support the positions. We also hope to use this technique to identify requirements for training for Journeyman through Seniorr Expert Inspectors. All of this will allow us to do a better job of developing policy and guidance materials for FAA inspection functions. In essence, the communication link between the FAA and the Aviation Safety Inspector will be improved.

To this point, we have been concerned mostly with communications in the form of written materials, whether they be directives or manuals, which support maintenance operations. Verbal communicatios also are quite important. Some of us have had the luxury of attending communications courses which attempt to improve communications skills and can be quite valuable. Such courses teach one how to actively listen. How does one actively talk and share one's thoughts with the idea of resolving a problem and not with the idea of winning a point? It is certainly true in aircraft maintenance that effective verbal communications are most important.

As we address the issue of effective communications, one issue comes immediately to mind. As I travel around the country and participate in meetings with industry and the public, I recognize that all of us are not communicating aseffectively as we might concerning the safety factor in commercial aviation today. However many statistics we present to support the safety issue, we still find a considerable body of the flying public that does not feel that way. All of us will benefit if we can develop communication procedures which reinforce the perception of safe travel rather than the opposite. We must be able to discuss the aging aircraft program, Service Difficulty Reports, and similar issues in such a manner that we do not undermine the proper perception of aviation as an extremely safe mode of transportation.

Another communications issue to note is that of getting information from foreign manufacturers who are providing a number of aircraft for U.S. aviation, particularly for regional air carriers. Establishing effective communications here, particularly with respect to maintenance, is an important problem and one about which you will hear more today. Aircraft Evaluation Groups are more actively involved in foreign maintenance programs today than in times past. Current regulations do address the manner in which maintenance programs will be constructed and the language in which they will be presented. At this time, bilateral agreements are in place to require maintenance programs to be delivered with the first airplane that is shipped. However, I realize that these agreements in themselves by no means solve the problem. We recognize that the Federal Aviation Administration in many instances can only establish a minimum standard. It is necessary for industry to work beyond these minimum standards to develop communication links and maintenance documentation that truly meets industry's needs. Industry must work directly with the foreign manufacturers to define exactly the type of documentation needed to develop a rigorous maintenance program.

The Federal Aviation Administration recognizes that today's aviation maintenance requires effective communication systems at all levels. We in the FAA are working to develop improved communication procedures with our own personnel and hope to contribute to improved communications throughout the maintenance community.

Major Air Carrier Perspective

Clyde R. Kizer
Air Transport Association

This presentation will describe, in general terms, communications in the aviation maintenance industry and some things being done in the industry in conjunction with manufacturers, the Federal Aviation Administration, and international organizations. It has been said that truth is the first casualty of war. If so, then communications is the first casualty of human endeavor. No matter what the institution, be it marriage, business, or tennis, one of the biggest problems we have is either miscommunications or failure to communicate. As was stated so nicely by the chain gang captain in the movie Cool Hand Luke, "What we have here is a failure to communicate." That generally is one of our major problems with regard to maintenance and engineering activities in the air transport system.

I found communications to be a problem in the military, and I again found it to be a problem when I came to industry. We either misunderstand one another or we don't talk to one another. Bob Doll is fond of quoting Winston Churchill who said that the United States and England are two nations of similar heritage separated only by their common language. Unfortunately, this is frequently one of our most common problems in aviation. Many communication problems arise because you think you understand the system, since it is similar to a system you do understand. In fact, there may well be a little nuance or a slight difference in the system that you do not fully understand. Such differences may well be more difficult to comprehend and to clear up than large differences between systems. As a result, communications suffer.

In this presentation I will provide a brief review of the general communications requirements of our air transport system, including the network between the airlines, the manufacturers, and the Federal Aviation Administration. I also will note the interaction of the Air Transport Associa- tion with that network. In particular, I will discuss current efforts of the Improved Airworthiness Communications Systems Committee, which falls under the auspices of the Airworthiness Assurance Task Force. This Task Force was developed to attack the problem of the aging fleet of commercial airliners, not just in the United States but throughout the world. The Task Force represents 42 international carriers, 32 U.S. carriers, the U.S. Navy and the U.S. Air Force. Also represented are seven regulatory agencies and five airframe manufacturers.

My experience with the Airworthiness Assurance Task Force indicated that it took about three months of meeting and talking candidly to one another before we began breaking down the barriers within which we were all confined. These included organizational barriers and/or institutional barriers that had developed over the years. After about three months, members became more serious in their attempts to really communicate in an honest, open, and responsible fashion. This seems to me to be the most important aspect of group activity. To achieve the objectives of the Task Force, all of the issues and hidden agendas must be honestly explored. Every organization that interacts with another organization has responsibilities for which it is answerable. When we communicate in an attempt to resolve problems, a major part of the endeavor involves breaking through these parochial concerns so as to get all of the information on the table so that we can truly understand the problem. We also must understand what everyone's responsibilities are, because when it comes to compromise there are positions for each institution or each organization where compromise is not possible. We must know what these limits are for each participating organization. The only way to do this is through open, honest, and responsible communication.

We frequently speak of the three-legged stool in the air transport system which involves the manufacturer, the airlines, and Government regulatory agencies. Indeed, this three-legged stool exists in all countries involved in air transport. Each leg of the stool has a responsibility. Each is answerable to its own constituency, be they the Government or the stockholders or the traveling public. Each must know and respect the responsibilities of the others and ensure that we do not deviate too far in any one direction in terms of over regulation or over liberalization of control. The members of that three-legged stool must communicate with each other at all levels on a frequent basis.

Manufacturers depend on airlines to provide data to support the design and performance characteristics of aircraft. Airlines must indicate the distances they want to fly, the seating capacity they need, and other design-related data. Airlines also must provide data on aircraft reliability. Manufacturers need to know how their systems work. Is one hydraulic actuator more reliable than another type of hydraulic actuator? Particularly in avionics, manufacturers must understand the reliability of a product they put in the field. Certain of this information is provided through the services of manufacturer's factory representatives who work directly with the airlines, frequently on the premises to ensure day-to-day communications.

Both manufacturers and the FAA depend on the airlines to provide in- service difficulty reporting. Both need to know the kinds of problems that occur with an aircraft that cause service interruption or safety concerns. They depend on this information from the airlines so that both the safety and reliability issues can be addressed properly.

Airlines depend on the manufacturer to provide product support information. Individual airlines require fleet reliability data so that each airline can determine whether its reliability is deviating significantly from the industry norm. They also require maintenance action and information documents, such as Service Bulletins, to provide information from which to base aircraft repair once a problem has been found.

The Federal Aviation Administration depends on the airlines and the manufacturer for data concerning in-service difficulties and product reliability. Such data form the basis for regulatory actions and general oversight of the transport industry. The industry depends on the FAA's awareness and surveillance capabilities to provide the safety net that the nation needs in air transport.

The Air Transport Association (ATA) serves a coordinating function in this three-legged stool arena. It is ATA's responsibility to keep the Government, be it the regulatory agency or the legislative bodies, aware of the technical capabilities and limitations of the industry. Congressmen, senators, and their technical staffs, must be aware of where industry limits are, as must the FAA. By the same token, airlines must be cognizant of regulatory and legislative requirements being imposed on them and what these will mean in terms of economic, safety, and operational impact. ATA serves to coordinate these activities and to bring the proper body of people together to address these issues.

Again, as stated earlier, one can never resolve a technical issue without understanding all ramifications of that issue. The manufacturer, if he has to solve a problem dealing with some technical aspect of the aircraft, will generally resolve that problem in a manner which will allow greatest manufacturing productivity. The airlines will generally resolve an aircraft technical problem with a means that will provide reliability in off-the-gate or out-of-the-dock capability for that aircraft. The FAA, if they had no other concerns, would resolve a technical problem to ensure the very safest system to a point where you might not be able to fly the aircraft. We all want the maximum, but there has to be compromise at all times. Compromise requires effective communication.

As important as it is, communications among the members of the three- legged stool does not cover all communications requirements. Communicating with the public is equally important. I firmly believe that the industry is best served when technical experts speak for the industry. Any portrayal of technical data by someone other than a technical expert, even if he is a professional communicator, is a veneer. In such cases, serious questions concerning technical issues can only be answered by those with the best technical understanding of those issues. Fortunately, in the past few years the industry has become considerably more effective in communicating with those outside the industry. However, we must continue to ensure that our technical experts are well schooled in the art of communication and can speak ably for the industry.

When the Airworthiness Assurance Task Force was initiated, we were charged to address certain short-term issues that affected the reliability of the fleet, such as structural integrity and corrosion prevention. We chose five short-term objectives which are being pursued now by three Task Force Working Groups and should be resolved in the very near future. Longer-term issues came under the direction of the Task Force Steering Committee. This Committee, in addition to being responsible for defining issues and ensuring consistency among working groups, has the responsiblity of pursuing the longer-term objectives. One of these longer-term objectives is to address the role of human factors in aircraft maintenance. Another longer-term objective is to develop a standardized technical data collection, storage, analysis, and documentation system.

One of the first actions of the Steering Committee was to examine the Service Difficulty Reports of the FAA to determine if changes could be made that would provide more meaningful data in a more responsive time. At this time, airlines are required to report certain events specified by regulations every time these occur in flight or on the ground incident to flight. The intent is for a data base to be developed which would be analyzed for safety trends. If trends develop, the FAA is required to alert the field as to potential problems, either with a fleet of airplanes or with the overall air transport fleet.

Unfortunately, the Service Difficulty Report System does not work in the manner originally intended. Information is gathered and is disseminated and the industry is aware of problems as they develop, but generally not through the formalized system of the SDRs. Industry learns through an informal system that exists among those responsible for the safety of the industry or the airworthiness of the fleet.

As noted earlier, airframe manufacturers have representatives on-site at most airline facilities, as does the FAA. FAA inspectors oversee activities on-site at maintenance activities of the air carriers. The airlines, the airframe representatives, and the FAA representatives form the informal communications link that detects problems as they occur in real time and reports them back to responsible agencies, in this case the FAA and the manufacturer. The FAA, the manufacturer, and generally the airlines then gather to determine how widespread the problem is. The manufacturer alerts the field to the potential problem through a Service Bulletin or a Service Letter which describes the problem, asks operators to examine their aircraft to determine if they have the problem, and then describes means for correcting it. If there is a safety implication to the problem, the FAA takes the Service Bulletin, generally an Alert Service Bulletin in that case, and publishes an Airworthiness Directive. This is how the information is disseminated. The alerting and signaling of potential safety problems are geared so that we get information to the field in an expeditious manner. But it is not done under the formalized system.

The Steering Committee would like to take the informal system and institutionalize it in some formal method so that we can (1) get the information disseminated quickly and (2) have a formalized and rigid analysis program that will allow us to determine not only the extent to which the problem exists throughout the fleet, but also the best resolution for the problem. At this time, if only one or two carriers have a problem it generally is resolved between the carrier and the manufacturer or between the FAA, manufacturer, and the carrier. A goal of the Steering Committee is to use the SDR system as it exists today and extract the data, of which there are vast amounts stored in the system, and create an analysis loop for the system that is geared specifically toward the needs of the airline industry. Analyses are conducted on data collected now and it is used for the FAA and for general aviation, but analyses of the data are not of great use to the air transport industry. Information comes about too slowly. By the time the FAA produces an analysis of significant findings from the SDR, everyone in the industry is aware of the problem and has already taken action to correct it. So that part of the SDR loop does not work well for the airlines. We need to determine means of formalizing that part of the analysis loop to make it indeed work for the airlines.

Another goal for the Steering Committee is to pursue means for developing a standardized international system for collecting, storing, analyzing, and disseminating technical data. Again, we have concentrated on the Service Difficulty Reporting system, but the effort has far greater ramifications than SDR. A short-term objective was to see how the existing SDR system might be improved. In the long term the objective is to design a technical data system from the ground up that will be acceptable internationally and will ensure that all carriers report the same information to their regulatory agencies or manufacturers in the same format. If this can be achieved, we will have done a great deal not only for the study of reliability but for the capability to detect safety trends with far greater clarity, accuracy, and speed than is the case now.

The format for a new system should ensure consistency not just for SDRs but also for data fed back to manufacturers based on reliability factors, or based on problems detected during normal maintenance inspections. In all, we need a single document that will go to all agencies and into a data base accessible to the industry in order that we have the most comprehensive data analysis program possible, whether one is concerned with reliability or with safety. This is an ambitious program and we anticipate a period of several years before we achieve an international standard, let alone a standard acceptable among the airframe manufacturers and to the FAA as well.

Another objective of the Committee is to specify electronic means for transferring data. At this time, if a manufacturer's engineering representative decides that a change is necessary to technical data relating to the systems of his aircraft, an average of about six months is required for the engineer to make the changes necessary and see that the information gets into the hands of the operator with the equipment. For instance, if he wants to change a reference or a part number on a hydraulic actuator because it has been modified, it takes about six months from the time the engineer recognizes the need to make a change before the engineer or manager at the airline receives that change in his hands. The airline itself then has a lag time generally on the order of about three weeks to three months before the information received from the manufacturer is incorporated into all of his manuals. The timeline for this data flow is of course too long. We need to reduce the time factor to hours or days. The only means to do this is electronically with a standardized communications system shared back and forth between the airlines, the FAA, and manufacturers. We must have a common format if this is to be achieved.

An additional activity of the Communications Committee, one quite important for airline operators but also of consequence for the FAA and for manufacturers, is to provide recommendations concerning changes needed in the aircraft of our older fleet airplanes over the next four or five years. It is critical to the industry that these recommended changes not be impeded as a result of lack of material, lack of manpower, or lack of facility. We must develop a coordinated industry plan which shows the schedule we are going to use to make these changes so that we don't all do 747 Section 41's in January of 1999, for instance, knowing full well there will never be enough material, there will never be enough manpower, and facilities will not be adequate if everyone decides to make the changes on the same day. The schedule must clearly show the implementation plan. This is crucial so that manufacturers can gear their production requirements so that material will be available when needed by the industry. It is also crucial for the FAA so that they know both their manning requirements for inspection and the regulatory requirements to ensure compliance. If successful, the plan should ensure that the AATF recommendations can be implemented without a hitch, without running into constraints of manpower, facilities, or material.

If the reporting and scheduling initiative is carried to its extreme, we might be able to use it to control the maintenance of an entire airplane from the time it is received from the manufacturer until the time it is retired from service. The program would record all routine and non-routine maintenance. At this time, although airlines themselves develop data of this type, there is no industry-wide sharing of that data. We do know that on the average approximately an hour and a half of unscheduled maintenance is required for every hour of scheduled maintenance. But we still need to know at the time an airplane is received on the line what its routine maintenance, non-routine maintenance, and material requirements will be throughout its lifetime. Given that, the operator can plan maintenance activities better and ensure the resources necessary for those activities. They will know, for instance, that the next time this airplane comes in for a C or a D check it will have 35,000 cycles on it and the data show that at 35,000 cycles on the average 5,000 hours of non-routine work will be required, which will be concentrated in certain areas of the airplane. The manufacturer then can make a long-term projection concerning his requirements for producing the material and the industry can save money by having proper resources available. Spot buys will not be necessary; overtime work may not be required; and dock scheduling conflicts can be avoided. From a planning standpoint it should reduce the cost of maintenance because the airline will not have to pay to store materials from the manufacturer to be on hand when not needed. However, he will have the materials when they are needed. Such planning also will give the FAA a far better projection of maintenance requirements for our various fleets of aircraft as they progress through their lifetime.

A data management and planning program as just described is ambitious but, if we are to ensure that changes to aircraft required to meet the AD's attendant to the AATF recommendations can be done within two or three years, this program itself, at least the first part of it, must be on-line also within two to three years.

The Communications Committee is pursuing many initiatives designed to improve the communications process as it affects the maintenance, engineering, and safety aspects of the air transport fleet. Many other activities are being undertaken in a cooperative industry effort. Every one of them is geared toward the absolutely essential need for open, honest, and responsible communications.

Mid-Level Air Carrier Perspective

Thomas F. Derieg
Aloha Airlines

To understand my perspectives concerning information exchange and communications in aviation maintenance you must know something about the kind of airline for which I work and its particular maintenance requirements. The concerns and problems I have are very much a function of my airline environment.

Aloha Airlines has been in business since 1946, although we have become well known to most people only in the last two years. We fly 14 Boeing 737's in Hawaii, providing strictly inter-island transportation between Honolulu and four outer island airports. Two of our Boeing aircraft are 737-300's. Twelve aircraft are 737-200's. Of these, nine are the advanced models and three are basic models well known through the industry for their cold-bonded lap splices. Aloha Airlines has 5,000 departures and carries approximately 350,000 passengers per month.

Aloha has an outstanding safety record. In its 43 years of operation, it has never lost a passenger. We have had one well-known accident with a fatality in which we did lose a Senior Flight Attendant. This was a real tragedy for all of us.

Communications in a smaller airline is different than in a larger carrier because of differences in size, organizational structure, and organizational behavior. With a small airline, you know the pilots; you know the mechanics; you know everybody in the company. The personal interface is good and decisions can be made with relative ease since all persons directly concerned can be in the same meeting.

The aviation industry, as noted earlier, operates as a three-legged stool. In our case, as shown in Figure 1, the stool consists of the regulator, the FAA; the manufacturer, Boeing Airplane Company; and the operator, Aloha Airlines. Since Aloha has a single aircraft manufacturer and flies a single type of airplane, our relationship with the industry is relatively straightforward and very much as shown in Figure 1.

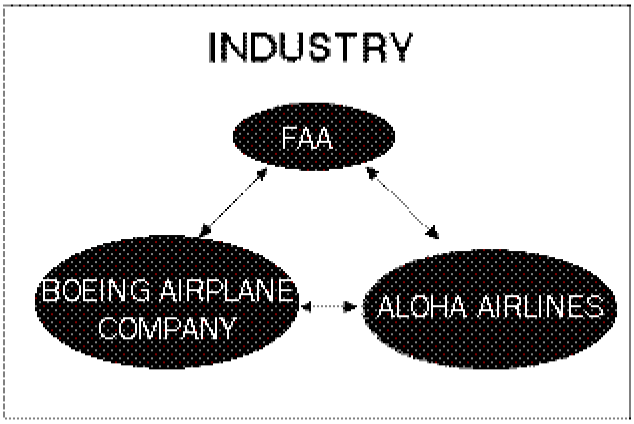

Figure 1

In our dealings with the aviation industry, we find that the Air Transport Association has almost made the three-legged stool into one with four legs, as seen in Figure 2. The Air Transport Association, as an industry group, is very important for a company such as Aloha. We are a long way from Washington and are not a big company, although rated as a national airline. We do not feel that we have a lot of impact in the industry or much influence on regulatory decisions, even those that affect us directly. The Air Transport Association provides this influence for us. They provide it for the entire airline industry and through them we are able to make our needs and desires known. The Air Transport Association has taken a leadership role in dealing with problems of aging aircraft. Their activities, coupled with those of the FAA Aging Aircraft Task Force teams, are making real progress. The combination of the knowledge provided by the ATA and the industry, working directly with the FAA, has proceeded faster, in my opinion, than would have been the case with the FAA working on its own.

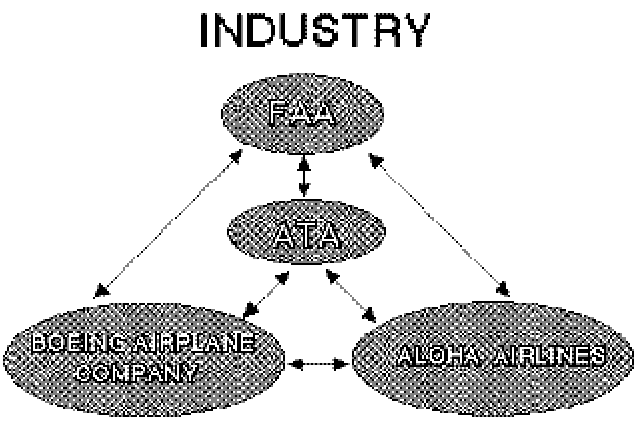

Figure 2

The communication network within which Aloha Airlines conducts its maintenance operations is shown in Figure 3. In the routine business of airlines, that involving Service Bulletins, Service Letters, and other maintenance messages, we have direct communication between Boeing engineering and our engineering department. This is primarily a one-way communication channel, with considerable information coming in daily from Boeing.

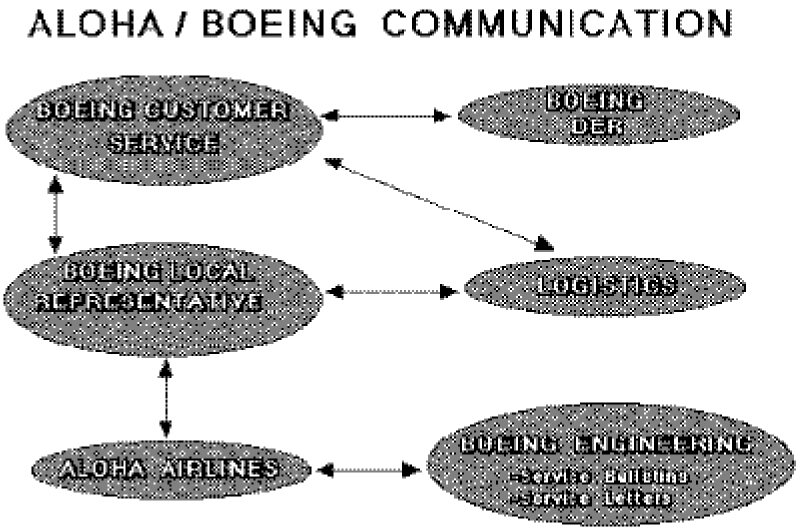

Figure 3

On a day-to-day basis, we deal primarily through our Boeing local representative. There has been a Boeing representative at Aloha since we started flying Boeing equipment in 1969. He is aware of our problems and serves as our primary communication channel to Boeing Customer Service.

Boeing Customer Service is very helpful for us and serves us in two ways. One is to assist in some particular troubleshooting problem. A larger part, however, is to provide us with information on repairs for which we do not have FAA-approved data. As those in the industry know, any repair classified as major must be accomplished using FAA-approved data. Primarily this information comes from your Structure Repair Manual or your Maintenance Manual or a Service Bulletin, if it has a repair listed. All of these provide FAA- approved data.

In the event we have a repair without FAA approved data, we go to Boeing Customer Service to develop a repair scheme. The best example is any repair we make now in the lap splice on an airplane in an AD area. Such repairs require FAA approval before being made. The engineer prepares a repair scheme, gives it to the local Boeing rep, and it is then transmitted to Boeing Engineering for review. Based on their review they either approve the repair or disapprove it and suggest an alternative scheme. If this requires FAA approval, we then go to the Boeing Designated Engineering Rep (DER), who evaluates the repair. If the repair meets FAA requirements, the DER issues what we call an 81103 and files it with the FAA. This becomes our approved repair data as long as we effect the repair as described by the DER.

The procedures just described are straightforward but do not always work that way. At times, when we request repair approval from the Boeing DER he may say, "We don't consider this a major repair. This is a minor repair since it is in secondary structure." With this, we face a problem which, in fact, is industry-wide. There is no good definition of a major or a minor repair in the industry, although there are definitions in FAR Part 1 and FAR Part 43. How- ever, anyone in the industry recognizes that there are problems with these definitions.

Every airline has its own definition of a major repair in its Operating Manual. This Operating Manual has been approved by the FAA and, although the definition may not be exactly as in FAR Part 1 or FAR Part 43, the definition is approved and we must abide by it. Therefore, even if Boeing tells us it is a minor repair, if our Operating Manual says it is major, we must deal with it as such. The FAA holds us accountable to administer our own program and follow our own approved manual. So we must proceed to get the FAA approved data.

The final point noted on Figure 3 is that Boeing Customer Service and the Boeing local representative help us with logistics matters, particularly if there is a requirement for Aircraft On Ground (AOG) parts. The local rep provides a great service in obtaining these parts.

We have two ways in which we communicate with the FAA, as shown in Figure 4. Primary FAA contact is through our local Flight Standards District Office (FSDO). In our FSDO, we have a Primary Operations Inspector who oversees our flight activities, and a Principal Maintenance Inspector, who oversees our maintenance program. These individuals look primarily for compliance. Does the conduct of our program comply with FARs and does it comply with our own program? FAA provides basic requirements in the FARs, in our case FAR 121. We then develop our own programs to demonstrate to the FAA how we will satisfy these requirements. They then accept our program and subsequently audit us to ensure that we are complying.

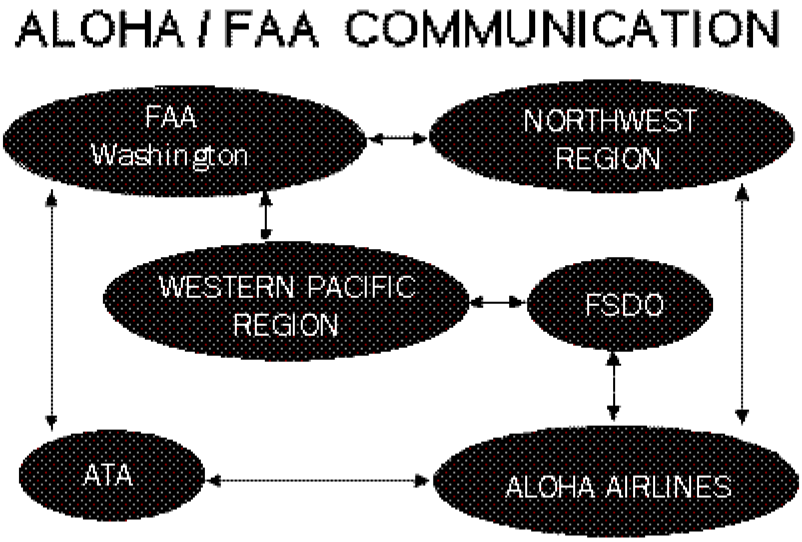

Figure 4

The other way in which we communicate with the FAA is through the Northwest Region. Airworthiness Directives (ADs) for the Boeing 737 airplane come from the Northwest Region. These are the documents that affect the engineering and maintenance of our airplanes.

Airworthiness Directives are not always clear-cut and easy to understand. When we receive an AD, we make copies and spread them through the organization to Quality Assurance, Inspection, and Maintenance. We then have a meeting until we come to a conclusion as to what the AD really requires of us. After this, we normally call Boeing engineering to see if they agree with our conclusion. Once Boeing concurs, we then talk to the Northwest Region, and say, "We think this is what the AD says; this is how we intend to meet it; do you agree with our approach and does it meet the needs?" Generally, the Northwest Region agrees; sometimes they don't. As this communication loop is proceeding, we also keep contact with our Principal Maintenance Inspectors at the FSDO. They are equally interested in ensuring that we comply with these Airworthiness Directives.

Every Airworthiness Directive, as I said, tells you how to accomplish a repair. However, sometimes the AD does not cover every aspect of repair, and you must go to the FAA for approval of an alternate compliance. For example, on ADs dealing with the Boeing 737 lap joints, you always need an alternate compliance. In this case, we contact the Northwest Region for approval for the repair we plan to make. We also go to Boeing engineering to be certain they concur with our approach. Finally, we may contact our Principal Maintenance Inspector at the FAA FSDO. So, as you see, there can be a considerable paperwork flow and a lot of personal interaction in our communications with the FAA and the manufacturer concerning repair plans.

At Aloha Airlines, our maintenance program is controlled through a well- defined planning process dominated by the Engineering Department, as shown in Figure 5. Inputs from the FAA FSDO come in through our Quality Assurance Department. Other outside inputs come through our Engineering Department, from Boeing or the FAA Northwest Region. It is also through Engineering that we communicate with the Air Transport Association. When a Service Bulletin or a Service Letter or similar document arrives, Engineering reviews it and gives copies to all other departments for their review. On a monthly basis, we meet to go over these Service Bulletins and Service Letters and determine which apply to us, what the requirement is, if we need to act on it, and how to accomplish it. If we decide we want to do it, Engineering creates an Engineering Change Order to accomplish the inspection or modification. The Planning Department then coordinates all other required activities such as acquiring the necessary material, coordinating this activity into our Maintenance Plan, coordinating with production and inspection activities, and scheduling the work to ensure that it is accomplished on time.

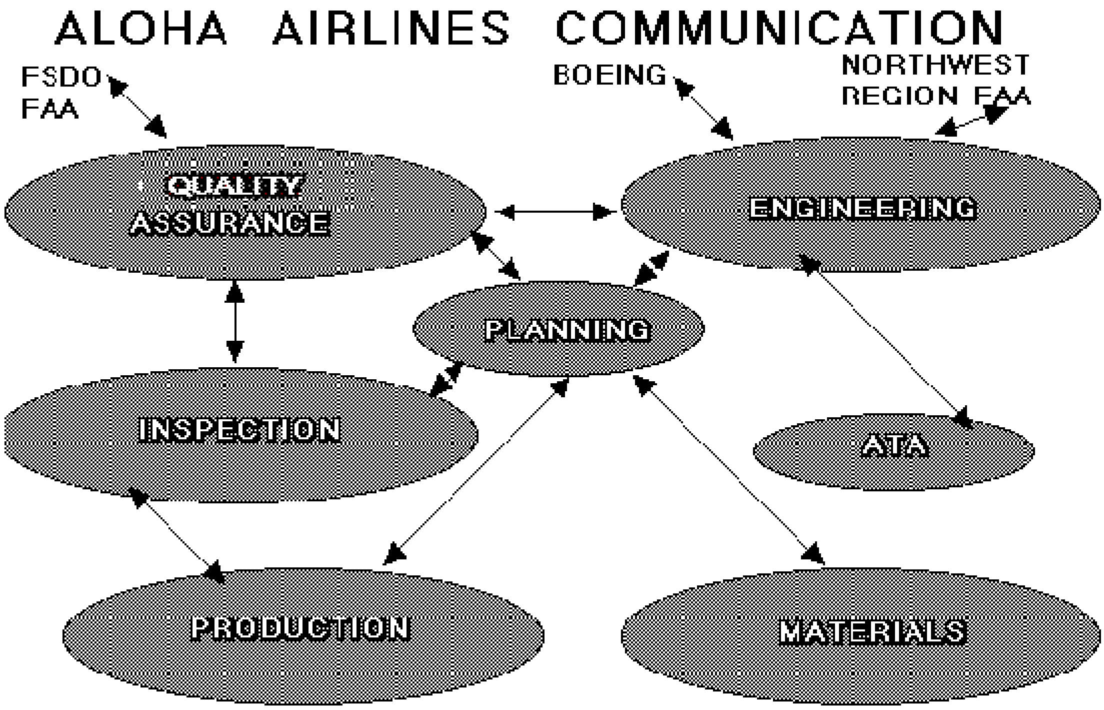

Figure 5

We meet on a daily basis to review the previous day's operations, to determine what our problems are, and to plan for the remainder of the day and the next few days. Our Boeing representative sits in on these meetings and is well informed as to what we are doing. Although he is a Boeing employee, we consider him part of the Aloha family and maintain a very open line of communication with him.

Each afternoon, we have another meeting. At this time we review current repair efforts, our manpower requirements, deadlines for various jobs, and any additional work we foresee. At this time, we plan the evening's maintenance work. One nice feature of a small airline such as ours is that every airplane is in maintenance at our home base every night. This is a luxury not many airlines have and it certainly eases our communication requirements.

I have described the communication procedures used at Aloha Airlines. As a final point, I would like to discuss briefly communications between the FAA and airlines in general. For the most part, I feel these communications have improved greatly over the last several years. In the 1985-86 period, large fines were being imposed on airlines for non-compliance and other problems. At that time, when we saw an FAA inspector arriving, we did not want to talk to him. Rightly or wrongly, many of us felt that he was there to make a profit. While I know that was not the case, that was the feeling. As a result, the industry "clammed up" on talking to the FAA and problems were not being solved. This is no longer the case. Problems now are being solved.

The task forces set up by the Air Transport Association and the FAA Aging Airplane Group represent forces which are improving our lines of communication. When the FAA group met with us recently, I felt it was the first time we could just sit with these Airworthiness Inspectors and other experts and talk over what we were doing and trying to accomplish. The FAA group was very knowledgeable and provided considerable feedback into what was a problem-solving session. We need more of that in the industry to improve communications and maintenance performance. Our industry functions better when we work directly with the FAA to examine problems and arrive at solutions as opposed to simply being inspected for compliance. The current changes represent a positive move.

Commuter Airline - Vendor Communications

A. Fred Giles
Continental Airlines Commuter Division

The communications network to support aviation maintenance, whether one is referring to the major carriers or to commuter airlines, exists as a three-way operation. Information moves, with greater or lesser efficiency, among the three major elements in the network -- the corners of the familiar industry "triad," as shown in Figure 1. The driving force behind a major part of these communications is purely economic. Manufacturers need to make money. Airlines need to run a profitable operation. Overriding these economic forces, however, is the regulatory issue. The Federal Government regulates and oversees the air transportation industry and the motives here are not economics but safety. Communications to and from the Government deal largely with matters of compliance. In the interest of safety, regulations are prepared. The industry must comply.

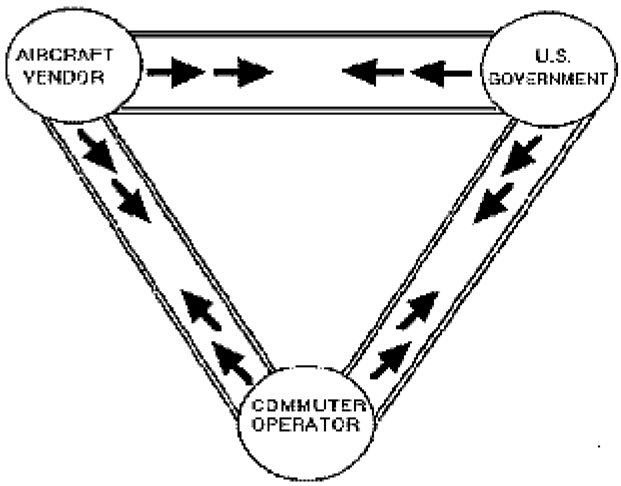

Figure 1

Compliance for a major carrier and compliance for a commuter airline are the same. All operators must comply with the regulations. However, there are realities which must be taken into account. The commuter industry is one which has grown in some instances from one and two man businesses to a Part 135 operation or a Part 121 operation with multiple airplanes. Thus, with commuters, there is not the same structure, authority, and research capability found with the major carriers. A director of Quality Control might be one person who does everything. However, he must contend with the same regulations and communications as the large carrier and must comply in the same manner.

Compliance is a matter both of procedures and of paperwork. A regulation will mandate some particular action or procedural change but it also inevitably requires accompanying paperwork.

Large carriers deal with the requirement through a Technical Publications Department. Commuters deal with the requirement in the same manner, except that the Technical Publications Department may be only a single person. This person is responsible for the paperwork and, in large measure, the communications link that is essential for continued operation of his airline. He is also responsible for the quality of publications underlying his operation. If these technical publications are badly written, that is how the airline will be run. Correspondingly, if publications are handled well, the airline will be a better operation.

Technical communications operate along the three dimensions described in Figure 1. From the point of view of economics, the most important of these is the "Airline Operator-Airline Vendor" dimension. Typical types of communications here include:

Aircraft Vendor to Operator

Service Bulletins

Information Letters

Recommended Repair Schemes

Modifications Update

Publications Revisions

General Vendor Communications

Operator to Aircraft Vendor

Completed Repair Schemes

Modification Compliance

General Operator Communications

The first part of the above communications link, that flowing from the vendor to the operator, is driven by compliance requirements but also by financial considerations. The vendor has a product to sell and the operator a product to use. For the vendor to remain in a competitive position, he must keep his airplane flying and flying well. This communication channel supports these goals.

The flow of information from the operator to the aircraft vendor varies, in the case of commuter airlines, with the relationship that exists between the vendor and the operator. In my experience with different commuter carriers, I have seen this link be sometimes cool and sometimes very active.

The next leg of the three-way communications system involves the operator and the Government, the regulating body, and contains the following types of communications:

Government to Operator

Regulations

Advisory Notices

Notices of Proposed Rules

Approval and Disapproval of Compliance Techniques

General Government Communications

Operator to Government

Proposed Compliance Techniques

Response to Proposed Rules

Proposed Alternate Means of Compliance Required by Advisory Notices

Discussion of Regulations

General Operator Communications

Communications from the Government to the operator deal with the regulatory environment in which all operators work. These regulations establish procedures and standards for our maintenance program to ensure that we achieve the desired safety goals. Our problem here is one of ensuring that we understand completely the meaning of the different directives from the Government. It is imperative that this link be clear, concise, and well understood by those persons using it.

The return flow of information from the operator to the Government generally deals with the manner in which the operator will meet the regulatory requirements. This part of the communications link is not as clear as that from the Government to the operator and frequently is subject to miscommunications. I have seen misdirected communications from the operator back to the Government which were sent to the wrong office, thereby greatly reducing the effectiveness of the communications.

The final leg of the three-way network deals with Government-vendor communications. The principal messages sent in this leg include:

Government to Aircraft Vendor

Certification Approval

Engineering Requirements

Advisory Notices

General Government Communications

Aircraft Vendor to Government

Certification Approval Requests

Proposed Engineering Changes

Proposed Advisory Notices Data

General Vendor Communications

We as commuter carriers have little involvement with the Government- vendor communications leg. We can give our views on some aspects of these communications but probably all we should do is simply try to understand the link.

To this point I have been describing "near perfect airline communications." I say near perfect because I am describing communications with a U.S. manufacturer and the U.S. Government. The value of these links depends on the quality of communications between the vendor, the operator, and the U.S. Government. But what happens to the quality of these communications when we deal with a foreign manufacturer rather than an American manufacturer?

Table 1 shows that commuter operators now deal with 11 major manufacturers, two of which are in the United States. Table 1 lists these 11 aircraft vendors and shows that, whereas in the United States there is one regulatory agency with which to deal, there is a different agency for each different foreign government. This table clearly illustrates the odds of a commuter carrier with more than one type of airplane having a foreign manufacturer within his hangar.

Table 1

COMMUTER AIRCRAFT VENDORS

	AIRCRAFT VENDOR	US GOV'T	FOREIGN GOV'T
1)	AEROSPATIALE	FAA	DGAC (Direction General Aviation Civil)
2)	BEECH	FAA	*N/A
3)	BRITISH AEROSPACE	FAA	CAA (Civil Aviation Authority)
4)	CASA	FAA	DGAC (Direction General Aviation Civil)
5)	DE HAVILLAND	FAA	MOT (Minister of Transport)
6)	DONIER	FAA	LBA (Civil Aviation Authority)
7)	EMBRAER	FAA	CTA/EC (Center Tech Aviation) (Certification Office)
8)	FOKKER	FAA	RLD (Bureau of Aviation)
9)	FAIRCHILD/METRO	FAA	*N/A
10)	SAAB	FAA	CAA (Civil Aviation Authority)
11)	SHORTS BROTHERS	FAA	CAA (Civil Aviation Authority)

*U.S. Aircraft Manufacture

Use of an aircraft of foreign manufacture does not mean that communications simply shift from the U.S. Government to the foreign government. The U.S. Government remains very much in the picture. The major difference, as shown in Figure 2, is that the foreign government now is interjected into the communications loop, principally between the aircraft vendor and the U.S. Government. However, the requirement to deal with the foreign government very much affects operations of the commuter carrier.

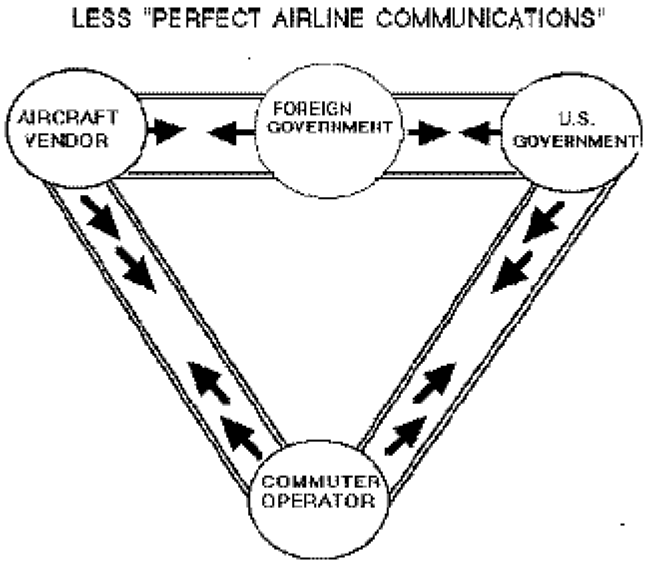

Figure 2

Let me provide an example of one of the communications issues we face on occasion when dealing with a foreign vendor. In this instance, we received an Advisory Notice for an aircraft modification which had an alternate means of compliance paragraph but did not show an alternate means. This means, of course, that if you wish to use the alternate means of compliance you must provide your own engineering data, which we did. Some time later, as a function of the lag in communication with a foreign agency, we received a Service Bulletin indicating a modification had already been approved. However, since we were so late in receiving this, we had to deal with the alternate means of complaince. To avoid this, it was necessary for us to write a letter to the U.S. Government stating that we planned to use this Service Bulletin, which had been approved in another country. Needless to say, this is not an expeditous way to do business.

Another problem we face with foreign vendors is that of getting paperwork for aircraft procedures prior to required installation of modifications. The creation of predevelopment procedures is not something foreign manufacturers do easily. In the case of one foreign aircraft, the FAA indicated we should comply with all mandatory Service Bulletins, to which we obviously agreed. The first Service Bulletin came and we made the necessary modification. However, we could not find the required paperwork for the Flight Manual to describe related procedures changes. After our call, the vendor said the paperwork had gone to his regulatory agency. Initially, we tried to obtain this paperwork through the U.S. Government, but with no success. I then called the foreign agency and found that the pages to the Flight Manual had been sitting on the desk of a lady who was on vacation. However, they couldn't be released because each page had to be perforated with punch holes which indicated the serial number of the airplane. Unfortunately, the individual responsible for that task also was on vacation. Finally, we located the woman who was on vacation and had her authorize another person in the office to punch the necessary holes. After a DHL delivery and a delay of three days, we were ready legally to get the airplane in the air.

The above example illustrates the kinds of problems faced by commuter airlines using aircraft made by foreign manufacturers. The issue is not insignificant. At this time, there are about 130 commuters flying aircraft made by at least nine foreign companies. And the commuters flying these aircraft may not have Technical Publications Departments ready to deal with such problems. Continental Express, TWA Express, and United Express are not necessarily representative of the entire commuter airline industry. Commercial airlines live with difficult and cumbersome communications. Communications and the exchange of information throughout the air transport industry are not perfect, as we have heard today. When a foreign government and a foreign manufacturer are introduced into the communications network, matters do not improve. Therefore, I request that as we work toward improvements in the exchange of information in the airline industry, we keep in mind that these changes must recognize the existence and the role of foreign governments and manufacturers. These foreign regulators and vendors represent important parts of our industry.

Human Factors Issues in Manufacturers' Maintenance-Related Communication

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McDonnell-Douglas Corporation

The inter-organizational communication system of an aircraft manufacturer can be described as a network of links that evolves over time to accommodate regulatory, market, and efficiency needs. A communication itself can be just about anything that transmits information. A communication episode, which can take all forms, is started by asking or by telling or by recommending something. A research report is one example; a drawing is another; others include telephone conversations, contracts, regulations, training manuals, maintenance manuals, a paint scheme on an aircraft, and so on. For business purposes, I would not include matters such as rumors, social greetings, and casual conversations. Here we are concerned with an intent to transmit information.

I would now like to show examples of regulatory, market, and efficiency concerns expressed by types of communication. One should recognize, of course, that these examples represent but a few of what could be quite a long listing. The following listing provides examples of communication processes that I believe capture regulatory concerns:

- Federal Aviation Regulations
- Maintenance Review Board
- Airworthiness Directives
- Designated Engineering Representatives
- Supplemental Inspection Documents

The Federal Aviation Regulations and the Maintenance Review Board establish, or communicate, the original maintenance planning for a new aircraft model. The Airworthiness Directives, DERs, and Supplemental Inspection Documents, address regulatory concerns as an aircraft proceeds through its useful life.

This next listing provides examples of communication processes oriented to market concerns:

- Customer Service Representatives
- Field Service Representatives
- Service Bulletins
- Maintenance Manuals
- Customer Training

Customer Service Representatives may number in the many hundreds. Possibly a thousand or more would not be unusual for a large manufacturer. Field Service Representatives are those agents of the manufacturer who are on site at large repair facilities of the operator. They represent a direct maintenance communication link. Service Bulletins play an important part and may be mandatory, such as those that might apply to aging aircraft. Maintenance manuals are the backbone of communication concerning aircraft maintenance and are being given increasing attention today. Focus is on procedures for automating maintenance manuals and/or presenting them in a way stressing ease of use, access, and resistance to destruction during field use. Finally, customer training represents a form of communication oriented to market concerns. Customer training, Customer Service Representatives, and Field Service Representatives are important factors in the buy decision for operators since the strength of customer service may play an important part in an operator's success in using an aircraft and keeping it in the air for ten to twelve or more hours a day.

Examples of communication processes oriented to efficiency concerns are shown in this next listing:

- Team conferences

- Maintenance audits
- Abbreviated component maintenance manual
- Customer support directory
- Periodicals for customers (Douglas Service)
- Participation in industry associations (Aerospace Industries Association, Air Transport Association)

Team conferences can be very useful. Douglas Aircraft has just published a report of the Team Conference for the MD-11 and the DC-10 aircraft held at Douglas recently. These documents cover many topics. The basic theme is to introduce a concern communicated by an operator to the manufacturer, ask for operator comments, and then present manufacturer comments. The meeting serves the needs of the customer in providing an opportunity for many different operators to talk about their concerns with certain products. The conferences have been successful because operators have a chance to talk to just about anyone they meet when they visit the manufacturer's plant. They also talk with other operators who might be having similar or related problems with their equipment.

During maintenance audits, teams of specialists from the manufacturer visit the facility of an operator. The operator benefits by understanding the extent to which he is meeting required maintenance and by obtaining a scale or an index of operator efficiency. Maintenance audits offer a useful exchange between the operator and the manufacturer.

Abbreviated Component Maintenance Manuals (CMMs) are another example of communication. The background of these manuals rests with the experience of one airline which found that, due to rising costs of parts, they would rather repair parts of certain components - bushings, bearings, sleeves, or wrought ends - than replace entire components. A suggestion was made that Douglas Aircraft produce abbreviated Component Maintenance Manuals. In less than a year, draft abbreviated CMMs were produced by Douglas which met the operators' need. I believe that Revision 27 of ADA-100 provides specifications for the publication of abbreviated CMMs. This is an example of communication taking place with the services of a voluntary association which worked quite successfully. Two examples of abbreviated CMMs at Douglas are for the inboard slat drive anti-torque wrought end assembly and for the air-driven generator retainer assembly. These manuals are only five or six pages in length but they enable an operator to repair a part and therefore not discard an entire component and have to buy a new one.

Customer support directories are another form of communication oriented to efficiency. It is efficient for an operator to have individual points of contact for different types of questions. At Douglas, there is a Customer Support Directory for the MD-11, the DC-10, the MD-80, and the DC-9. These directories list the area of specialization for scores of people. They show not only business but home telephone numbers. By developing these directories, the manufacturer illustrates that he is providing needed customer service support and satisfaction. He also shows that customer service is available 24-hours a day, seven days a week, throughout the year. Business can be conducted efficiently and as needed.

Periodicals are the final example of communication processes oriented to efficiency. The Boeing Aircraft Company produces a number of very fine periodicals. Douglas Aircraft, I am pleased to say, has reinstituted Douglas Service, a publication prepared for 42 years, followed by a two-year hiatus. When publication stopped, many protests were received and it is now being republished. This particular publication is dispatch-oriented. It discusses specific problems that are keeping aircraft on the ground.

The attributes shared by the diverse forms of communication described above are those that enable organizations to (1) understand the needs or requirements, (2) predict the consequences of a message, or (3) control events as may be appropriate.

Communication systems can be modeled, as shown in Figure 1. Basically, the model refers to energy entering the system, being transformed, and leaving the system in a different form, with possibly a feedback to change the energy flow for the next message. For a communication system, there is a communication requirement, or question, which triggers the system. The transformation process might involve policy or ownership decisions applied to the communication media. The scope and structure of the communication could be defined during the transformation stage. How shall the communication be done? At the output, we want a product, an answer, or an action of some kind. Also, feedback is often part of this system model. The inter-organizational communication system used today is open because boundaries are not rigid. Output actions can serve to modify the communications system to make it more efficient or more responsive.

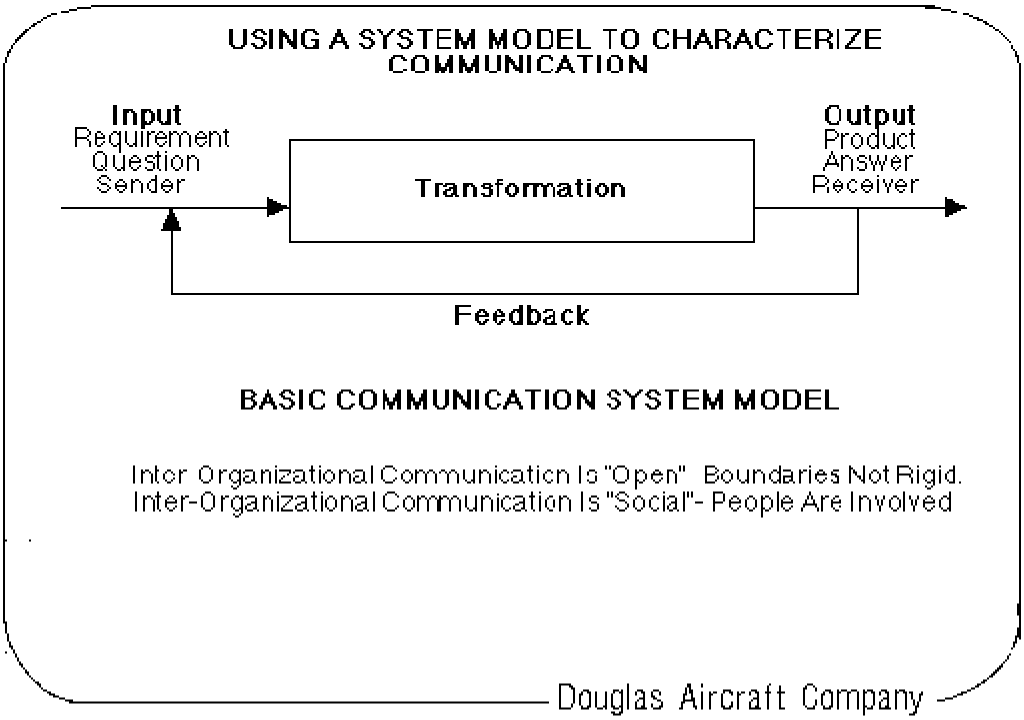

Figure 1

Here are a number of problems and characteristics of inter-organizational communication, taken from the communication literature. They are presented with comments to relate them to our present discussion.

1. Communications efficient at one level may be inefficient at another.

Federal Aviation Regulations and Airworthiness Directives, for example, may be efficient at an upper or management level of maintenance and not be so efficient at a lower or working level.

2. Some systems may be over- or under-rationalized.

By rationalize, I mean a deliberate and systematic attempt to organize communications. Some systems work best when highly structured or organized; others work best when loosely structured.

3. Communication "on the behalf of . . ." can lessen an agent's involvement.
4. Perceptions of communicative functions may limit the value of the system (transformation affected by perceptions).

Differences in employees' perceptions of their responsibilities can create differences in output. As an example, a person in the manufacturer realm might think that his job is to report company policy. A second person, with essentially the same message to deliver, may feel that his job is to satisfy customer needs. Airline operators obviously would rather talk to the second person.

5. "Full and complete" communication is not a cure-all.

Here I mean that one should not necessarily try to be open and complete in every communication. There is always something more to say about a particular question. However, there comes a point at which the person seeking information does not need more information. The provision of excess information is not efficient. The greater challenge is to provide the necessary information.

6. Conflict between short- and long-term business viability may create communication problems.

7. Conflict between an organization's norms and its formal policy may create communication problems.

8. "Information ownership" may adversely affect transformation.

Some organizations, or individuals within organizations, may withhold information for reasons of power or prestige or misplaced career building. Since deregulation, some may believe that certain maintenance information is economically important, and that may be true. However, it makes forecasting and ultimate support of operators more difficult not to have comparable information about maintenance programs or costs.

9. The system may have current uses for which it was not designed.

10. An assumption of perfect communication (no feedback) is common; planning for imperfect communication is not.

We generally assume that a trained person will perform correctly. We frequently assume that a person assigned to schedule will schedule; a placard will be seen; or a manual will be read. None of these assumptions is always true.

11. Mistaking inter-communication effectiveness for system efficacy may be an unwitting sacrifice.

This means that we can hold interpersonal communication so important that we may sacrifice a more effective system to hold on to that interpersonal communication. Systems in which the interpersonal factor has been abandoned can be very effective. The automated voice from Directory Assistance in telephone service and automatic teller machines are examples. Automobile rental car systems which provide automated driving directions with standardized language represent another. Here, the driver indicates his destination and receives a map that uses the same language every time. It is quite effective. Only now, in my opinion, is the aircraft industry beginning to exploit simplified English with standardized terms. Words such as "disassemble," "lubricate," "shall," and "would" should have consistent meaning.

12. There is a normal (input) difficulty in specifying in advance what information will be needed. This may create a problem in supplying information.

A manufacturer may supply inadequate information about maintenance of a new aircraft because of the difficulty in specifying -- before operational experience has been gathered -- what information will be needed.

13. There is no magic in communication; it cannot offset poor planning at input, transformation, or output stages.

Many examples support this conclusion. A supplier cannot fix an incorrect part shipment by words alone; a manufacturer cannot correct a poor design with a sophisticated communications system; an operator cannot overcome a fundamental scheduling problem by generating numerous memoranda; and a regulatory agency cannot make a staffing problem go away by widening its communication network.

Finally, I would like to offer a few recommendations. These are global recommendations, but the topic itself is global.

1. There should be an ongoing program to solicit ideas for communication mechanisms to support maintenance. People in all parts of our industry are involved in communications. They have needs and they have certain ideas for answers.

2. Feedback should be used to improve communication processes. Feedback to improve any process is a necessary step, and feedback often is ignored due to our assumption that the system is working as it should.

3. We should intentionally focus on communication mechanisms. There are specialists

who know about communication and how it works. Studying what these people have to say or talking with these people might provide new insights into means for improving or fixing problems in given communication links.

4. We can evaluate communication mechanisms. Are they serving the purpose for which they were intended in the first place? Are they truly effective? Regarding communication effectiveness, I would like to relate an incident that happened as I was boarding a plane in Orange County to come to Washington. At this time the John Wayne Airport is undergoing a major building program and does not have jetways or other motorized conveniences for planing and deplaning. Planes must line up on the apron or tarmac or gate area one-by-one and passengers have to walk to the aircraft. Just before I boarded the flight, the boarding agent said over the public address system, "Flight 1256 is in final boarding. Passengers should proceed through Gate C. The plane is in the middle of the runway, it is facing south, and it's a Boeing." Other than the experienced traveler, who would know where to go with these instructions? How much of our communication in maintenance could take on similar tones because the communication is not clear and the maintainer does not know where to go with the instructions? There is still much to be learned concerning the communication process and ways for making it most effective.

Facilitation of Information Exchange Among Organizational Units Within Industry

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Introduction

In these remarks I will discuss some of the barriers to communication between organization units, and I will introduce concepts which may offer insight into coping with these barriers.

First, I would like to emphasize that the air transport industry is living in an environment that is becoming increasingly complex. Indeed, we might call it "chaotic." Today's maintenance environment includes an increasing passenger load, increasing international competition, a short supply of new passenger aircraft, more short-term cost concerns, increasing fleet size of aging airplanes, more complex technology (both in aircraft and tools), heightened concern over the curriculum of A&P schools, and a reduced supply of applicants to those schools.

If we want people in maintenance and inspection to be able to adapt to this complexity, rather than merely react or succumb to it, they must have a greater understanding of their place in their environment -- a complex international system of air transport. My remarks today will address ways that exchanging information affects understanding, and in turn improves that adaptability.

Barriers to Communication

What follows are some barriers to information exchange in aircraft maintenance. An understanding of these barriers offers ways to think about successfully adapting to complexity.

Aircraft design philosophy has changed over the past 15 years. This change has direct effects on maintenance practice and philosophy. First there was "fail-safe" philosophy which relies on redundant parts; if one component breaks there is another component in line ready to carry its load. Therefore the failure is not threatening, and maintenance can be "after-the-fact" in repairing what has broken. Another philosophy is "safe life," in which individual components and parts can be tested to failure before manufacture. With these test data, plus an appropriate time added to be conservative, replacement time for those parts can be predicted. When the component has operated for that time, the maintenance task is to simply replace the part regardless of its condition. A third maintenance philosophy is "condition monitoring." This has to do especially with the problems of aging aircraft, and to the situation of the pressure cabin -- for which there is no redundant part. In condition monitoring it is necessary to monitor sheet metal skin to determine whether design life can be extended. Using condition monitoring, cabin life can be theoretically extended without limit. The result is that older airplanes become harder to work on, and mechanics become less experienced. In short, the older mechanics don't know the new sheet metal techniques very well, and the younger mechanics don't know commercial airliners very well.

Condition monitoring generally involves supplementary structural inspection documents (SSID's) which call for new inspection procedures. "Damage tolerance analysis," which specifies crack growth rates, allows one to program inspections at times when crack damage has progressed, but has not yet produced an unsafe flight condition.

These are fairly new ideas throughout the industry, and different people have different meanings for these terms. For example, some maintenance people simply do not know what damage tolerance is; while others believe that any addded inspection policy is a SSID. Obviously such confusion does not facilitate information exchange.

Another barrier to appropriate information exchange is occupational language. Occupational language refers to specialty language used by different disciplines. Generally, it is not necessary and may actually get in the way. For example, "hard-time replacement" and "safe life" seem to mean the same thing, yet they are different terms in use by different groups.

The industry also is beset with imprecise use of terms. Various FAA documents and manufacturer's recommended standards use imprecise terms. For example, for mechanics tools or maintenance equipment, one may refer to "standard tools" or "common tools." Is there a difference and, if so, what is it? Another example would be the difference between "light" versus "moderate" corrosion in the commuter fleet. At this time, the corrosion problem needs to be addressed before it becomes moderate -- whatever that condition actually is.

Arcane language, such as that found in many places in the Federal Aviation Regulations, and a multitude of acronyms also represent barriers to information exchange. Acronyms particularly can be misleading. For example, "MISTS" means severe thunderstorms. Others have dual meanings, such as "SID" which can mean either "supplemental" or "structural" inspection documents. The idea of a standardized and simplified English for use in maintenance makes more and more sense.

International communications is a topic of interest. I have noticed that international operators tend to have a sense of community that I believe is rare and not often found outside this industry. They share a strong pride when it comes to aircraft safety. Also, the simple fact of possessing a national airline gives one pride in being part of a larger technological society.

Ironically, even with this strong community, information exchange between companies can lessen. Interorganization communications has been affected by airline deregulation. In a deregulated industry, subtle pressures can be placed on maintenance to reduce costs. Even though one might like to communicate with other maintenance people in other places, the pressure to get the work out lessens one's ability to share information and to attend industry conferences.

Intracompany communications is a particularly important topic. Aviation maintenance can be described through the concept of functional "silos." In this instance mechanics and inspectors are separated, for the good reason that one does not want too much collaboration between the group doing the maintenance and the group doing the "buy back." Functional silos, however, generally do not represent good arrangements for effective communications. As a metaphor, it is a powerful image to have people in silos who are trying to communicate with others by shouting up and hoping that others elsewhere hear it.

The key to understanding information exchange and organizational barriers is in the idea of system stability. We would all like to have an international system of air transportation which is stable. This should be a system that is progressing and developing rather than becoming more and more entangled in its own environmental complexities. System stability in a turbulent environment is the goal.

How can organizational stability be achieved under present chaotic conditions? In such environments, individual organizations, however large, cannot expect to adapt successfully through their own direct actions. They depend on others in the industry. This solution is based on the emergence of values that have overriding significance for all members of the industry. These social values represent coping mechanisms and help overcome the barrier of complexity. They are mechanisms that make it possible for the industry to deal with persisting areas of uncertainty.

Coping with Communication Obstacles

To understand the importance of coping with communication barriers, let us view the maintenance community as a sociotechnical system. This is a system which delivers a technical output achieved through cooperation and coordination among its members -- and of course that is where the communication comes in. The key requirements to facilitating information exchange in a socio-technical system are:

- Understanding the larger system
- Choosing appropriate philosophy and values "for the industry"
- Taking a product focus
- Using a common language
- Holding conscious and collaborative expectations

The first requirement is to understand the larger system. What is the nature of the environment? Since the commuter airline fleet has not had the same well-publicized accident as the larger carriers, one could say that the same aging aircraft problems do not exist with the commuter carriers. However, commuters are part of the larger air transport system and one should find the same generic maintenance issues and problems there.

The second requirement for facilitating communication -- "choosing appropriate philosophy and values," is a key topic for this discussion. Social values really represent coping mechanisms. This mechanism makes it possible to deal with persisting areas of uncertainty by providing a common vision or focus. If a single large organization cannot successfully adapt by itself, what can it do? To the extent that effective and appropriate values emerge, large classes of events can be addressed through this ethical code of values. Given the right set of values, we can come to understand more about and cope with the complex environment we are facing. This organizational transformation will be either regressive or constructively adaptive according to how far these emergent values adequately represent the new environmental requirements. In other words, we have to understand the environment in order for our system's values to really make sense.

The value of collaboration among members of the maintenance industry is crucial. There is, in fact, considerable collaboration at this time. Certainly there is more collaboration in the maintenance departments of the airline industry than one perhaps would find in the marketing departments. In marketing, some information might be proprietary, but in maintenance the value system supports collaboration. Collaboration in safety can lead to a conscious agreement on common maintenance philosophies and to ways to communicate common values to every member of the system. There may be more sense of cooperation between different company's maintenance systems than between the departments within a single company.

Information exchange can be used to reinforce the understanding and the utility of common industry values. As noted, collaboration is one such common value. However, there are some maintenance philosophies that may or may not be shared by many members and certainly are not shared by most members of the larger international air transport system. Examples include a commitment to "condition monitoring," and to the frequent inspection required by "SSID's."

An analysis of a sociotechnical system not only discusses important elements in the environment and the kind of values that help make the environment make sense, but it also says that the technical system is important. A technical system analysis is undertaken only when we understand the importance of the appropriate values in adapting to environmental chaos. Further comprehension of the technical and social aspects of the system then is in order.

The third requirement for enhancing communication is focus on product. Human effort, coupled with instructions, machines, and tools forms the technology of aircraft maintenance. Safe aircraft in commercial service are the through put, or product, of the maintenance and inspection function of the air transportation industry. The technical systems analysis focuses on what happens to these aircraft (the product), as they pass from manufacturing to flight and to engineering and maintenance systems again and again. Does everyone hold a consistent view with respect to this industry product? If the industry purpose is to safely put as many people in the air at the lowest possible price, industry views and values may not be consistent concerning maintenance values. One segment of the industry is looking for maximizing short-term profits; another segment is looking for maximizing size of market. Are members of the maintenance community aware of those differences?

The fourth item in the listing of requirements for facilitating communication is "using a common language." Common language comes from the product, but the common language also comes from a conscious attempt to share information in a way that is unequivocal. There are many examples of imprecise use of language in the maintenance industry. When one includes international carriers, the issue becomes even more difficult.

The final requirement for facilitating communication discussed here is the conscious and collaborative expectations by members of the maintenance community. In the maintenance social system, the web of relationships among all parties involved comes into focus. What significance does this network have for communication? For one, it means that, depending on his expectations at work, a mechanic or inspector can respond in a number of different ways to a maintenance problem. For example, if a mechanic discovers a possible flaw and expects to learn from this occurrence, he will welcome help from a supervisor. However, if he expects the supervisor to trust him and leave him alone, he will resent the supervisor's intervention. From the supervisor's point of view, if he is expected by his superiors to know at least a little more than his subordinates, his intervention may be normal and proper for him despite how it appears to the mechanic. Thus the social system is a set of expectations sometimes positive and constructive, and sometimes not so constructive, with others in the workplace, with others elsewhere in the organization, and with outsiders as well. Depending upon the context, and organizational and individual history, such expectations will lead to different behaviors.

Appropriate behaviors are what we are concerned with ultimately. These behaviors include flexibility in the application of maintenance technology, cooperation and coordination. All of these behaviors are linked to the product -- in this case safe aircraft.

A common focus on the product -- a safe aircraft -- should be a straightforward matter for maintenance personnel. However many factors can serve to distort this focus such as pressures from the regulators, pressures from the marketplace, pressures from the competition, and other factors. The fact that we may not have a common language, the fact that we may have multiple (if not conflicting) maintenance philosophies, the fact that we may have arcane technical language, the fact that we may have imprecise use of terms, are all things that can cause loss of product focus and consequent problems in the maintenance system.

Another communication concept now in use in aviation is cockpit resource management (CRM), introduced by NASA about 10 years ago and now being increasingly adopted by air carriers. In its simplest form, cockpit resource management posits that flight deck personnel should be working together more than simply operating as a fixed military hierarchy where someone at the top gives orders and others follow them. This recognizes that give-and-take information and different perspectives are important on the flight deck. CRM applied to flight crewmembers is being accepted among the air carriers. The concept has begun to be applied to maintenance departments.

Intracompany communications are beginning to be supported by new ideas concerning teamwork in maintenance. In most maintenance operations, however, individuals still have clearly defined job assignments and job roles and rigidly adhere to these. Expectations for these people can be identified completely in terms of their job descriptions. This is not a flexible use of personnel nor does it foster productive communications.

Using teamwork in maintenance, people retain specific job assignments but are given more freedom to work with other units and to develop better procedures for cooperation. In one instance, an organization determined that it was top heavy in the specific job of quality control inspectors. Rather than continue with an inefficient organizational structure and organizational staffing, some of the quality control inspectors were given a training role and assigned to work with some of the less skilled mechnics. Now, rather than simply saying "this is wrong, do it over," inspectors guide the mechanics through the process and become what might be termed "allies in maintenance." The improvement in maintenance could be attributed both to the redefinition of roles and to the improvement in communications between specialties.

As a final point for your consideration, I would like to note that Japan Airlines now forms maintenance teams for specific aircraft. These teams focus on one particular aircraft. This approach is expensive since Japan Airlines has almost double the ratio of mechanics to aircraft that we find with the American system. Their teams include specialists, for example in hydraulics, electronics, and avionics, and the point is that they are willing to invest that. Whether this is a good investment or whether it is the appropriate solution for the U.S. is debatable. However it does maximize collaboration among maintenance personnel and certainly fosters good communications between the maintenance team and the flight crew.

In conclusion, I would like participants at this meeting to seriously question the extent to which there is collaboration and community within the air transport industry. Are our communication systems as good as they might be? Can we find ways to deal with some of the barriers to information exchange and instead use these features of our maintenance system as means for facilitating information exchange.

Information Needs of Aircraft Inspectors

Michael T. Mulzoff
Pan American World Airways

Predictions concerning the future role and information needs of aircraft inspectors can best be made by first examining the evolution of that position. Let's look back four decades at the inspector -- how he has changed, and how his job has changed. We will begin in 1947, simply because I first became an inspector in that year and can personally attest to that environment.

The 1947 mechanic and inspector had a different relationship with their aircraft than exists today. In those simpler times, a mechanic was more than vaguely familiar with most components of his aircraft and could essentially maintain most systems on his own. Even in those days, radio ("avionics" had not yet been born) was the one exception. Still, the complexities of today's aircraft had not yet arrived.

In the 1940's, "HARD TIME" was the prevalent maintenance program. Under this program, all major components were removed at specified intervals, regardless of their condition or how they were performing. These components were overhauled after which they were considered essentially new, and reinstalled with "zero time."

In addition to periodic component removals, these programs relied heavily on relatively frequent maintenance performance checks of the aircraft systems. Inspectors were most often involved in accomplishing these system checks (pressures, temperatures, operation, etc.).

Inspectors were also responsible for determining condition of the aircraft structure. Although of serious concern even in those days, the task was relatively simpler with the absence of pressurized fuselages and fleets that were less aged than is common today. As a result of these maintenance program requirements and less demanding structural considerations, the majority of a typical 1947 inspector's time was spent on aircraft systems rather than structures.

Inspection equipment was also much simpler when measured by today's standards. Dye penetrant and metal particle inspection methods were the main processes in use throughout the 1940's and 1950's. X-ray was a dental tool not often seen at the airport.

Throughout these four decades of evolution, some form of work sheet or guide has been used to outline the task to be done, and as a signature receipt for accountability. Early guides most often provided a general description of the task required, in most cases relying on the mechanic's or inspector's knowledge for proper accomplishment. As the aircraft became more complicated, the guides became more complex, and presently often contain detailed instructions, specifications, and illustrations.

Maintenance training in the 1940's and 1950's was patterned after the military schools and was excellent. This training provided the bulk of the airline workforce with their basic aviation education into the mid-1970's. This training concentrated on detailed systems knowledge which supported the "HARD TIME" maintenance program reliance of maintenance system checks.

Now let's move forward to the maintenance environment of the 1990's. Along the way, industry and the Federal Aviation Administration (FAA) recognized that systems could be best maintained by monitoring the continuous operating performance of the systems as reported by the flight crews. This would provide immediate knowledge of deterioration and be more effective than a later alert by a scheduled maintenance check. This ability to detect deterioration at an early stage also provided the means to allow components to operate until deterioration started rather than having a fixed removal time. With these revelations, "HARD TIME" programs gave way to "ON CONDITION" maintenance programs and Reliability Analysis Control.

The movement from "HARD TIME" to "ON CONDITION" maintenance programs has had a major impact on the inspection function. As previously stated, system checks with inspector involvement were a large part of the "HARD TIME" program. Most system checks now are accomplished by operational monitoring with little or no inspector involvement. The inspector's requirement for detailed systems knowledge and background became less essential than previously required. This factor does not imply that the need for systems knowledge has been eliminated. An inspector still requires a respectable knowledge of all systems that cause the structure to operate as a unit. However, today's maintenance programs no longer rely on the inspector to determine system condition, whereas his surveillance of structural condition is critical to the program.

The development of pressurized fuselages has been a balance to the inspector's functional change brought about by the "ON CONDITION" maintenance program. Where the "ON CONDITION" program reduced inspector responsibility for systems monitoring, the pressurized fuselage has generated an at least equal demand. Additionally, application of the "Supplemental Structural Inspection Program" created specifically for aging aircraft has added additional requirements to the inspection function. At this point, it is certain that the size of the aging fleet will increase in the next decade and with it the demand for structural attention by the inspector.

As the aircraft structure was becoming more complex and aged, the inspection methods and devices used to monitor airworthiness integrity of the structure also were developing. X-ray is now in common use and seen on most every heavy aircraft service. Ultrasonic and eddy current equipment are now considered basic tools for inspectors. The knowledge needed by inspectors for proficiency in Non-Destructive Inspection (NDI) in many cases exceeds aircraft systems knowledge that previously was considered the backbone of an inspector's education.

Figure 1 shows that in 1947 the career path of most inspectors traced back to the aircraft mechanic position. This served the inspection function well since it carried a strong background in aircraft systems to the position, and provided the type of knowledge best suited to support the "HARD TIME" maintenance program.

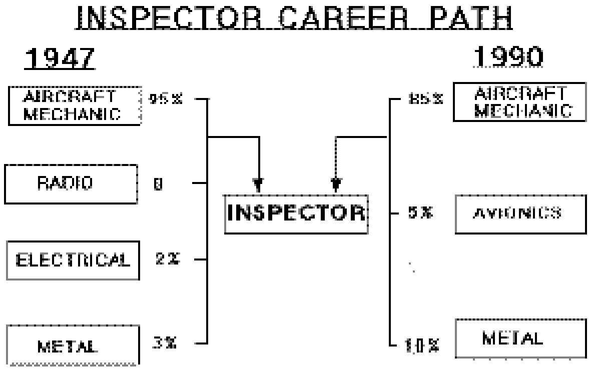

Figure 1

Figure 1 also compares the 1990 inspector career path with the 1947 era. The shift from mechanic to the metal specialty evident in this figure, as a career path for inspectors, lags the functional environment change that has occurred during this period. As Figure 1 indicates, the education and experience background of the majority of inspection recruits is still best suited for a 1940's environment. Ideally, the 1990's inspector should have detailed knowledge of aircraft structures, with experience in metal repairs. He should also have a general knowledge of structural design philosophy, and the maintenance program concept. In addition to all this, the 1990's inspector should be proficient with most types of NDI equipment.

Unfortunately, the knowledge disciplines previously listed as ideal for a 1990's inspector are not yet generally available in most training curricula except within individual Inspection Departments. NDI familiarization is not yet a requirement in FAA-approved FAR 147 schools and usually not covered in those courses (except for 1940 era dye check and metal particle inspection methods). Structural design concepts such as Fail Safe and Damage Tolerance are not yet generally recognized as beneficial to the metal repair specialist or inspector. The 1990's should see a change in this attitude with training in these subjects displacing some systems training.

No prediction for the future would be complete without some words about computerization. Since the invention of the printing press, no event in history has had as great an impact on the storage and transfer of information. The manipulation of bits and bytes now allows management to base decisions on a previously prohibitive amount of retrievable data. Miniaturization of computer hardware has allowed installation of built-in logic test circuits ("BITE") for many of the aircraft on-board systems. Further uses and advancements in computer technology will certainly be with us into the 21st century. However, all coins have two sides and there is a debit side to computers.

In their early stages of development it was often proclaimed that for all practical purposes, computers would make as a "paperless society." Are there any organizations that have adopted computer systems that have not actually multipled their use of paper by some X number? Underutilized 50 and 100+ page statistical reports are often routinely published based on ease of production rather than a legitimate distribution need. Hopefully, the 1990's will see a change in the handling of this prodigal child with an insatiable appetite for data, and better management of the ensuing waste.

A more serious consequence can result when the information system is insensitive to the human factor environment at the mechanic and inspector level. In one actual case, an internal company audit found part numbers on two critical, non-interchangeable parts so similar that the probability of an error was extremely high. The recommendation for a number change was refused because the change would have deviated from the system standard. Only after the probable error became reality, resulting in an in-flight incident, did the computer system become subservient to the needs of the working level.

Another example, less obvious but no less important, is a substantial increase, at least at one airline, in data collection requirements for each aircraft log book entry. During line departures, processing of the aircraft log is only one of many concerns facing the mechanic in a relatively short period of time. It is not uncommon for a departure to develop into a tense situation where the added administrative burden would be a definite human factor detriment. These situations will be minimized if management recognizes that the effectiveness of any maintenance program will always depend on how well mechanics and inspectors accomplish their tasks, regardless of how sophisticated computer systems may become; and that system design must serve rather than interfere with the accomplishment of these tasks.

Better Utilization of Aircraft Maintenance Manuals

Richard G. Higgins
Boeing Commercial Airplanes

The use of digital data to support aircraft maintenance operations is a fact of life now. Specification 100 of the Air Transport Association (ATA) says we must use digital data. The Boeing Company is firmly committed to such use and is moving rapidly in this direction.

The use of digital data systems is necessary because of the tremendous documentation now required to support aircraft maintenance. Boeing delivers about 70 manuals to support an airplane. To illustrate this information overload, Figure 1 presents a partial list of maintenance data deliverables supporting a single airplane. The list shown in this Figure is less than one-half of the total number delivered.

MAINTENANCE DATA DELIVERABLES

(Partial List)

MAINTENANCE DOCUMENTATATION
- Maintenance Manual
- Engine Ground Handling
- Corrosion Prevention Manual
- Non-destructive Test Manual
- Ground Equipment Manual
- Ground Handling Document
- Illustrated Tool & Equipment Manual
- Baggage/Cargo Loading Manual
- Ground Support Equipment (GSE)
- Systems Schematics Manual (Project)
- Component Maint./Overhaul Manuals
- Powerplant Buildup
- BITE Manual
- Structural Repair Manual
- Ramp Maintenance Manual
- Maintenance Task Cards
- Fault Reporting/Isolation Manuals
- Wire Diagram Manual (Project)

PLANNING DOCUMENTATION
- Maintenance Planning Document
- Facilities & Equipment
- Supplemental Inspection
- Condition Monitoring

MANAGEMENT DOCUMENTATION
- Service Bulletins
- SB INdex
- Airplane Recovery Document
- Storage/Inventory Document

* AVERAGE CUSTOMER RECEIVES OVER 70 MANUALS/DOCs

Figure 1

The volume of maintenance documentation prepared by Boeing each year is massive. Figure 2 shows that the 1988 publishing activity at Boeing included maintaining 1,126 active manuals for some 5,300 airplanes and 425 operators. The size of this data base gives us almost 20 million page sets to maintain, with each manual being revised on about a 120-day cycle. Some years ago we used Mt. Saint Helens, about 8,000 feet tall, as a comparison for the height of the paper stack we publish each year. Now we have passed the height of Mt. Everest for comparison purposes. Soon we will begin to make our comparison with the 100,000 foot tall mountain on Triton, a satellite of the planet Neptune.

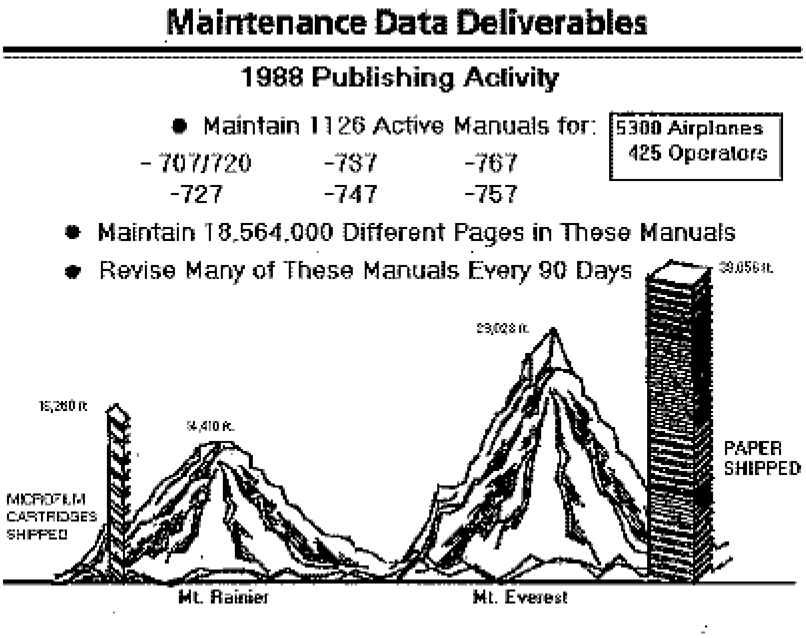

Figure 2

Our paperwork volume is a problem because none of us can deal with these data in an efficient way any longer. The person who can pick up a document and efficiently translate that information into an airplane action is quickly disappearing. This is true even though that person might have a support staff, Federal regulatory agencies, airframe manufacturers, and many others trying to help him. The data are difficult to use because, for example, one might need three or four of these documents at a minimum for a particular task.

Apart from the complexity of the documentation, there is the time factor in publication. There is approximately a six-month turnaround time to get an issue into a document and available for users. The existing production process is simply too slow to support customer requirements.

In an attempt to better understand our documentation process, some time ago we began asking customers about the way these documents were used, particularly for maintenance planning. As shown in Figure 3, maintenance data is received by the customer in paper or microfilm form; the data undergoes some customization; and the information then is used in a manual task-planning process to structure aircraft maintenance.

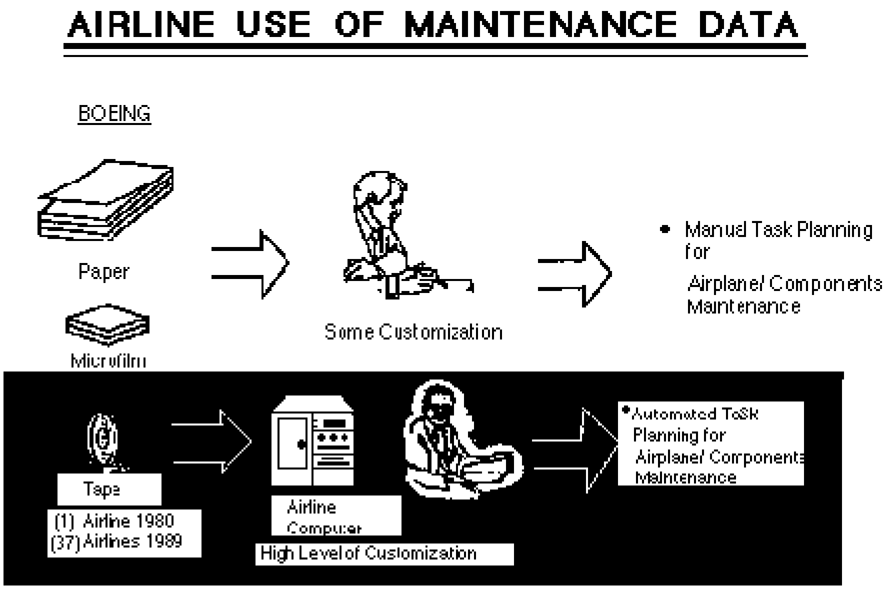

Figure 3

In 1980, one customer asked us for a magnetic tape of their maintenance manual. At that time, we didn't quite understand why they wanted it, but since we could produce it from our system we gave it to them. This continued for a few years and more customers started to ask for magnetic tapes. Thirty-seven airlines now get some of their maintenance documents in digital form from the Boeing Company. They load these tapes onto their own computer, exercise certain customization, and produce automated task planning for their maintenance.

As we move into increased automation in the delivery of maintenance data, the Air Transport Association is developing requirements designed to standardize the manner in which all of us approach this issue. The listing in Table 1 illustrates recent ATA requirements for content, format, and retrieval of maintenance data. I would now like to describe those pertaining to content in greater detail.

Table 1 Recent ATA Requirements

Content Standards

- AMTOSS
- PMDB
- Simplified English

Digital Format Standards (In Development)

- Graphics
- CGM
- (Vector)
- CCITT, Group IV
- (Raster)
- Text
- SGML

Optical Media Retrieval Standards

- Art

Aircraft Maintenance Task Oriented Support System (AMTOSS)

AMTOSS is simply a numbering system. It is an extension of a six-digit ATA numbering system to identify key maintenance steps. It uniquely identifies every task and subtask that has to be performed. Use of this AMTOSS coding means that we must rewrite entire maintenance manuals for conformity. However, when the rewrite is completed, we will have a consistent, logical format for identifying maintenance procedures.

The numbering system of AMTOSS allows one to automate the maintenance manual for those people who are using it. For example, if an operator wishes to gather all items that must be done on a particular C-check or that have to do with a particular zone of an airplane, he can use these task codes to gather all appropriate tasks into one grouping. Once this is done, he can sort the data to build basic work packages. There are many benefits to use of AMTOSS. This system allows faster access to maintenance procedures through its full automation. Maintenance data can be grouped and sorted. The system also provides a tie between maintenance instructions and required resources.

Production Management Data Base (PMDB)

The Production Management Data Base is used to identify resource requirements needed to perform aircraft maintenance. This is a fully automated system; there is no hard-copy counterpart. PMDB works in conjunction with AMTOSS to define the next level of maintenance requirement, the needed resources. What parts are needed? What skill levels are required by technicians? What expendables are required? What repairable materials will be covered? Answers to these and many other questions can be obtained through PMDB. In short, PMDB allows electronic access to resources both for planning purposes and for provisioning.

Simplified English

Simplified English can best be described as creating a limited vocabulary for technical writers and engineers -- whoever is writing the maintenance manual data or any other type of document specification. For example, an access area in an aircraft now must be referred to as a "hatch." We cannot call it a door, a panel, a limited access area, or any of the other 500 words or so we would like to use to identify it. Under all circumstances, it is a hatch. The result is not necessarily a simpler language, but it is a standard language. Now if a person wishes to retrieve all items having to do with "hatch," he asks one question and not 20 in order to get all of these items.

In addition to providing a limited and standard vocabulary, Simplified English also provides a set of writing rules. These rules serve to clarify the presentation of maintenance instructions. At Boeing, an artificial intelligence unit provides a checker which reviews the writing rules and saves an engineer from having to do this review himself. It tells the engineer where writing violates the set of rules and allows him to make immediate corrections.

Airline/Boeing Partnership

Boeing is now undertaking a program to rewrite its maintenance documentation in digital format using the new standard for production airplanes. AMTOSS tasking, PMDB, and simplified English are being employed in this program for several aircraft including the 737-300/-400/-500 series, the 747-400, and the 757/767 aircraft. We also plan to digitize our maintenance board files for out-of-production aircraft such as the 727 and earlier 737 and 747 series.

The Boeing Company wants to ensure that all changes being made are acceptable to the customer. All new formats and standards need to be validated by the airlines. If changes are required, we have pledged that we will not go in an individual Boeing direction. Results of the Boeing-airline interactions will be presented, as required, to committees of the Air Transport Association/Aerospace

Industries Association of America. We will request approval from these committees before proceeding. In this manner, we hope to ensure that smaller airlines which might have a different view of what is effective in maintenance are not left out of the picture.

At this time, Boeing is using the 747-400 as a "pilot" model for checking our new digital maintenance data efforts. In this pilot effort, use of AMTOSS tasking procedures for the identification of maintenance tasks was completed in the fourth quarter of 1988. Validation of the Production Management Data Base and Simplified English both are ongoing at this time. Since we feel that the specification dealing with PMDB will change through time, we have issued a test tape and are asking for feedback from the airlines. We also have built a demonstration PC computer program illustrating PMDB which is available for those interested in learning about this effort.

To conclude our discussion of the development and implementation of digital programs for the delivery of maintenance data, I would like to make the following points:

- New technical standards for maintenance data are essential to program success.
- ATA/AIA Task Group members have made substantial contributions to these standards.
- ATA/AIA cooperation has been very good.
- Boeing is committed to this program.
- Airlines must become involved
    - The program must be given priority
    - The program must receive high-level management attention

On-Board Maintenance Information System (OMIS)

Boeing is exploring the uses for an On-Board Maintenance Information System (OMIS). The purpose of an On-Board Maintenance Information System is to provide all required data to support ramp and flight line maintenance on an airplane. It contains necessary maintenance information to correct airplane faults reported by the Central Maintenance Computer. In a sense, OMIS provides the intelligence to support ramp and flight line maintenance and allows an airplane to become self supporting. As long as maintenance personnel are available, this system provides all necessary information for these people to respond to maintenance needs. For aircraft structures which do not have a monitoring system, OMIS provides access to fault isolation and maintenance procedures.

Figure 4 shows the different areas of information included within the OMIS data base. As you can see, it includes spares information, maintenance information, minimum equipment list information required for aircraft dispatch, and other needed items.

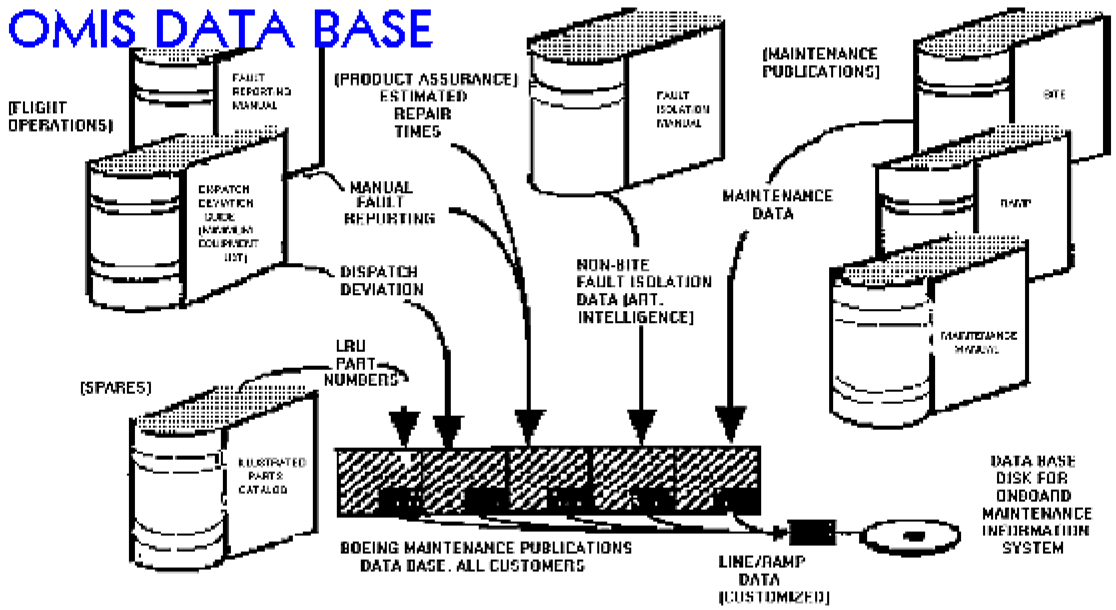

Figure 4

The small boxes within the larger hatched boxes at the bottom of Figure 4 indicate that only that portion of a data base may be carried which is required by a particular airplane. Theoretically, OMIS is smart enough to know on which airplane it is being carried. The tail number of an airplane determines what is in the data base.

In a full on-board maintenance system, the Central Maintenance Computer is the key entity for support of the airplane. This computer continuously monitors the airplane. It also contains information concerning all preventive maintenance schedules. As shown in the lower left of Figure 5, the on-board maintenance system works with the Central Maintenance Computer to exchange information concerning maintenance probabilities. For a given event, OMIS might tell the Central Maintenance Computer that there is an 80 percent probability that the problem lies with one certain component. With this information, the Central Maintenance Computer can use ACARS, the down link radio system now in use with some airlines, to radio the data ahead so that a mechanic and the part are waiting at the ramp to support that maintenance requirement.

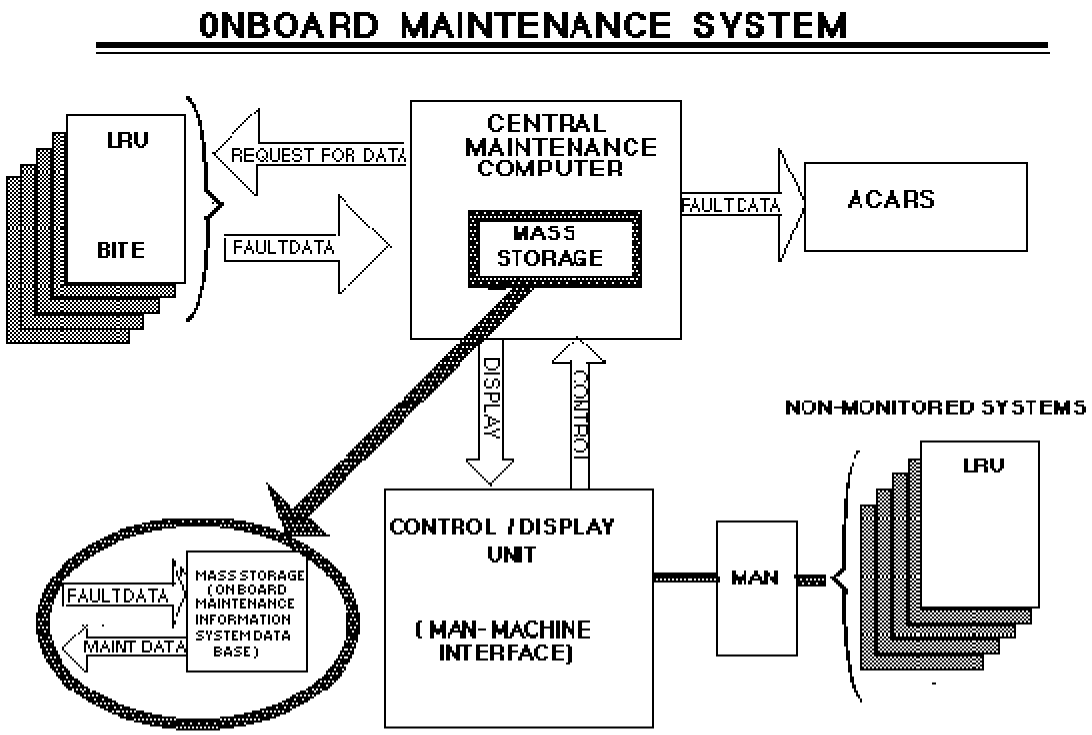

Figure 5

Note that Figure 5 shows that man, the human operator, remains as a component within the on-board maintenance system. Man must look at systems that are not monitored or that he has flagged as safety concerns. He also must remain within the system to provide a monitoring function to ensure that the complete system is operating appropriately.

We anticipate a number of benefits when the On-Board Maintenance Information System becomes fully operational. Maintenance data then will be easily accessible with the on-board system right at hand. There will be centralized storage of data for easy retrieval. Fault isolation and correction also should be improved. Finally, and of considerable importance, maintenance time will be lessened and we should reduce the requirement for retesting of good components incorrectly flagged as possibly defective.

In summary, the Boeing Company is firmly committed to the development of systems for the delivery of digital maintenance data. Within the next ten years, we hope to see all of our current developments in operational use. For this to be accomplished, Boeing and the airlines, in concert with industry committees, must work together to ensure that the new maintenance data systems are effective and responsive to the needs of all users. In any event, it is apparent that the day of hard-copy maintenance documentation is ending. The future of digital maintenance data systems is now.

The Information Environment in Inspection

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Introduction: Airframe Inspection

Inspection is information processing. Other aspects of the inspector's task, such as physical access to the work and body posture during work, are subordinate to this central task. The human as information processor has been studied for many years (e.g., Wickens, 1984 for review) and, indeed, the whole foundation of experimental psychology between the 1940's and 1970's has been on this model.

If information is the essence of inspection, we must examine the sources of information used (and not used) by the inspector: how information is received, processed and generated. Hence, we consider the inspector's information environment.

To provide structure for examining a job as complex as that of the inspector, a generic Task Description of inspection will be used. Task Description is a listing of the tasks involved in a job, but it also includes any rules for how tasks are sequenced within the Job (Drury et al., 1987; Shepherd, 1976). From such a Task Description we can determine how the demands of the tasks compare with human capabilities to meet those demands. This comparison is Task Analysis, which is one way to consider this paper: A Task Analysis of the inspector's information processing. Although task descriptions of inspection have been proposed many times for manufacturing inspection (Bloomfield, 1975; Drury, 1982), we will need to modify these to be specific to airframe inspection. Table 1 shows a generic task description of the inspection performed when an aircraft arrives for service. Examples are shown of both visual and non-destructive testing (NDT) tasks. Note that only if a defect is found will the final two tasks occur: Repair and Buy-Back Inspection. Each of the first five steps will be considered in turn to cover incoming inspection.

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

Task Description	Visual Example	NDT Example
1. Initiate	Get workcard, read and understand area to be covered	Get workcard and eddy current equipment, calibrate
2. Access	Locate area on aircraft, get into correct position	Locate area on aircraft, position self and equipment
3. Search	Move eyes across area systematically. Stop if any indication.	Move probe over each rivet head. Stop if any indication.
4. Decision Making	Examine indication against remembered standards. eg. for dishing or corrosion.	Reprobe while closely watching eddy current trace.
5. Respond	Mark defect, write up repair sheet or if no defect, return to search.	Mark defect, write up repair sheet, or if no defect, return to search.

6. Repair rivet. Drill our and replace on rivet hole, drill out for oversize rivet. Drill out rivet, NDT

7. Buy-back Inspect marked area. Visually inspect marked area. Visually inspect

Any system involving a human is typically closed-loop (Sheridan and Ferrell, 1977). Obvious examples are in flying an aircraft or driving a car, but the concept applies equally to inspection tasks. As shown in Figure 1, the human in the task receives some instruction or command input to use systems terminology. The operator and any associated machinery transform this command input into a system output. To ensure stable performance, the system output is fed back to the input side of the system, where it is compared against the command input. If there is any difference (command minus output), the system responds so as to reduce this difference to zero. Thus, in flying aircraft the command input may be the heading given by air traffic control. The system (human plus aircraft) compares the output of current heading (from, for example, the gyro compass) to the command heading, and uses aileron and rudder to make the output match the command. A closed-loop model of the inspector (Figure 1) will be applied to the generic task description of inspection (Table 1) to locate and evaluate the sources of input (command) and output (feedback) information.

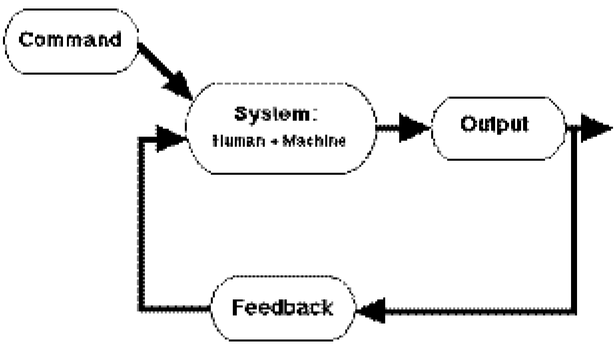

Figure 1 Closed-Loop Control

Information in Inspection

From the model in Figure 1, it is obvious that two types of information can be distinguished. The input is command information, while the output is feedback information. Both have been shown to be amenable to manipulation to improve system performance. Not obvious from Figure 1 is that the command input may be complex and include both what needs to be accomplished and help in the accomplishment. Input may give both directive and feedforward information. Thus, a workcard may contain "detailed inspection of upper lap joint" in a specified area (directive) and "check particularly for corrosion between stations 2800 and 2840" (feedforward). There are really three potential parts to the information environment: directive information, feedforward information, and feedback information. All are known to have a large effect on manufacturing inspection performance. A short review of this data is needed before we can consider aircraft inspection in detail.

Directive Information involves the presentation of information in a form suitable for the human.

This is the basis of good human factors. An example from inspection is the work of Chaney and Teel (1967) who used simplified machinery drawings as an aid to inspectors. These drawings of machined metal parts were optimized for inspection rather than manufacture, with dimensions and tolerances in the correct placement and format and with similar characteristics grouped together to encourage systematic inspection. Compared to a control group with the original drawings, inspectors using the optimized drawings found 42 percent more true errors in a test batch.

Feedforward Information can consist of two parts: telling the inspector what defects are expected and providing the probability of the defects. Because there are typically a large number of potential defects, any information made available to the inspector is valuable in focusing the search subtask in particular. Many investigators (Gallwey and Drury, 1985) have found that looking for more than one type of defect simultaneously can degrade detection performance, so that focusing on likely defects can be expected to result in more detections. Drury and Sheehan (1969) gave feedforward information on fault type to six inspectors of steel hooks. Missed defects were reduced from 17 to 7.5 percent, while false alarms were simultaneously reduced from 5.5 to 1.5 percent. Information to the inspectors on the probabilities of a defect being present has not led to such clear-cut results (e.g., Embry, 1975) and, indeed, a recent experiment (McKernan, 1989) showed that probability information was only useful to inspectors for the most difficult to detect defects.

Feedback Information has had consistently positive results in all fields of human performance (Smith and Smith, 1987) provided it is given in a timely and appropriate manner. Indeed, it is the basis of most training schemes: trial and error does not result in learning without error feedback. Wiener (1975) has reviewed feedback in training for inspection and vigilance and found it universally beneficial. Outside of the training context, feedback of results has had a powerful effect on the inspector's ability to detect defects. Embry's laboratory studies (1975) showed a large effect, but so did Gillies (1975) in a study in the glass industry where missed defects were reduced 20 percent when feedback was implemented. Drury and Addison (1973), another glass industry study lasting almost a year, showed a reduction in missed defects from 15 to 8.8 percent after rapid feedback was introduced. More recently, Micalizzi and Goldberg (1989) have shown that feedback improved the discriminability of defects in a task requiring judgement of defect severity.

Information in Aircraft Inspection

Each task inspection will be considered in turn.

Task 1: Initiate. Here, the command information predominates. For visual inspection, the workcard gives the location, type of inspection to be performed and, at times, feedforward information of use in the search and decision phases. Typically, however, this information is embedded in a mass of other, necessary but not immediately useful, information. Often the information contains attached pages; for example, with diagrams of parts to be inspected. While laser printers making a new copy for each workcard have helped diagram quality, inspectors still find some difficulties in interpreting this information. Supplemental information is available in manufacturers' manuals, FAA communications, and company memos/messages, but these sources are typically not used at inspection time. This places a large burden on the inspector's memory.

For NDT work the initiate task also includes obtaining and calibrating the equipment. From observation of the NDT equipment currently in use, calibration is not as straightforward as it would appear from equipment manufacturers' brochures. The controls, and particularly the displays, are not usually well designed for rapid, unequivocal information transfer with inspectors. They give the impression that they were designed as pieces of scientific equipment with none of the human factors engineering input which has been available for decades (VanCott and Kinkaid, 1972).

Feedback from the initiate task is obvious is many cases because it comes from Task 2 -- Access. Thus, if the part to be inspected is left inner flap track, this needs to be physically located on the aircraft in Task 2. The potential problems are best dealt with under that task.

Task 2: Access. In order to access an area of an aircraft, the area must first be opened and cleaned, neither of which are under the control of the inspector. Thus, scheduling information required for access is the assurance that the area is ready to inspect. Work scheduling systems typically assure this, but wrong information does get to the inspector at times, giving time loss and frustration. It is at Access that confusions in location from Task 1 become apparent--hopefully. The next time the wrong location has been inspected will not be the first time. . .nor the last. Improved information systems for locating an area on an aircraft unequivocally are needed. Physical access for both the inspector and equipment represent a human factors difficulty in much inspection, but are not the concern of this paper.

It should be noted that feedback on accessing the correct area can be given by the work-card system by incorporating unique landmarks into the diagram on the work card so the inspector can be assured that the correct area has been reached.

Task 3: Search. It is in the tasks of Search and Decision Making that information has the largest potential impact. In visual search the inspector must closely examine each area for a list of potential faults. Which areas are searched is a matter of prior information -- from training, experience, or the workcard. The relative effort expended in each area is similarly a matter of both directive and feedforward information. If the area of main effort is reduced, the inspector will be able to give more thorough coverage in the time available. The workcard can, if accurate and up to date, provide an information source which can overcome the prior biases of training and experience, if indeed these biases need to be overridden. Similarly, the fault list the inspector uses to define the targets of search comes from the same three sources. This fault list must be realistic and consistent.

In many industrial inspection tasks, developing a consistent list and definition of fault names to be used by all involved is a major contribution to improving inspection performance (Drury and Sinclair, 1983). Faults often go by different names to inspection personnel, manufacturers, and writers of workcards, causing misdirected search and subsequent errors in decision and responding. Probabilities of the different targets or defects are rarely presented.

Feedback of search success only comes from Task 4 -- Decision Making, and then only if an indication was found. If the indication was missed, then feedback awaits the next inspection or audit of that area. Hopefully, the subsequent inspection occurs before the fault affects safe operation. Note that if an indication is found, feedback is immediate, but if missed, feedback is much delayed. Delayed feedback is often no better than no feedback.

Task 4: Decision Making. The information required to make a correct decision on an indication is in the form of a standard against which to compare the indication. Such standards at the working point can be extremely effective. For example, McKennel (1958) found that they reduced the average error of a trained inspector to 64 percent of its magnitude without such standards. It has long been known that comparative judgement (against an available standard) is more accurate than absolute judgement (against a remembered standard), but this data does not appear to be used consistently in airplane inspection. The closest we come to a standard in visual inspection is to use adjacent areas (lap joints, rivets) to make the comparison; adjacent areas are not a reliable standard. Similarly, with NDT inspection the inspector must judge the deflection of a meter as the transient shape of an oscilloscope trace by absolute rather than comparative judgement. At times the calibration specimen is carried to the workpoint, but it is not often used there, for a variety of reasons.

Feedback to the inspector in the Decision Making task is not rapid or obvious. If an inspector marks a defect (and writes it up), it will be repaired and go to a buy-back inspection. Because of scheduling constraints and shiftwork, it will rarely be the same inspector who gets to reinspect that repair. Only by chance or individual initiative will the inspector talk to the repairer or the buy-back inspector. Thus, an opportunity for feedback is being missed. In addition, some repairs will destroy the defect without confirming it, e.g., drilling an oversize hole to take a larger rivet when Eddy Current inspection has indicated a small crack in the skin by that rivet.

Task 5: Response. The physical response made by the inspector represents the output information from the inspector to the system. It is as much a part of the information environment as input and feedback. In order to report correctly, the inspector must both make physical marks on the aircraft and issue a work order for repair, or at least further inspection, of each defect. Typically, more than one defect may be found in a job, so that memory is required to store these defect locations and types until a formal report can be filed, usually at the end of the workcard. Inspectors often carry a small notebook to aid this memory, but there is no formal system to prevent forgetting or mis-remembering. All of this becomes more problematical when the inspector is interrupted. These interruptions have to do with both scheduling (e.g., an extra inspector is required on another job) and unscheduled events such as more cleaning being required before an inspector can complete a workcard. In addition, maintenance operators have to interrupt the inspector to buy-back any repairs which have been completed. Again there is potential for error.

Feedback as a result of the Response is rare. Only a small sample of work is audited, and any feedback from this is typically negative rather than positive. If a defect is reported, then feedback to the inspector who reported it can be arranged. However, if the inspector does not report the defect (either search failure or a wrong decision), only an audit or subsequent inspection will give feedback.

For many defect types, a defect may only be an indication, and hence not reported. Unfortunately, the information that the inspector found an indication is then lost forever, as the chance of the same inspector being assigned to the same part of the same aircraft months in the future is small. Capture of some of these indications may be a way to provide more detailed feedforward for subsequent inspections.

Conclusions

The information environment has been shown to be a particularly powerful determiner of human, and hence system, performance in inspection. Applying these ideas in a systematic manner to aircraft inspection has revealed places where the current system is working well, e.g., some aspects of directive and feedforward information using the job cards. It has also shown that there is room for improvement in integrating information at the inspection point and in providing feedback to the inspectors.

In this paper, many areas have obviously been ignored. The use of information in the training process has not been analyzed nor the concept of using feedforward and feedback to keep inspectors in the equivalent of a continuous retraining program. Also, specific recommendations have not been made, as they require completion of the ongoing task analysis study of the National Aging Aircraft Research Program. Effects of other important task variables (e.g., lighting), job variables (e.g., social pressures), and individual variables (e.g., inspector's basic ability) have similarly been omitted.

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Data Base Support for Maintenance Requirements of the Nuclear Power Industry

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My experience with the Departments of Transportation and Defense, the aerospace industry, and now the U.S. Nuclear Regulatory Commission has shown me that these agencies and activities, while they deal with different systems, have more commonalities than differences. All are involved with complex, high-reliability systems where a maintenance failure or an operator error can be catastrophic, not only for the operator but for those around him. This basis for commonality means that each activity can learn from the others.

To provide a context for this presentation, I would like to describe briefly the operation of the U.S. Nuclear Regulatory Commission. The Commission was formed at the breakup of the old Atomic Energy Commission and has responsibility for regulating civilian applications of nuclear power. At present, the USNRC is responsible for some 119 nuclear power plants located within the 48 contiguous states and some 65 nuclear research reactors located primarily at universities. We also are responsible for spent fuel handling until it leaves the operating site. Finally, we are beginning to be involved in the regulation of nuclear materials as used in the medical profession. Within the USNRC, human factors research is directed toward the development of data gathering instruments, data management systems, performance analysis tools, performance criteria, and provision of technical data to support various licensing and regulatory decisions made by the USNRC dealing with both operations and maintenance.

This presentation has three objectives. The first is to acquaint participants with five human performance data management systems and analysis tools developed by the USNRC and the U.S. commercial nuclear industry to support the design, development, and evaluation of maintenance, test, and surveillance programs. Two of these are data management systems; two are computer simulations; and the last involves development of criteria to allow us to equate tasks in our industry with ones in your industry so that data may be exchanged to support technical analyses in each industry.

The second objective is to indicate procedures whereby participants might gain access to any or all data management systems and analytic tools described here. Documentation is free of charge; the technologies themselves are available on an information-exchange basis.

The final objective today is to request participant assistance on a USNRC project. This project will be noted later in the presentation.

The USNRC became interested in maintenance tests and surveillance as a direct result of the familiar Three Mile Island accident (or event) in March 1979. Until that time, the USNRC was strictly a nuclear engineering organization. However, a review of the Three Mile Island event indicated that people were very much involved. That initiated an era of human factors in our industry and at the Commisssion.

For the next three or four years, the Commission focused on human factors in operations. A particular interest was in the behavior of operators once an abnormal event was initiated.

Two things changed the focus on operators. One is our experience in analyzing abnormal events that have occurred since then. We have found that much of the cause of these events often has to do with latent factors in maintenance, test, and surveillance that preceded the actual event. Another factor causing a change in focus was a requirement placed on industry to perform a probabilistic risk analysis. As we license a nuclear power plant, the operator is required to analyze all sequences that could possibly lead to a melt-down followed by a massive release of radiation. As these analyses were conducted, it became apparent that we needed to attend much more to our maintenance and surveillance activities. These literally turned out to be precursors or initiators of some potentially catastrophic events.

In setting the stage for a review of the development of our human factors data bases, I should mention the particular sensitivity of our industry. With any regulatory agency, there is some controversy between the agency and the industry it regulates. With both highway transportation and aviation, there is controversy but it is muted by the fact that we all must ride in the same vehicles. When one considers the generation of electricity by means of nuclear power, matters are much different. There has been a real gulf between Government regulators and the industry itself in terms of information exchange, especially in the area of human performance. Nonetheless, we have been able to proceed with the development of various data base systems to support our human factors program.

Maintenance requirements of the nuclear power industry are supported by five principal data management systems and analytic tools. These are:

- Nuclear computerized library for assessing reactor reliability (NUCLARR)
- Nuclear plant reliability data system (NPRDS)
- Maintenance personnel performance simulation (MAPPS)
- Cognitive environment simulation (CES)
- Criteria for equating human tasks within and between jobs within an industry and between industries

Each of these developments will be described next in some detail.

Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR)

NUCLARR is a data management system containing human and hardware reliability information. The system is constructed in a series of matrices that bring together the individual, whether on the operations side or the maintenance side; the kind of action the individual is involved in, whether a single action or an action sequence; shaping factors, those factors associated with the individual, the task, or the environment which influence the particular behavior; and finally the equipment, whether it be an individual display or control or the entire system itself. This information is presented both in probabilistic form, the likelihood that a particular error will be committed, and in the form of the raw data used in the calculation of the error probability. The library also contains information concerning failure rates for hardware components.

NUCLARR comes in two forms, an automated version for a personal computer (PC) and a hard copy version. The PC version is menu driven and also uses ad hoc commands in order to locate human error and hardware failure rate and causal factor data. The system then aggregates these data using certain rules and will format the information for processing through a statistical package. The desired reliability information then can be presented either on the computer display or in hard copy form. Inasmuch as documentation is maintained for all failure rate data, the system acts as a clearinghouse for documentation on controlled studies, field data collection programs, and system risk assessments.

NUCLARR also comes in a hard copy format, called a NuReg Report. This is a five-volume document, actually broken into four parts, which is updated every three months. The four parts consist of:

Part 1 - User's Guide

Part 2 - Human Performace Data Store

Part 3 - Hardware Performance Data Store

Part 4 - Aggregated Data Store (human performance combinations, hardware combinations, human/hardware combinations)

Data for NUCLARR are prepared by an Idaho National Engineering Laboratory management team, which collects the data and prepares it for input into the system. About every two months, a Quality Assurance Team is sent to Idaho Falls to review the collected information to determine its appropriateness, where it goes in the system, and whether or not the data distributions will allow for any kind of aggregation. This review team contains individuals from the nuclear industry, the military, NASA, and other appropriately qualified organizations.

NUCLARR is updated quarterly. Those having the hard copy version receive updates at that time. Those having the automated system receive a new set of floppy diskettes.

The NUCLARR library is available to all interested agencies, groups, or individuals. The hard copy version is available at no cost to those who apply. The automated version is available on a data-exchange basis. Since the USNRC is a Government agency, we cannot sell this technology. Therefore, our management and legal counsel have established a procedure where the automated version is available to industry and universities on this information-exchange basis. Details are provided upon written request to the USNRC.

Nuclear Plant Reliability Data System (NPRDS)

The Nuclear Plant Reliability Data System is a voluntary reporting system sponsored and maintained by the U.S. commercial nuclear power industry which includes data on maintenance events, usually hardware failures. The data system contains approximately 500,000 event reports dating back to 1974. NPRDS data can be recalled by hardware description, vendor, plant, type of failure, source, timeframe, or combinations for use in risk assessments, establishing trends, and for comparisons between facilities. NPRDS is managed by the Institute of Nuclear Power Operations (INPO), in Atlanta, Georgia. Users include the nuclear industry, USNRC, vendors, and design engineering companies. Access is by request to the NPRDS Operations Office at INPO.

Maintenance Personnel Performance Simulation (MAPPS)

Maintenance Personnel Performance Simulation is a stochastic task networking computer simulation which focuses on overt behavior. Its output can be systematically influenced by up to 24 personal, task-centered, and environmental factors that might reasonably be expected to influence performance. It allows one to simulate a particular situation of interest at a very detailed level.

MAPPS is capable of simulating the behavior of maintenance mechanics, electricians, instrumentation and control technicians, operations controllers, and supervisors, in teams of two to eight, in complex high-reliability systems settings.

The output from MAPPS includes some 70 housekeeping and evaluation indices. Housekeeping indices include general information about the subtasks making up the task sequence being simulated, the task sequence itself, characteristics of the personnel involved, protective clothing, and shift change information. Evaluation indices include performance of individuals being simulated, performance of the team simulated on each subtask, and performance on the overall task.

Evaluation indices are both probabilistic and non-probabilistic and can even deal with impact of supervision on operator performance as well as factors having to do with organizational climate. In fact, in our reviews of every major incident which has occurred in the nuclear arena we have concluded that it was not so much what the maintenance man did or did not do, or what the operator did or did not do, but rather the climate in which these people were operating. The organizational climate seemed to be a primary determiner as to whether operators recovered from a situation or exacerbated it.

MAPPS is housed at the National Institutes of Health (NIH) Computer Facility in Bethesda, Maryland, and, for European users, at the EURATOM Computer Facility in Ispra, Italy. A PC-based version "Micro-MAPPS" is scheduled for completion at the end of FY 1990.

In the initial construction of MAPPS, concern was expressed over its ability to dissect a task sufficiently to really understand the task. The current capabilities of MAPPS dispels such concerns. MAPPS now has the following features:

Maximum number of subtasks (per task) 100

Types of subtasks (by action statement) 28

Maximum task duration (days) 2

Number of shifts 1-10

Catagories of protective clothing 3

Maximum number of tasks on-call in the MAPPS library 200

There are two features of the MAPPS simulation that should be of interest to those concerned with aviation maintenance. First, we spent a considerable amount of time in developing operational definitions of action words. We now have a list of some 28 orthogonal action words derived from the many hundreds of terms people use. These action words are used to characterize the maintenance task with great impact on the way the simulation progresses. Also, we have developed a task analysis library. As a task is completed it is fed into the MAPPS library so that an investigator at a later time, who may not have time to do a complete task analysis, can simply call up an earlier task and modify it somewhat for his own particular needs. A regular simulation then may be conducted.

The USNRC is using the MAPPS simulation capability for a number of purposes. One use is to supplement data management systems. For example, we may find there are some combinations of operators, actions, environmental factors, and equipment that we simply can't study directly because of political reasons, logistics reasons, cost reasons, or other issues. However, these tasks are important when we need to perform more broad analyses of reactor maintenance. In this case, we use MAPPS to simulate the unavailable actions.

MAPPS also can be used to provide probabilistic inputs to risk (safety) assessments, somewhat in the manner in which NASA developed its safety assessments after the Challenger accident. The system also can provide non- probabilistic inputs to licensing reviews and inspections. It can be used to preview effects of remedial actions. Finally, the system will provide design information concerning maintenance schedules, staffing, and function allocation requirements, and for development of performance aids such as written procedures. MAPPS is available on an information-exchange basis through the USNRC.

Cognitive Environment Simulation (CES)

Cognitive Environment Simulation is an automated artificial intelligence system for analyzing the decision-making behavior of individuals and groups under normal and abnormal conditions in complex system settings. CES generates the intentions or the decisions that might be made given a specific set of circumstances. The system is currently on a symbolics computer.

Operation of CES requires certain inputs. First, the system must be provided a knowledge base describing the decision maker or decision-making group. What do they know? Next, a set of process mechanisms must be provided. These are the rules we would expect these people to use as they apply the information in their knowledge base. Finally, some well-defined scenario used to initiate a decision-making sequence must be provided. In a decision-making sequence, it is most important that some kind of algorithm be provided that will illustrate to CES the impact of earlier decision making.

CES outputs include housekeeping information concerning the knowledge base and scenario parameters. It prints out an entire sequence of the decision-making process. As the situation becomes more complicated and no reasonable decision can be made, CES will print out information concerning all attempts that were made through hypothesis development, information search, verification attempts and other processes in a decision effort. There is a complete audit of everything that the simulation does.

CES can be used for analyzing cognitive errors of comission and omission and to support risk (safety) assessments. The simulation itself does not produce error probabilities. To achieve this, we developed another "tool" called CREATE, the Cognitive Reliability Evaluation Technique. Using the two together, we can generate the likelihood that a decision-making error might be made. CES also can be used to study decision-making behavior per se. For example, under certain stressful situations, we have found that both operators and maintenance personnel may regress in their behavior. Where normally decisions would be made using a series of hypotheses, in these cases individuals regress to that which is familiar. They regress to decisions used in the past.

Another type of decision-making process being studied is one which we call "going down the primrose path." Again, this occurs under conditions of serious stress. Here individuals generally are required to make a series of interdependent decisions. We find that stress effects cause individuals to commit themselves to an initial decision and try thereafter to confirm that decision even in the face of conflicting information. They may even block out new information in order to maintain the validity of their initial decision. We have seen this happen in many of the accident situations that have occurred in our industry. Using CES, we attempt to simulate and understand these two decision-making processes. We then may be able to build into the simulation certain factors, that later could be put into actual equipment, to force people to maintain a more orderly decision-making process.

The Cognitive Environment Simulation also is used for intellectual augmentation. We have concluded that automation is not a complete solution for many task requirements. Automation takes tasks away from people. Then vigilance and motivation both become problems. In fact, nuclear power plants have been closed because people were sleeping on the job. In order to combat this, we are using an expert system in an attempt to have this system perform the more mundane tasks and thereby augment the ability of an individual to make the kinds of decisions he should make.

A final use of CES is for previewing the effects of decisions taken but not yet implemented. We feel this preview function of tactical decisions will improve the planning phase, the decision-making phase, and final implementation.

Criteria for Equating Human Tasks

We at the U.S. Nuclear Regulatory Commission, as I suspect is also true for the Federal Aviation Administration, suffer from a lack of appropriate and quality human performance data to support some of the decisions we must make. There are many reasons. We work in a regulatory environment; there are logistics difficulties in collecting data and we have superficial data-gathering protocols; reporting systems do not emphasize human factors; there is limited involvement of human factors specialists, and always the cost.

In order to make proper human performance data more available, the USNRC has contracted with the George Mason University to develop psychological and behavioral criteria for equating human tasks within and between industries and the military. A taxonomy of data from a variety of sources also is being prepared which we hope to use as part of our technical basis for analyses and decisions. These criteria should be useful in many circumstances. For example, an Army investigator studying maintenance on an Abrams tank might be able to make good use of human performance data from the nuclear industry simply by being able to justify equating the tasks.

As we are developing our taxonomy, we are soliciting any kind of human performance data from any kind of environment that might be useful for inclusion in this taxonomy. Interested persons may contact the USNRC or the Center for Behavioral and Cognitive Studies at the George Mason University.

In summary, we are engaged in five major efforts at the U.S. Nuclear Regulatory Commission to develop data management systems to improve operator and maintenance safety and reliability at nuclear power facilities. The systems we have developed are not tailored specifically to nuclear power operations but, instead, may be applicable to maintenance activities in many other settings. We welcome inquiries from others who might wish to expand the use of these technologies.

CD-ROM and Hypermedia for Maintenance Information

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Introduction

Problems with Maintenance Information

Modern aircraft are complex systems that require tens or hundreds of thousands of pages of technical information to operate and maintain them. This information is organized as hundreds of manuals created by dozens of contractors and subcontractors. To make it easier to keep information accurate and up-to-date, this information is logically organized (perhaps according to ATA or other standards), which helps minimize redundancy. However, this means that many tasks require information from different parts of a manual or from more than one manual. In principle, following cross references to find needed information is a simple task: we all can visualize using a bookmark or a thumb to hold our place in a book while we turn elsewhere. But in practice, it is always time-consuming and error-prone for the maintenance mechanic to track down needed information that is spread throughout manuals, since thousands of pages of manuals occupy dozens or even hundreds of "shelf-feet." The mechanic might have with him the three or four most useful manuals, since that is all he can carry, and important information always seems to be back at the hangar or maintenance depot in yet another manual. This means that maintenance must often be carried out without all the information that could conceivably be needed.

The Solution: An "Intelligent Electronic Manual"

Recently, many people have been proposing various realizations of an "intelligent manual" to solve these problems with locating and using information in large document collections. The common theme is to use a portable computer with enough storage capacity to contain all of the information from the printed manuals. Typical features of this intelligent electronic manual are:

- vast amounts of storage for text, graphics, illustrations, and other kinds of information
- support for familiar ways of finding information, using tables of contents and indexes
- other entry points that are impossible on paper but made possible by the presence of the computer, such as (1) full-text search through the information database for sections that contain key words or phrases or (2) interactive troubleshooting using intelligent assistance
- display functions for viewing information page by page or for browsing by jumping many pages at a time
- progressive display of detail, so that a reader can start with an outline view of the information (like a table of contents) and then "zooming in" to get details where they are needed
- computer-supported cross references or links between related information that can be quickly followed to display the cited information as if it were directly connected
- embedded training and job aids, often using media like audio or video to optimize the instructional transfer.

Plan for this Paper

Taken together, these features have come to be known as "hypertext" or "hypermedia," and they provide a compelling vision of the how maintenance information might be delivered and used in the future. Nevertheless, as with any new technologies, turning this vision into practical applications is hard. In this paper I will introduce the key concepts of optical storage and hypermedia, review several examples, and suggest ways to overcome the problems that stand in the way of successful applications.

Hypertext and Hypermedia

Definitions

In 1987 Conklin defined hypertext as "computer-supported links within and between documents" (Conklin, 1987). My own definition of hypertext emphasizes its evolutionary relationship to printed documents, rather than focusing on the new role of the computer. Anyone who has carefully studied the structure of an encyclopedia, dictionary, regulation, or maintenance manual is well aware of the many non-linear presentation conventions these documents use. Cross references, sidebars, footnotes, sidenotes, call-outs, and type sizes all signal that texts need not be read in strict linear order.

From this perspective, hypertext is a concept for displaying information on computers that exploits the non-linear conventions used in printed information to make text easier to use on computers. These conventions have evolved over hundreds of years and work well for short documents, as anyone knows who has put a thumb in the back-of-the-book index and sequentially browsed the separate topics pointed to by the index. The conventions begin to break down for larger document collections because a group of authors cannot use them as consistently as a single author can, and because of physical limitations imposed by the sheer bulk and size of documents.

Even more recent than the term "hypertext" is the term "hypermedia," which is generally used to enlarge the hypertext concept to include other media, such as sound, video, or computer animation/simulation. One consequence of a separate concept of hypermedia is that it implies that hypertext includes only text. This seems to limit the notion of hypertext unnecessarily, since any application that includes even the simplest figures or diagrams to accompany text becomes hypermedia, making the hypertext subset of hypermedia an extremely limited one. In particular, this means that a computerized version of a print document that includes the graphic components becomes a hypermedia document. It is more useful to draw the boundary between hypertext and hypermedia by saving the latter term for applications that involve media that printed documents cannot incorporate. Hence, applications that contain text and static graphics are hypertext.

Example Applications

I will briefly describe some recent applications of hypertext, beginning with one that is closest to the vision of an intelligent maintenance manual with which I began this paper.

Integrated Maintenance Information System. IMIS, the Integrated Maintenance Information System, is a concept and set of prototypes for a portable computer that integrates diagnostic and maintenance information and presents it to technicians via a hypertext user interface (Link, Von Holle, & Mason, 1987). IMIS is being developed by the U.S. Air Force Human Resources Laboratory and is funded as part of the Department of Defense CALS initiative.

IMIS is designed to use diagnostic information obtained directly from an airplane to configure and customize the maintenance instructions provided to the maintenance technician. Field trials of IMIS prototypes have demonstrated that this interactive combination of diagnostics and maintenance manuals can greatly reduce the amount of extraneous information presented to technicians, while appropriately tailoring the information to the technician's expertise.

One proposed user interface for future IMIS prototypes is shown in Figure 1 (Thomas & Clay, 1988). Two steps of a maintenance procedure are shown on the screen, along with simple diagrams of the equipment used to carry out the steps. The numeric keys of the portable computer can be redefined as shown at the bottom of the screen to provide hypertext functions for using the IMIS maintenance manual. For example, selecting "1" moves to the next screen, "2" moves back to the previous screen, and "5" jumps to a table of contents.

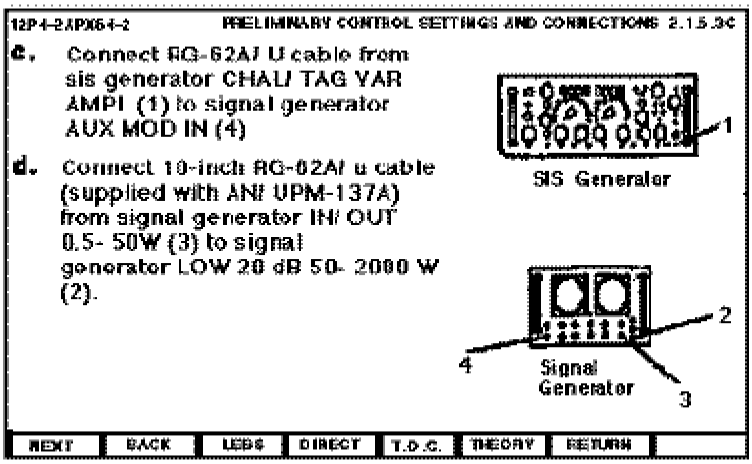

Figure 1 IMIS Prototype

Document Examiner. In 1985, Symbolics began delivering the complete reference manual for its Lisp workstation software in an online hypertext system called the Document Examiner (Walker, 1987). The initial release consisted of 10,000 text modules called records, corresponding to 8000 printed pages. The Document Examiner takes full advantage of the enhanced display resolution and large screen on the workstation to display pages much as they appear in the printed manual. Figure 2, from (Walker, 1987), shows that the Document Examiner screen display of a section of the online manual resembles a printed manual. Of course, the Document Examiner also takes advantage of the workstation's processing power to support other features not available in the printed form. On the right side of the Document Examiner display are candidate text units located using full-text search and a list of "bookmarks" created for any unit previously viewed. Selecting a bookmark for a unit re-displays the unit.

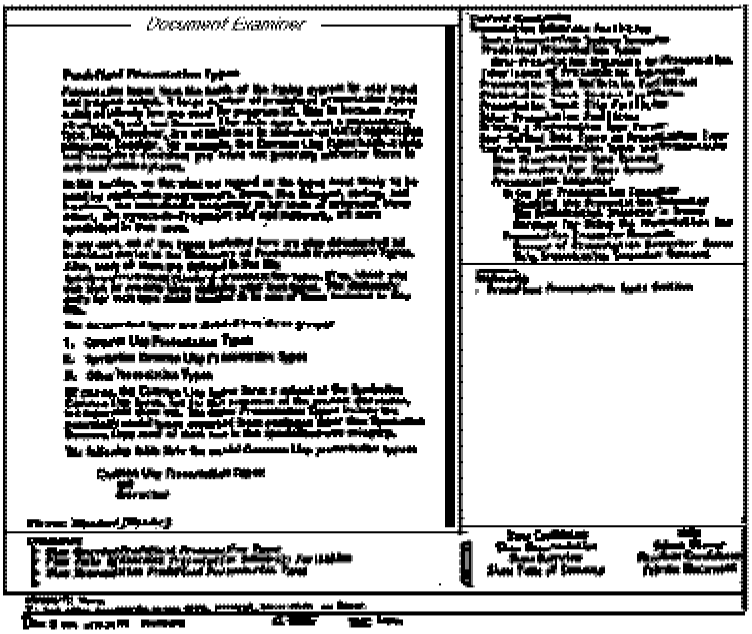

Figure 2 Document Examiner

Figure 3, from the same article, shows an automatically generated graphic display that is a logical map of the parts of the manual that are logically connected to the currently-displayed record. Selecting the name of any of the records in this graphic map causes it to be displayed on the screen.

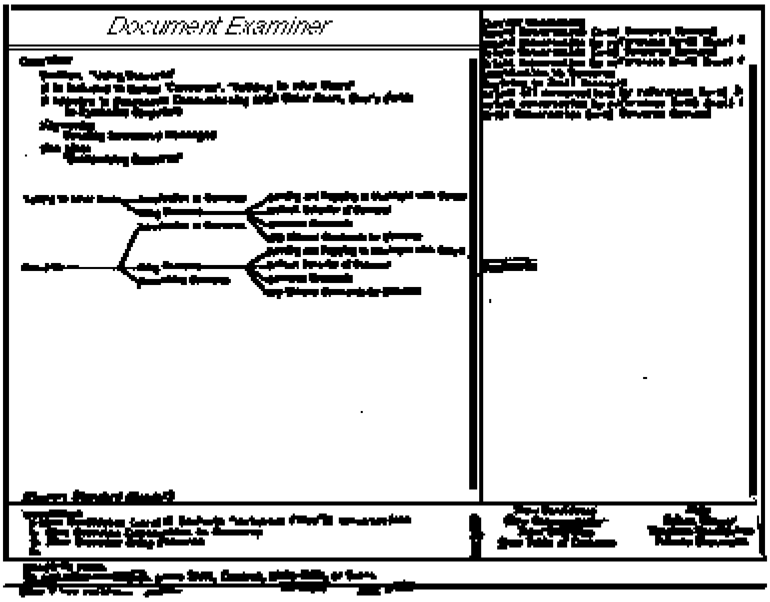

Figure 3 Document Examiner - Graphic Map

In 1987 some of the software tools that had been developed by Symbolics to support the development of the Document Examiner were released as the Concordia hypertext authoring environment (Walker, 1988). Concordia is probably the most powerful and comprehensive hypertext authoring toolkit today; one of the applications being developed using Concordia is an online reference manual with 30,000 pages of documentation for an aluminum rolling mill (Van Sickel, Sierzega, Herring, & Frund, 1988).

Engineering Data Compendium. The Engineering Data Compendium is a 3000-page reference book containing over 1100 articles about various aspects of human perception and performance, developed by the U.S. Air Force Armstrong Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, Ohio (Boff & Lincoln, 1988). At first glance, it may seem to be the perfect candidate for hypertext: it consists of highly structured articles designed to stand alone, that are enhanced by a rich set of cross references, and that can be accessed using several complementary entry points. These entry points include a scientific table of contents, an extensive back-of-the-book index, and an alternate table of contents called the design checklist. The design for a hypertext version of the Compendium (Glushko, Weaver, Coonan, & Lincoln, 1988; Glushko, 1989) calls for hierarchical outline viewers for the existing entry points, hypertext links for the explicit cross references, and derived hypertext links for implicit cross references like embedded glossary terms and shared keywords.

Figure 4 (Glushko, 1989) depicts the original design for the hypertext Compendium. The boxed "buttons" in the sidebar at the left are hypertext links to other entries. The "Bookmark" function in the menu at the top of the screen is modeled after the bookmark panel in the Document Examiner interface, but the small screen for which the former design was intended turned a dedicated screen area into a menu function.

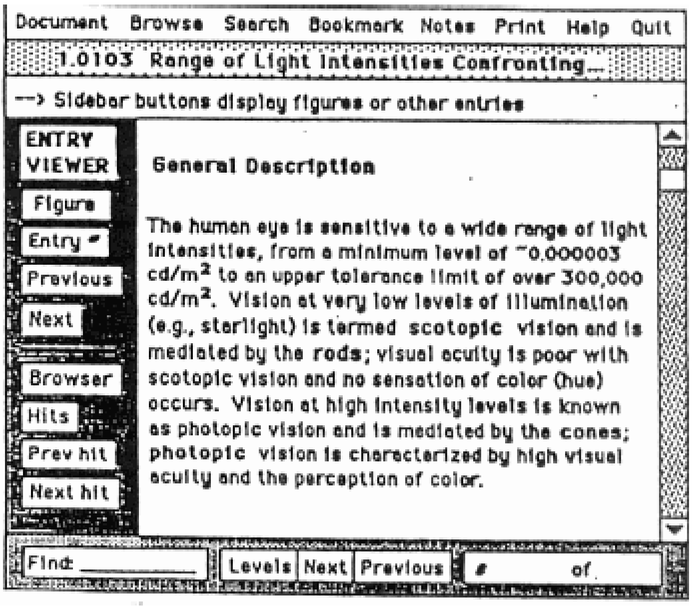

Figure 4 Engineering Data Compendium

HyperCard Help. HyperCard is an extremely popular hypertext program that has been used for literally thousands of different applications in the three years it has been marketed by Apple Computer (Apple Computer, 1987). The basic unit in HyperCard is often presented as a card; hypertext applications are often designed as a "stack" of cards connected by links between related cards that are shown by link markers typically called "buttons."

The HyperCard software contains its own help system that illustrates how familiar metaphors in hypertext systems can enhance the usability of online information while hiding irrelevant detail. Figure 5 shows the "flip chart" that appears to users when they select help. Users view different parts of the help manual by selecting the tabbed divider buttons at the bottom of the screen. Since users see details only in the locations they select, few realize that the help system contains over 400 different cards.

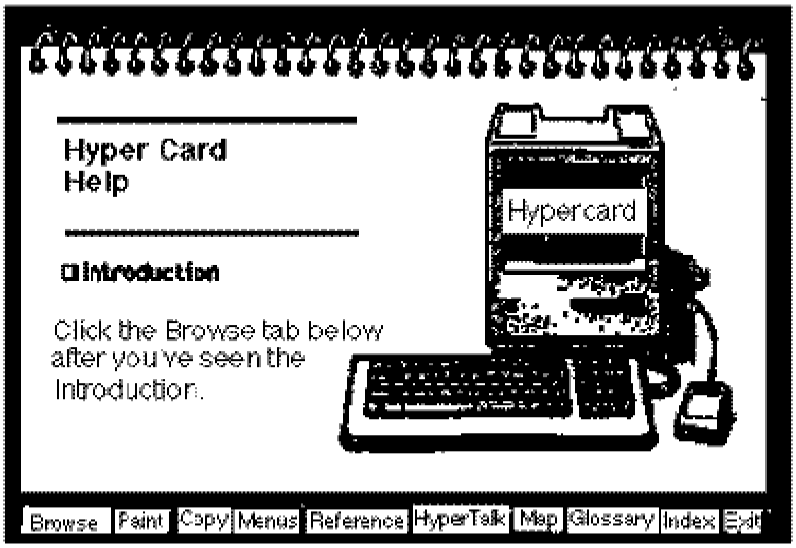

Figure 5 HyperCard Help

A secondary metaphor used by HyperCard help is that of a map that represents the logical structure of the help manual, shown in Figure 6. When users select (using a mouse) an icon representing a specific stack of cards in the help manual, it is as if they "zoom" through space to view the list of cards within that part of the manual.

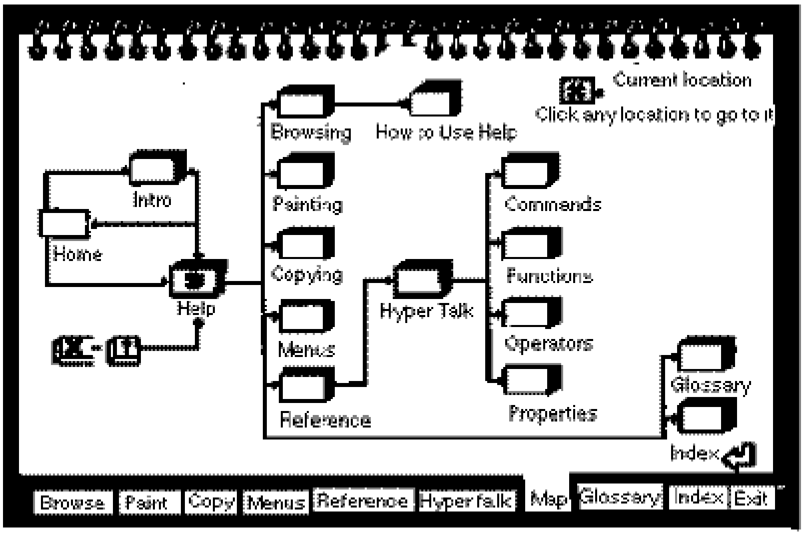

Figure 6 HyperCard Help - Graphic Map

CD-ROM

Definitions

CD-ROM, or compact disc read-only memory, is a storage format for optical discs that is a cousin of the familiar audio format (Chen, 1986). The storage capacity on CD-ROM is roughly 660 megabytes, which can be thought of as the equivalent of 250,000 pages of typewritten text, or a combined 10,000 text pages, 2000 diagrams, and six hours of telephone-quality audio. An important benefit of CD-ROM is that disks are inexpensive to duplicate and distribute. Once a master disk is prepared, it costs only a dollar or two to create additional copies, and it costs only another dollar to ship a disk anywhere in the country. When compared to the production, shipping, and storage costs for printed information, CD-ROM wins by orders of magnitude.

CD-ROMs can be installed as another disk drive on standard DOS computers, and a typical scenario for using a CD-ROM drive is as a file server from which needed information is retrieved and possibly printed on demand.

Example Applications

Lotus One-Source. Lotus Development, the makers of the Lotus 1-2-3 spreadsheet, is also the world's largest publisher of CD-ROMs. Lotus One-Source (Lotus, 1989) is an information subscription service for the business and financial community; One-Source CDs contain company reports, financial data, and other information needed by investment analysis and forecasting.

Subscribers to One Source pay thousands of dollars annually for updates, but they clearly perceive that the increased availability and timeliness of the financial information they receive is worth it.

Hewlett-Packard LaserROM. In 1988 Hewlett-Packard began distributing its system support documents, including user manuals, using a CD-ROM application they market as LaserROM (Rafeld, 1988). A couple of CDs that are updated monthly can contain all of the documentation Hewlett-Packard produces, and Hewlett-Packard has found that it much easier to ship every major customer everything rather than configure specific shipments for each customer.

How CD-ROM and Hypermedia Complement Each Other

CD-ROM technology is not limited to hypertext applications but is made significantly more useful because of them. Many hypertext and hypermedia applications seem especially complementary to CD-ROM, especially those that are inherently static like reference manuals, dictionaries, or encyclopedias (Carr, 1986; Oren, 1987; and Rafeld, 1988). Hypermedia systems, especially heavily graphic ones, require more storage space than traditional forms of information presentation. In addition, hypermedia applications typically include multiple views and entry points, multiple indexes, and rich navigation support features like graphic maps and numerous prespecified paths. CD-ROM provides the needed storage capacity to make these features possible.

In return, hypermedia provides CD-ROM with an excellent justification. Without a good user interface, CD-ROM is just digital microfilm, and the enormous amount of storage capacity it provides means more places to put information to make it inaccessible or unusable.

Problems and Prospects for Hypermedia and CD-ROM

Who can resist the vision of a hypermedia maintenance manual in which thousands of pages of text, graphics, voice, and other diverse information sources are seamlessly integrated by links with each other? The diverse set of projects in which hypertext concepts have already been applied and the excitement in the popular press about hypertext is encouraging many more hypertext projects in still other application areas.

Nevertheless, hypertext applications that make information more accessible, more useful, and more entertaining are hard to design and build. Some of the problems result from the design tradeoffs that are involved in creating hypertext units, links, entry points, and navigation support features. But from a project perspective, there are more global obstacles that hypertext project managers and their organizations must overcome for their projects to be successful. I have presented in another paper some of these challenges in "Making the Hypermedia Vision Happen" (Glushko, 1990b). Here I discuss some of the problems that are most directly relevant to the context of maintenance information.

Realistic Expectations

Most organizations that get interested in hypertext start with a small-scale demonstration project. Typically, this demonstration project uses a popular hypertext program like HyperCard and emphasizes user interface capabilities. A carefully hand-crafted system is built to show the enhanced usability that hypertext features, like links and navigation aids, bring to a problem that might previously have been handled in a traditional database or document archive with a less user-friendly interface.

The apparent success of the demonstration project justifies the start of a full-scale development program to convert the entire database or document archive to hypertext. But too often this full-scale development is doomed to failure. The organization tasked to carry out the follow-on effort often has unrealistic expectations about how hard it is and about the capabilities and resources needed to do it. Many demonstration projects "succeed" by using methods and tools that are impossible to scale up (Alschuler, 1989). Often the demonstration project uses an off-the-shelf software package that provides neither the capacity nor the performance to deliver the bulk of information now managed by the traditional database or file system. Worse, the information examples and links in the demonstration project may have been carefully hand-crafted, an unworkable approach for a system several orders of magnitude larger. If a demonstration project takes three months to convert five procedures from an manual into an interactive hypermedia form, how long will it take to convert a thousand procedures using the same techniques? Automatic or semiautomatic techniques are the only realistic option for large conversion projects.

A related problem of expectations results with CD-ROM when people focus on the duplication and distribution costs, which are negligible, and ignore the development costs, which can be considerable.

Design Guidelines

Because hypertext is a relatively new design field, there are few detailed published case studies or design guidelines that designers can readily use. Published reports about hypertext are not representative, typically biased toward small-scale demonstrations or research projects. While hypertext applications of practical scale have been successfully designed and implemented, in general such projects are not documented in the open literature because of resource constraints in development organizations or proprietary considerations.

While there is a growing body of empirical research evaluating particular hypertext systems or specific design options, this work does not usually generalize well. In addition, what formal experiments have been able to establish is that most of the design choices, when considered in isolation, have only small percentage impacts on system usability (Nielsen, 1989). Far more important are individual differences in users, especially motivational differences, and the effects of different tasks. Yet who the users are and the tasks they want to carry out are often not something the hypertext system designer can control.

However, designers of hypertext systems can take steps to ensure that their systems are acceptable and effective for their users. While empirically validated design guidelines remain some way off, design methodologies for hypertext are being proposed; the most comprehensive of these is that of Perlman (1989). Other less ambitious statements of hypertext design methods for certain classes of hypertext applications or particular design problems have been proposed (Hardman, 1988; Jonassen, 1986; Lacy & Chignell, 1988; Landow, 1987; and Walker, 1988). General guidelines for user interface design can be successfully applied to hypertext (Department of Defense, 1989; Smith & Mosier, 1986) if they are made explicit goals and compliance with them is monitored during the design process.

Any design feature can be the basis of or contribute to a future guideline if the system is instrumented to collect data on its use. When coupled with observation of users, objective data about the use of various system features can lead to design improvements if the system is designed to support easy modification (Egan, Remde, Landauer, Lochbaum, & Gomez, 1989; Hardman, 1989; and Perlman, 1989).

Installed Base Constraints

Hypertext demonstration projects are often done in research organizations that have advanced technology, including workstations and high-resolution 19-inch monitors. HyperCard on the Macintosh personal computer is also a very popular environment for demonstration projects.

In contrast, the users for whom full-scale versions of these demonstration systems must be targeted often work with an older installed base of computing equipment. This installed base may consist predominantly of IBM AT-compatible processors with small display screens having limited graphics resolution.

This situation often poses a dilemma for hypertext projects. Advanced technology may be needed to demonstrate the benefits of hypertext capabilities, but the presentation of these capabilities in the demonstration projects exceeds what the installed base will support. It is essential that the funding or marketing organization promoting the project knows the costs and tradeoffs implied by various technology alternatives. Which is more successful, a project that uses less-advanced technology to create lower expectations that can be met, or a project that uses state-of-the-art technology that is not readily available for the average user? There is no right answer, but it is essential to ask the question when project goals are being established.

Temporary constraints in processing power for installed base computers can be overcome by exploiting space vs. time tradeoffs in hypertext designs by using the enormous storage capacity of CD-ROM to store indexes and features like navigation maps instead of computing them in real time (Oren, 1987).

Source Files

Many hypertext conversion projects are plagued by the poor quality or availability of source files. Many documents have no digital form, and even when one exists, unless a hypertext version was planned or contracted for when the documents were created, the existing digital form may not be readily usable.

Optical character recognition (OCR) technology is rapidly improving, and new OCR devices that output text in SGML form are especially promising. Nevertheless, error rates are non-negligible, so proofreading is always required.

Taken together, potential problems with source files make it essential that hypertext projects carefully investigate source quality and availability before committing to a project schedule. A single document sample may not be representative; often a large document or document collection (such as the complete set of manuals for a large system) was assembled from parts created by different vendors or subcontractors. Each supplier may have provided documents in a different source form. If documents are obtained in various source formats, it is generally more cost-effective to have a third-party text conversion service transform all of them to a common format than to use project software resources to carry out the conversion.

Hypertext projects whose application involves periodic publication of text created elsewhere should define formatting standards and quality control procedures for the organization that produces the information. These measures can lead to substantial improvement in the productivity of hypertext conversion by enabling the development of automatic conversion software.

Software Tools

Most off-the-shelf hypertext software is oriented toward creating new hypertexts and is not well-suited for converting existing documents (Alschuler, 1989; Glushko, 1990a). Demonstration projects often use this software to create expectations about the look and feel of a full-scale implementation, and it often comes as a harsh shock to discover fundamental limitations in the software that jeopardize the viability of a project.

It may be worth waiting for the next generation of hypertext software that directly supports conversion. Alternatively, some database programs or expert system shells may better support hypertext features than programs that call themselves hypertext.

Summary: Toward Hypertext Engineering

I end this paper with a summary of what I have tried to convey about hypertext and CD-ROM. Elsewhere I have characterized this philosophy as "hypertext engineering" (Glushko, Weaver, Coonan, and Lincoln, 1988):

- Hypertext is an attractive vision, but practical hypertext applications are hard to build.
- Hypertext is not a revolutionary idea; it is the natural extension of non-linear presentation conventions from print documents now that enabling technology and user interface concepts have arrived.
- Disciplined approaches to analyzing information, identifying constraints in its structure and in the task environment, and using the appropriate implementation technology are required. Current hypertext software technology is better suited for creating hypertext than for converting existing documents.

- CD-ROM and hypertext are complementary. Hypertext systems, especially those involving extensive graphics or other media, require more storage space than traditional forms of information presentation. The innovative user interface concepts of hypertext and hypermedia make CD-ROM something besides digital microfilm.
- Successful hypertext projects are those that take a cautious approach to problems of scale and that make the right tradeoffs along the way.

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An Integrated Maintenance Information System (IMIS): An Update

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The Air Force Integrated Maintenance Information System (IMIS) is based on a concept developed in 1979 in which computer technology would be applied to the growing volume of information required in aircraft maintenance. At the FAA Human Factors Meeting in October 1988, I described the IMIS program in some detail. Today I will review mostly progress made since that time and indicate out program plans for further development. This status update will center on three ongoing IMIS activities:

1. F-16 diagnostic demonstration
2. Content data model specifications
3. IMIS requirements analysis

At the Air Force Human Resources Laboratory, where we are working on IMIS, we are following a definite strategy in the development of this system. In the laboratory setting, we are able to develop new ideas for computer-based maintenance information systems at relatively low cost before making a major dollar commitment to a system. We can develop enabling technologies to aid in our overall progress. We also are conducting our studies with full focus on the end user, i.e., the maintenance technician. System operations are planned from the technician's point of view and field evaluations are conducted with Air Force technicians. A major goal is to develop or recommend specifications and standards which others might use as they develop information systems for their own purposes. In this way we have been very much involved in a number of Air Force programs, such as the Advanced Tactical Fighter, the F-16, the C-17, and the Air Force Technical Order Management Program. This latter program is the Air Force attempt to digitize the massive amount of technical data now required to support aircraft maintenance.

The basic concept for the Integrated Maintenance Information System is shown in Figure 1. IMIS provides through a portable maintenance aid all of the technical information that an individual needs to perform maintenance on a daily basis. This includes technical data, diagnostics, training, data collection, historical data, and maintenance management information. There also is an aircraft interface. With IMIS, a technician can go to the aircraft, open a panel, activate a switch, and a small screen will come on which will provide a self check of that part of the aircraft. The portable maintenance aid, the computer, will plug into the maintenance bus on the airplane and through this bus be able to communicate with any system that is handled by the Built-In Test (BIT) on the airplane. The final part of the system is the connection back with ground processing and data bases that already exist in maintenance. The maintenance technician then will be able to plug into the airplane and get all available information from the Built-In Test, run that against a diagnostic algorithm contained in the portable computer, make the best diagnosis he can to reduce false removal at the flight line, and then proceed with the appropriate maintenance.

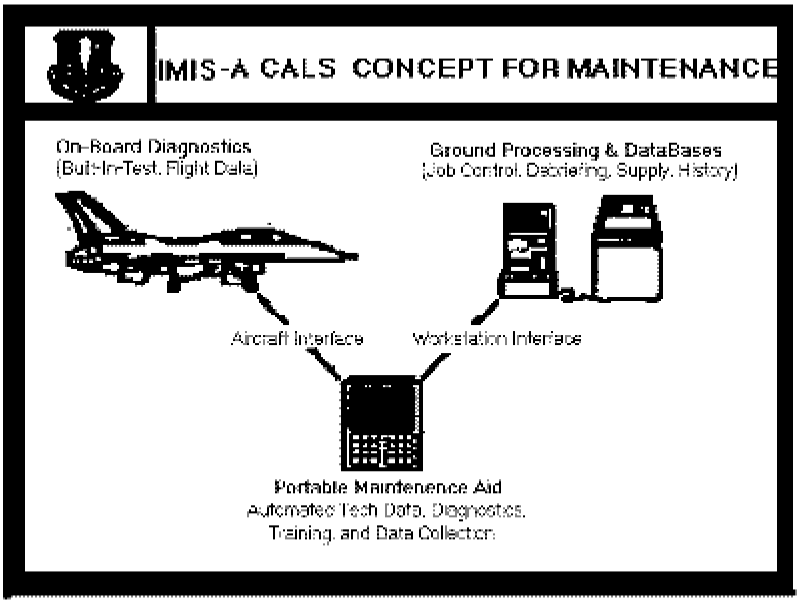

Figure 1

With IMIS, a technician will not have to worry about aircraft configuration. The airplane will identify itself to the portable computer. Then the technician will be provided with individual data that applies only to that airplane. He will not have to sort through data anymore to see which data apply.

A technician working with IMIS will deal with one computer interface only. All data will be provided through this interface. The technician himself should not care about this, as long as his information needs are being met.

An operational IMIS system should improve operational capabilities of technicians through more effective presentation of maintenance information. The quality of technical information will be improved and tailored to meet the technician's needs. Time-consuming paperwork will be reduced through automation. Improper parts removals also will be reduced through improved diagnostics. The result, from the Air Force point of view, will be better utilization of available manpower, an improved capability for maintenance in dispursed operations, and more mission sorties with available resources.

Figure 2 illustrates the flow of data in and out of IMIS. The circle showing "flight data," for example, refers to information obtained directly from the airplane. In the Advanced Tactical Fighter, when a module fails, IMIS will be provided information about the altitude at which it failed, the G-forces operating against it, pressures, vibration, and other information important for maintenance. The important thing to note is that IMIS provides all of this information through one interface. If IMIS were not available, the technician would have to interact with computer systems for each one the outside circles on a daily basis.

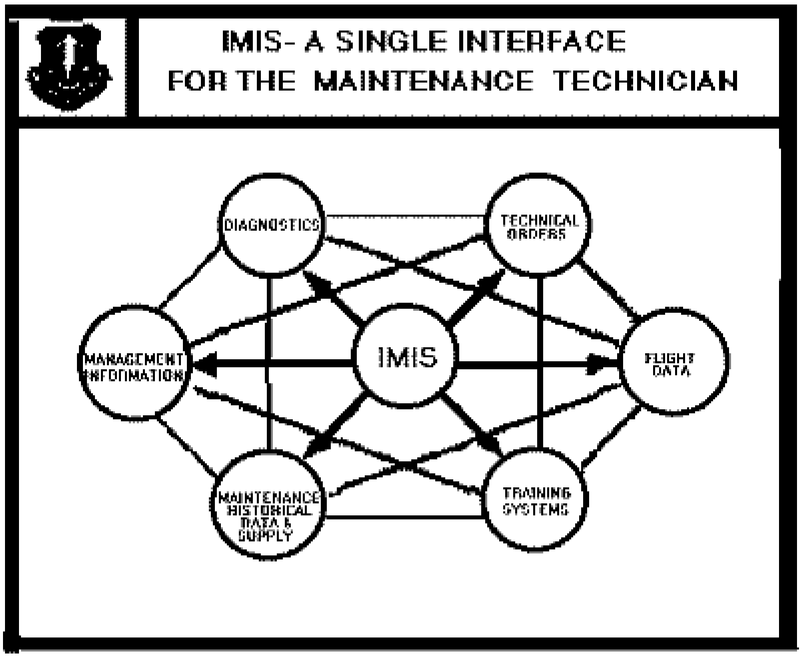

Figure 2

The phased approach being followed in the development of IMIS is shown in Figure 3. In the first phase, concluded in 1987, concern was only about data content, user requirements, user presentation formats, and similar issues. Little attention was given to computer hardware. In Phase II, which is ongoing at the present, we are concerned with diagnostic presentation, development of maintenance algorithms, and the integration of technical data. When flight line diagnostics are in process, and technical data are required, the technician should be able to access the data immediately. Phase III, scheduled for completion in 1993, will be a formal engineering analysis of the requirements for an Integrated Maintenance Information System and a full field test of the system as developed. The principal activities and results of Phase I, the development of electronic presentation techniques, are shown in Figure 4. Initially we worked with a small off-the-shelf computer. Even so, we were able to link it with multiple data sources so that a technician could go from the task to diagnostics to historical data to remedial background information as he worked with the computer. We also worked extensively in the development of efficient presentation formats for the computer interface.

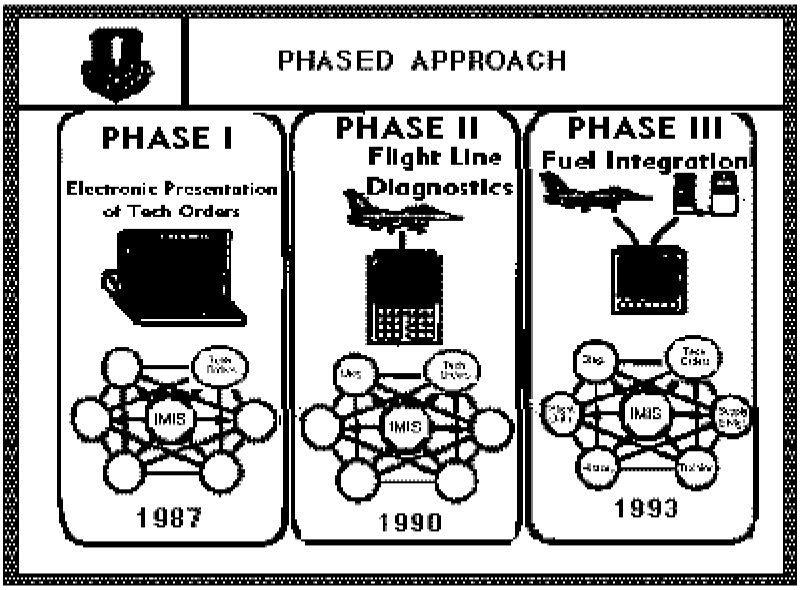

Figure 3

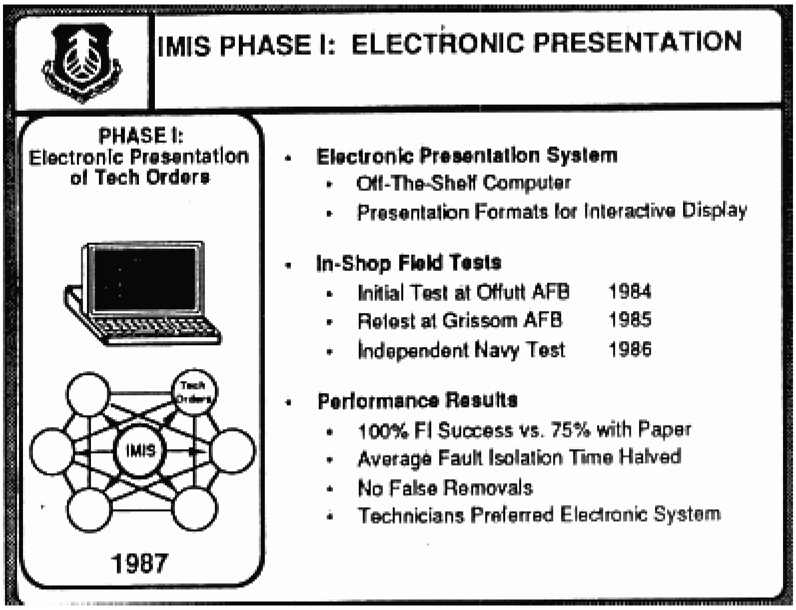

Figure 4

Three in-shop field tests were conducted to evaluate our electronic presentation techniques. Two were at Air Force facilities and one was an independent Navy test. In a comparison test, we found 100 percent fault isolation success with the electronic system versus 75 percent success with a paper presentation system. In addition, we found that fault isolation time with electronic presentation generally ran about one-half that with a paper-based system. With the electronic system, there were no false removals, which is a tribute to the ability of IMIS to provide diagnostic information. Finally, technicians liked the electronics system. Acceptance scores were high.

In our electronic presentations, two levels of detail for maintenance information were provided since both novices and experts worked with the system. Developing maintenance information for a dual-track system was not a simple matter but it was done. This approach was successful in making the system useful for technicians at different levels of experience and capability.

The principal activities of Phase II, Flight Line Diagnostics, are listed in Figure 5. As we began this phase, it was apparent the small off-the-shelf computer used previously no longer was satisfactory. Consequently, a Portable Maintenance Aid (PMA) was constructed in-house with appropriate features to allow use at the flight line. We also began an authoring system for "Type C" data, about which more will be said later. In flight line tests to date, the F-16 has been used as the test aircraft. In May 1989, we completed our diagnostics tests for the fire control radar in the F-16. In 1990, the Navy F/A-18 aircraft will be used as a test vehicle since it has a more extensive maintenance bus and will represent more of a challenge for our diagnostic system. The final step in Phase II will be the preparation of a Content Data Model Specification which will detail software requirements for our authoring and presentation system.

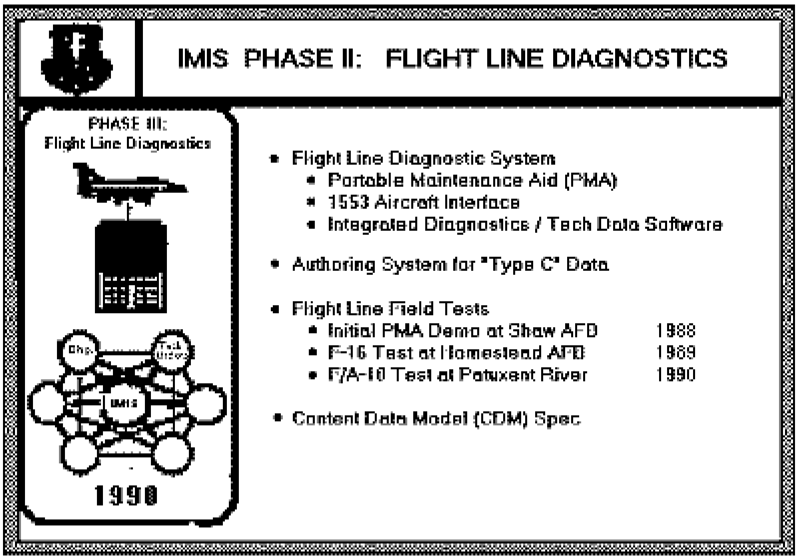

Figure 5

The F-16 flight line test was conducted to demonstrate the feasibility and utility of flight line diagnostics. In this test, the Portable Maintenance Aid was loaded with the F-16 Fire Control Radar data base. Into this data base were inserted six radar faults. Twelve F-16 technicians then attempted to isolate and repair these faults using the PMA as a diagnostic system.

The diagnostic logic of the PMA optimized the isolation and repair sequence. Technicians indicated they preferred the IMIS diagnostic system over a handbook approach. The technicians commented positively about (1) the graphical depiction of diagnostic logic, (2) the diagnostic sequence controlled by the technician, (3) easy access to required data, (4) the expert/novice levels of detail, and (5) the automatic maintenance data collection feature. One problem noted was with the weight of the PMA, which now is about 13 pounds. Within the next several years, plans call for the PMA to be reduced to a size essentially defined by the size of the display. Including batteries, this should weigh approximately six pounds.

A separate effort within the IMIS program is to examine the potential of this system for training maintenance technicians. Logic indicates that the same data base could be used both for training and for maintenance support. When used in this manner, a trainer can examine a trainee's logic as he attempts fault isolation. Since the trainee's attempts are recorded, the trainer does not have to observe all activities. Simulated faults and systems can be programmed as well as "what if" logic. One advantage is that the system could be used to preview little used tasks. It also has the advantage of providing multi-level presentations (expert, novice, trainee).

IMIS technology is being evaluated at this time in a study of its impact on Rivet Workforce training. The Rivet Workforce is a program in which the Air Force is attempting to expand the technical capabilities of individual technicians. The Air Force is trying to broaden these individuals so they are not entirely vertical specialists. The objective is to do this without greatly increasing training costs. In this program, which will be completed in 1990, various approaches are being taken to determine the training potential of IMIS. Subject matter experts are being interviewed at the Air Training Command and in the field. Opportunities for use of IMIS technologies are being described. The result will be recommendations for use of IMIS, development of a test plan, and demonstration of a test protocol.

The development of IMIS is working toward use of "Type C" data. The advantages of moving in this direction are shown in Figure 6. Type C allows a neutral-format free data base. In this approach, when data are entered into the data base, the data can be used to support many applications. When a data item is updated, all applications are updated. For instance, if a piece of data were to be used in three different manuals, it would not be necessary to update all three when the data item changed. A simple update of the data item itself would accomplish all necessary changes.

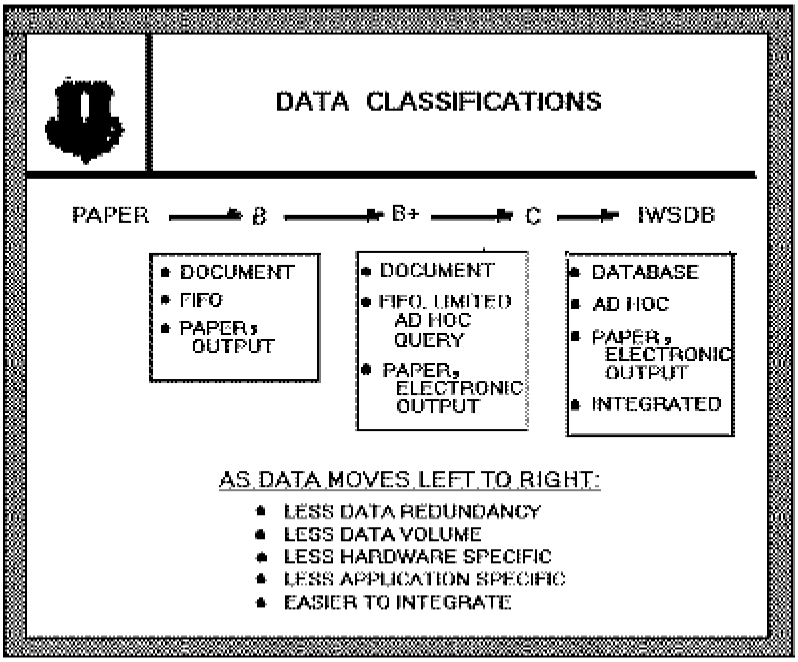

Figure 6

There are many advantages to use of Type C data. For one, technical data to support a vehicle is contained in an integrated data base rather than a collection of manuals. The data base itself can be used to support many devices and many presentation layouts. The biggest advantage, of course, is that a neutral technical data system, using Type C data, allows the development of an integrated flight line maintenance system rather than one requiring a number of technician interfaces.

The movement toward use of Type C data is not just in the Air Force. The Technical Manual Technology Exchange Subcommittee of the Department of Defense recently formed a tri-service working group to develop an initial set of DoD specifications for "Type C" data. The Army is represented by the Army Materiel Command, the Navy by the David Taylor Research Center, and the Air Force by the Air Force Logistics Command and the Air Force Human Resources Laboratory.

The Phase III activity of IMIS is working toward a full integration of the system, with a 1993 deadline. The Portable Maintenance Aid will interface with all maintenance work stations, with all supporting software systems, and with Air Force aircraft. A detailed requirements analysis will be completed to ensure that the system supports all maintenance functions and that all required information elements are taken into account. There will be additional field testing of the IMIS prototype at the Air Force Base level. Finally, functional specifications will be developed to support full implementation of IMIS.

The progress of IMIS from 1985 until its scheduled completion in 1993 is shown in Figure 7. Upon completion, the Integrated Maintenance Information System (IMIS) should allow the Air Force to take a quantum step forward in aviation maintenance. Use of an integrated system will make maintenance technicians more efficient, lessen the number of false removal of parts, and make the entire activity a more cost-effective effort.

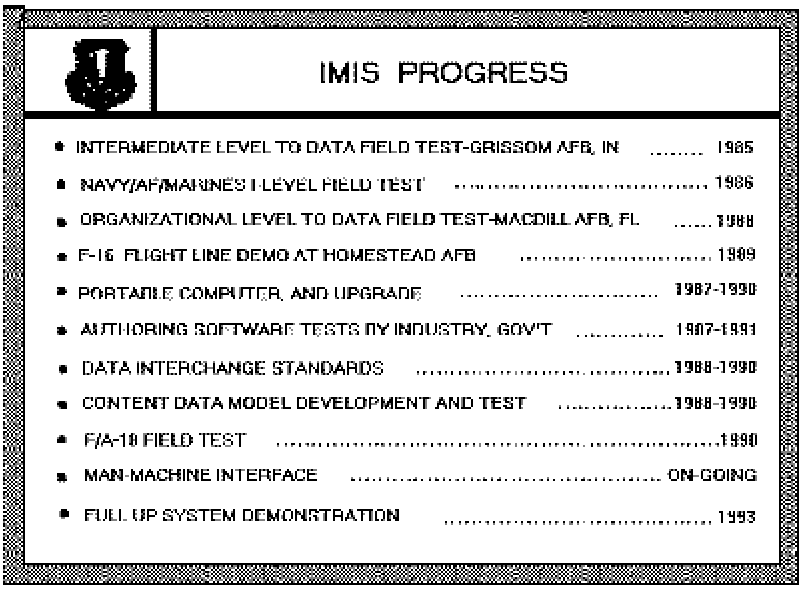

Figure 7

As an update of my presentation last year, I would like to note in summary the following key accomplishments of IMIS:

- The F-16 test demonstrated the feasibility and utility of interactive, on-aircraft diagnostics using "Type C" data.
- The Content Data Model specification development is proceeding and will provide a framework for "Type C" data.
- The IMIS Requirements Analysis will soon produce a detailed model of the information and functional requirements for a fully integrated IMIS system.

Communication and Transfer of Non-Destructive Inspection Information

Stephen N. Bobo
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The inspection of aircraft, particularly aircraft structures, is increasingly dependent on non-destructive inspection (NDI). There are four points I would like to cover concerning NDI procedures in relation to communications in aircraft maintenance and inspection:

1. The preparation, recording, transmitting, and archiving of non-destructive inspection data.
2. The type of data required in non-destructive inspection.
3. The role of aging aircraft non-destructive research.
4. The future of NDI technology and the extent of data transfer.

Use of non-destructive inspection is based on an understanding of the probability of damage to an aircraft as a function of normal operation. Figure 1 shows the incidence of failures in an aircraft during its service life. Infant mortality is on the left and, as the aircraft goes through its service life, the number of incidence of damage reports and damage revealed by inspection increases to a point where the aircraft reaches its extended service life threshold. At this point the aircraft must be studied and additional inspection methods, practices, and schedules invoked to compensate for the increased likelihood of failure. This is the point on which the Aging Aircraft Research Program will focus and it represents a threshold point for our use of NDI inspection procedures.

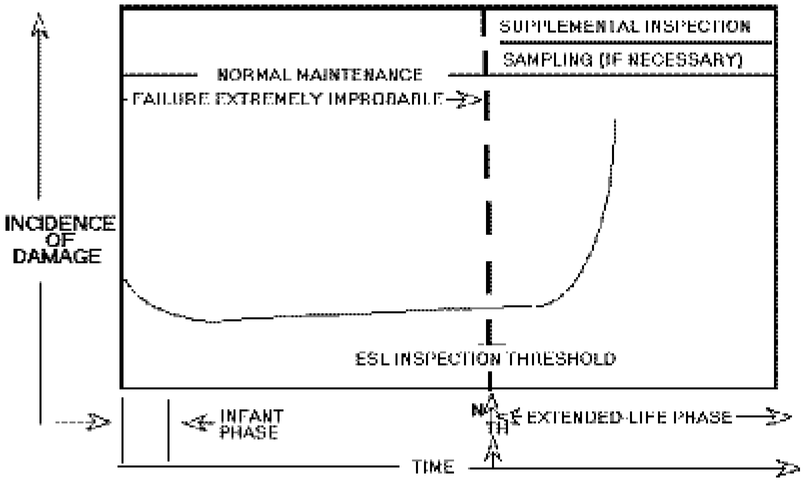


Figure 1 When in the life of an aircraft does damage occur?

To appreciate the demands being placed on non-destructive inspection technology, one must understand the aging characteristics of the U.S. commercial airline fleet. Figure 2 shows the number of aircraft and the age of the respective aircraft in our national fleet. There are nine types of major aircraft in this fleet and all of these except four have exceeded, on an average, their designed service life. A large number of aircraft will require a very large number of inspections in the future.

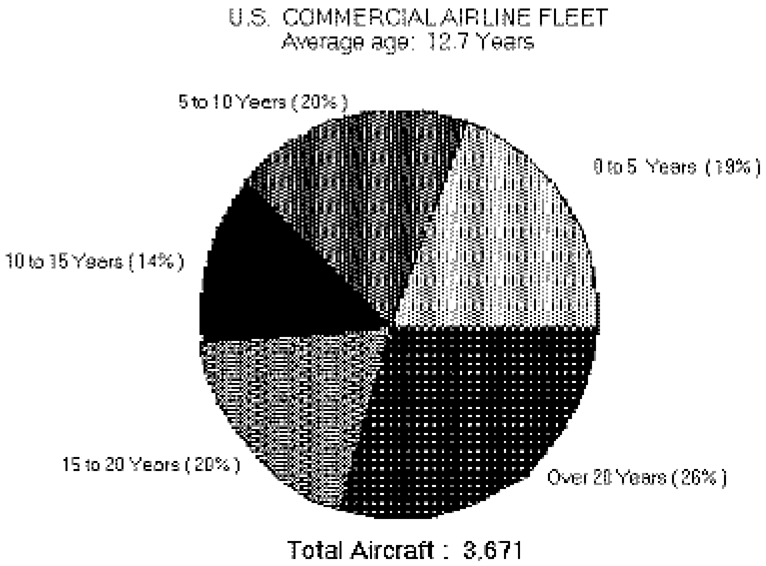


Figure 2 Estimated age of the commercial airline fleet.

The aging aircraft issue is further illustrated in Figure 3. In this figure, the dark band shows the number of cycles (one complete flight) for the aircraft in the fleet with the highest number of cycles. The light band shows the number of cycles established as a "design goal" during the initial development of the aircraft. As can be seen, each type of aircraft except the DC-10 and the L-1011 shows aircraft which have exceeded their design service life.

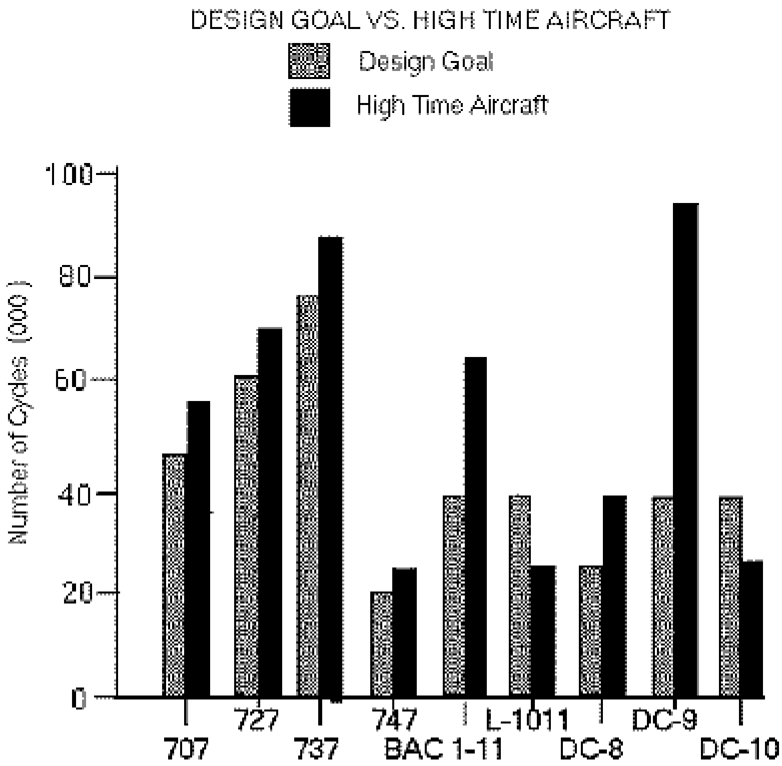


Figure 3 Comparison of design age with actual age of highest time aircraft in fleet

Ominous signs have been present for some time that the structural integrity of commercial aircraft is threatened as the fleet increased in average age. Three well-known events which carried this message include:

1. Far East Airlines Boeing 737 accident in 1983
2. Japan Airlines Boeing 747 accident in 1985
3. Aloha Airlines Boeing 737 accident in 1988

In studying aircraft as a result of these events, the problem of greatest consequence was found to be multiple site damage. This means that at some point in the aircraft's service life there will be an onset of structural fatigue and multiple cracks will appear in the structure of the aircraft. These cracks, when they link up, cause the potential for catastrophic failure to increase at a more rapid rate than the nominal growth of individual cracks.

An example of multiple site damage is shown in Figure 4. This is an instance in which individual cracks around rivet holes started to propagate and resulted in a single crack about 18 inches long which depressurized the cabin to the extent that passengers were aware of the condition. The bottom drawing in Figure 4 shows the manner in which the multiple cracks joined to form the single long crack. This incident occurred in 1987 and caused a Service Bulletin to be issued in an attempt to preclude such events in the future.

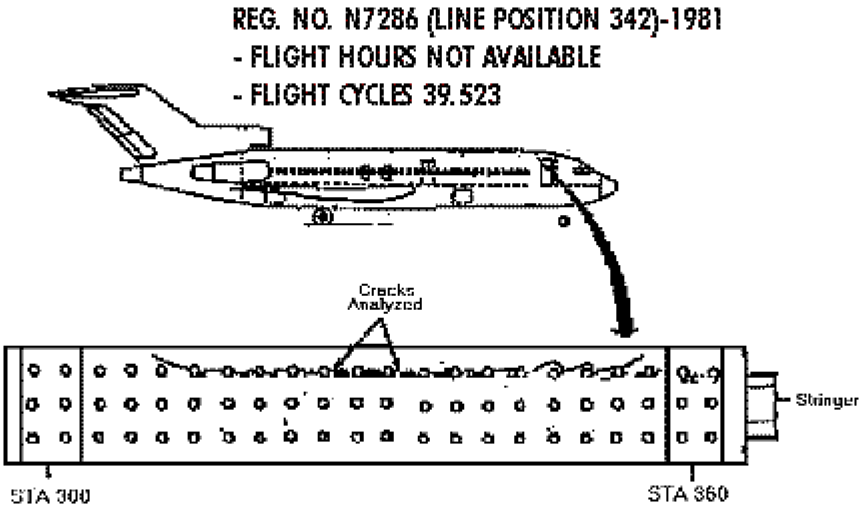


Figure 4 Example of multiple crack elongation

After the Aloha accident, a review was made of airplanes in the commercial fleet with cold bond lap splices, believed to be the condition underlying the development of multiple cracks. This review showed that multiple site damage might be present on over 1600 aircraft to some extent. The number and type of aircraft involved were:

	Number
Boeing 727	849
Boeing 737	620
Boeing 747	195

An immediate problem faced after this review was that of transmitting information concerning potential damage in these aircraft to individual operators to ensure that timely inspections could begin.

One week following the Aloha Airlines accident, a message was sent to all operators of aircraft believed subject to this kind of damage. This first message gave the inspections and other procedures believed necessary to ensure the continued airworthiness of aircraft that were flying. Specific items in this message included:

- Cabin pressure differential limited to 5 psi
- Visual inspection required of all lap joints
- Eddy current inspection required of stringer-4 and stringer-10 lap joints

Following the transmission of the initial bulletin, a more detailed inspection procedure was defined and transmitted as an Airworthiness Directive. Airworthiness Directives were sent for Boeing 727, 737, and 747 aircraft. To illustrate this process, the actions required of the operator by Boeing 727 Airworthiness Directive include:

- Within 2500 landings, conduct High Frequency Eddy Current (HFEC) inspection for cracks at stringer-4 and stringer-10
- Perform subsequent detailed visual inspections of all fuselage lap joints at intervals not to exceed 15 months
    - If corrosion is found, conduct a Low Frequency Eddy Current (LFEC) inspection and repair if necessary
    - If cracks are found, perform a High Frequency Eddy Current inspection and repair

- Carry out terminating repair at stringer-4 and stringer-10 within four years

Similar Airworthiness Directives were sent for the Boeing 737 and 747.

The preparation of an Airworthiness Directive of this type requires an extensive analysis of flaw characteristics for a given aircraft. To do this, for a given NDI inspection method a determination is made through statistical analyses of the minimal size of a flaw which can be detected by the individual and the specific type of eqiupment he is using. This gives you the probability of detection of a flaw as a function of flaw length. Figure 5 shows detection probability curves for four non-destructive inspection procedures in general use in the industry. These are eddy current, dye penetrant, radiography, and ultrasonic inspection. Based on a determination of the rate of flaw growth during experiments, we can establish an appropriate inspection interval based on the size of the crack that can be detected by NDI. The Federal Aviation Administration establishes the procedure and the frequency of inspection and then submits this information to air carriers who in turn are responsible for preparing a procedure to carry out these inspections. In addition to the carriers, there are some 4,000 repair stations which also receive these notices. Oversight of this community of repair stations and individuals maintaining these airplanes is accomplished by some 3,600 inspectors covering the three areas of manufacturing, maintenance, and certification.

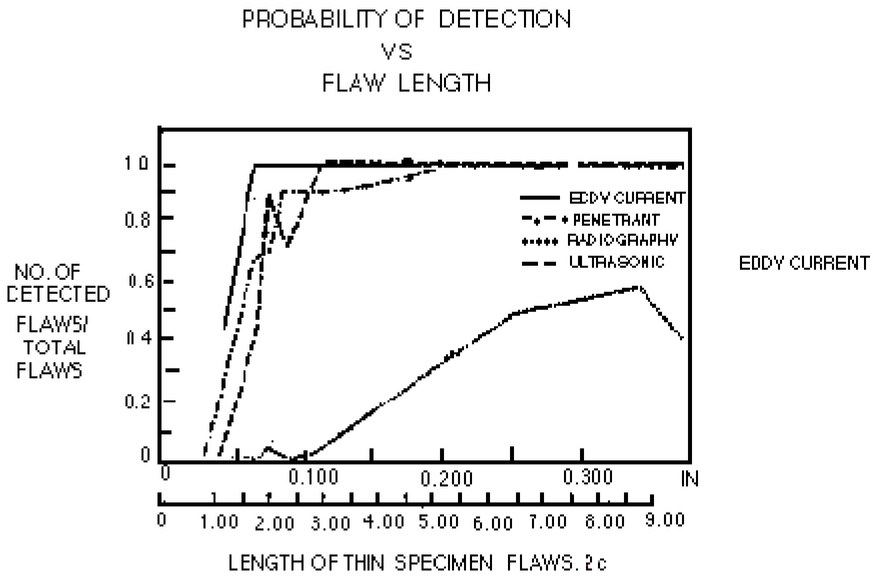


Figure 5 Detection probability curves for four NDI procedures.

The base document for non-destructive inspection is the NDT Manual. Figure 6 is taken from a page in the Boeing NDT Manual describing eddy current inspection for the lap joint found to be a problem with the 737 aircraft. This illustrates the transformation of an engineering drawing into an inspection drawing. Drawings such as this are available at the technician level. The technician will get a sheet of these instructions when he goes to look at the airplane.

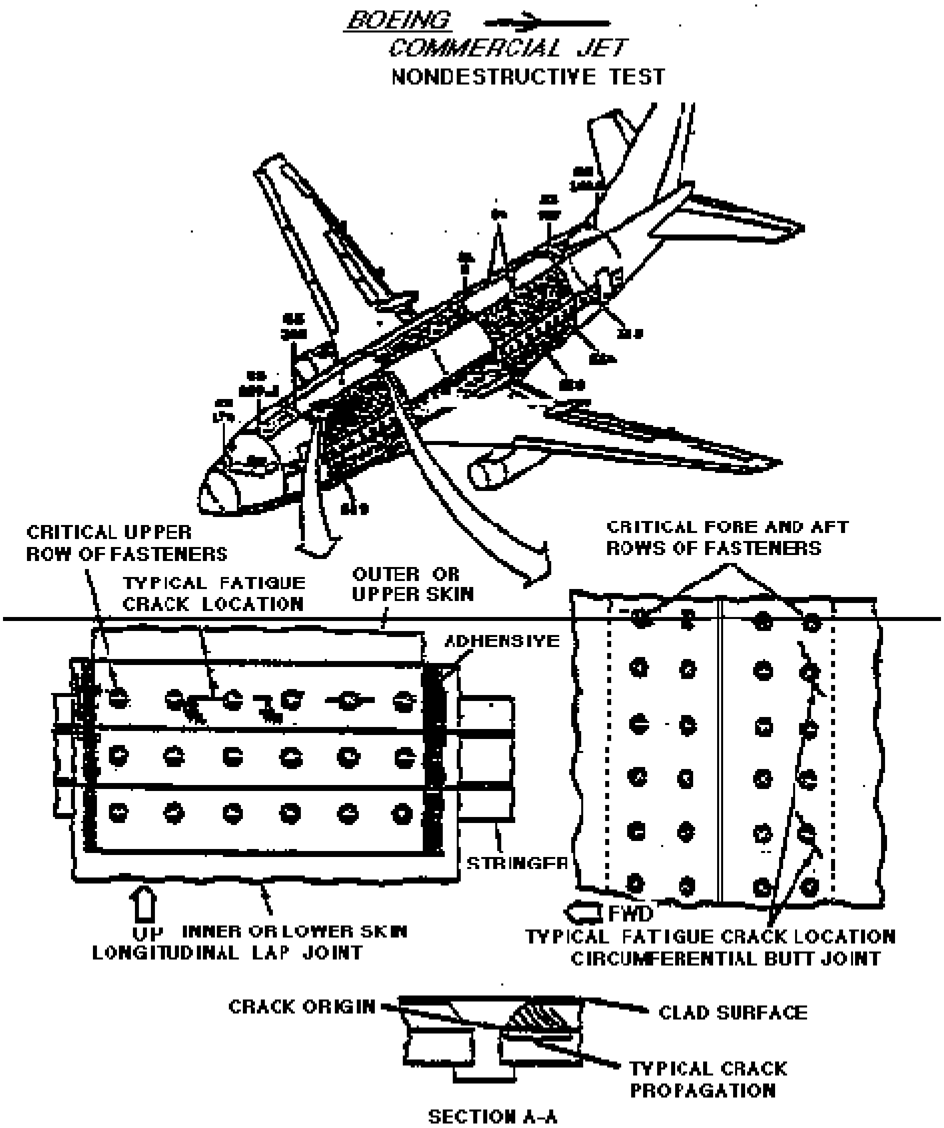


Figure 6 Typical fuselage skin joint configuration and crack orientation.

Figure 7 shows three graphs, prepared by Douglas Aircraft, depicting the presentation on the cathode ray screen for two eddy current probes inspecting for aircraft corrosion. These particular signal patterns are for exfoliation corrosion found around fastener holds in wing skins. This is the type of information that must be present in the NDT manuals.

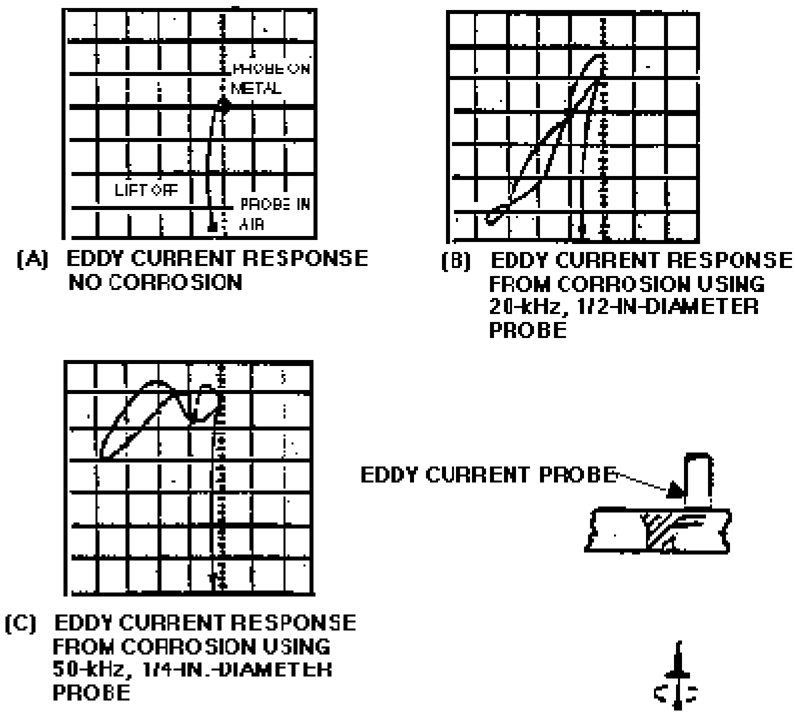


Figure 7 Eddy current impedance-plane responses for exfoliation corrosion around fastener holes in wing skins.

Figure 8 is another example of the type of information contained in NDT manuals. This figure shows ultrasonic cathode ray tube responses from a non- corroded region of the aircraft and from a corroded section.

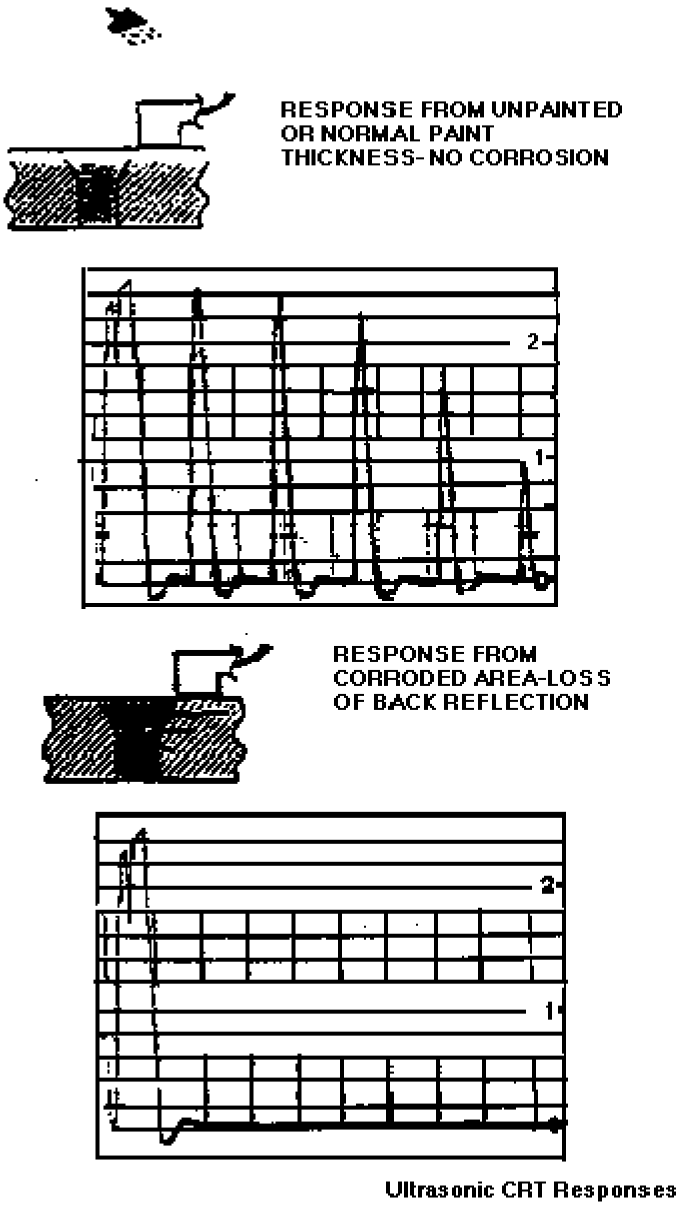


Figure 8 Contact ultrasonic CRT responses

A typical crack environment for ultrasonic inspection is shown in Figure 9. This is an element of the Special Inspection Document (SID) for the McDonnell-Douglas DC-10. This procedure requires an inspector to climb up into the elevator structure, lie on his stomach, and look at the video presentation shown in Figure 8. This is a very difficult inspection and is one that requires a real measure of dedication on the part of the inspector.

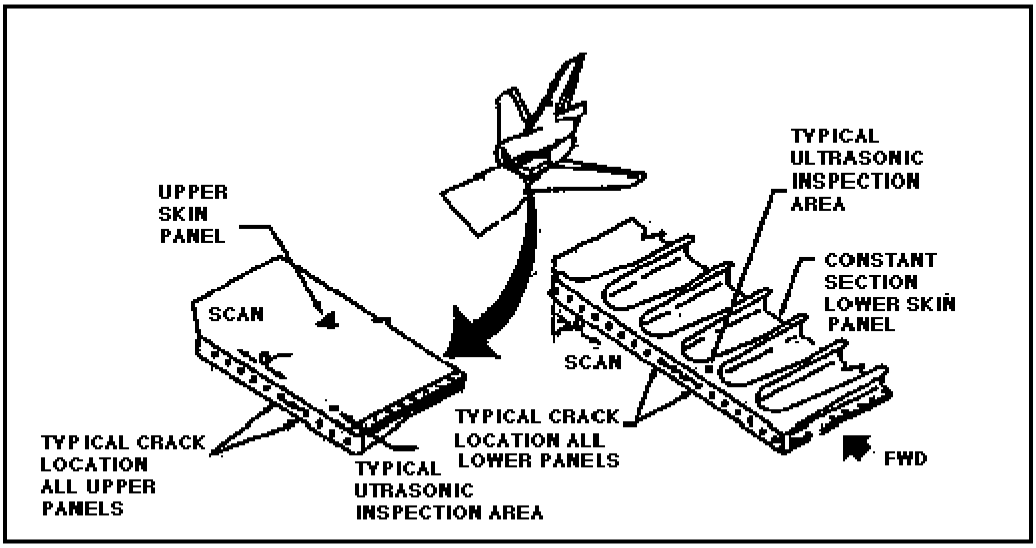


Figure 9 Typical crack environment for ultrasonic inspection.

There are many interconnecting documents, messages, and other communications which send information among the Federal Aviation Administration, the aircraft manufacturers, and the air carriers. Listed below are some of the more important of these communications and the particular segment of the triad having major responsibility for the communication:

Federal Aviation Administration

1. Federal Aviation Regulations - FARs represent the overriding document in the communications network. These regulations take precedence.
2. Advisory Circulars - ACs provide non-mandatory guidance for the control of inspection processes.
3. Airworthiness Directives - These directives are mandatory and are issued to control some specific problem. Some say that ADs are used only following a severe accident; the FAA is not being proactive with respect to the issue. However, the FAA does not like to place additional burdens on the aviation industry unless it can be conclusively proven that a problem exists.
4. Orders - These are issued by FAA Headquarters to regions in order to convey specific engineering information.
5. Technical Standard Orders - TSOs are certifying documents either for a manufacturing process or for a procedure for testing discrete aircraft components.
6. Alerts - A method for general communication to the industry.
7. Notice of Proposed Rule Making - NPRMs are a means of alerting the industry to changes under consideration by the FAA.

Aircraft Manufacturer

1. Performance Certification - Results of negotiations between the manufacturer and the FAA allowing the manufacturer to request a Certificate of Airworthiness or a Type Certificate for an aircraft to allow it to go into passenger service.
2. NDI Manual - The manufacturer's means of communicating inspection procedures to air carriers.
3. Notices - An adjunct to a larger publication such as the NDI Manual.
4. Service Bulletins - Messages to aircraft operators which provide recommendations concerning correction of some problem.

5. Supplementary Structural Inspection Document - A message to operators to update recommendations concerning structural inspections.

Air Carriers

1. Certificate of Airworthiness - A certificate required to be physically in each operating aircraft.
2. Inspection Procedures Manual - This manual is prepared for Repair Stations and directs the repair station concerning FAA-approved procedures.
3. Process Specification - This document is developed as a result of a carrier's interpretation of the manufacturer's NDI Manual and makes the process specific to his aircraft. It is approved by the FAA.

The communication process supporting non-destructive inspection will be affected by the Aging Aircraft NDI Program initiated by the Federal Aviation Administration. This program is diagrammed in Figure 10. This R&D program has a significant survey activity under its technology transfer effort. An assessment is being made of all NDI technology to find that most relevant for aviation requirements. Considerable work done by the Department of Defense, the Electric Power Research Institute, and others will be incorporated into aviation NDI procedures. At the bottom of Figure 10 is ISU, which is Iowa State University, an institution with a large Non-Destructive Inspection Center.

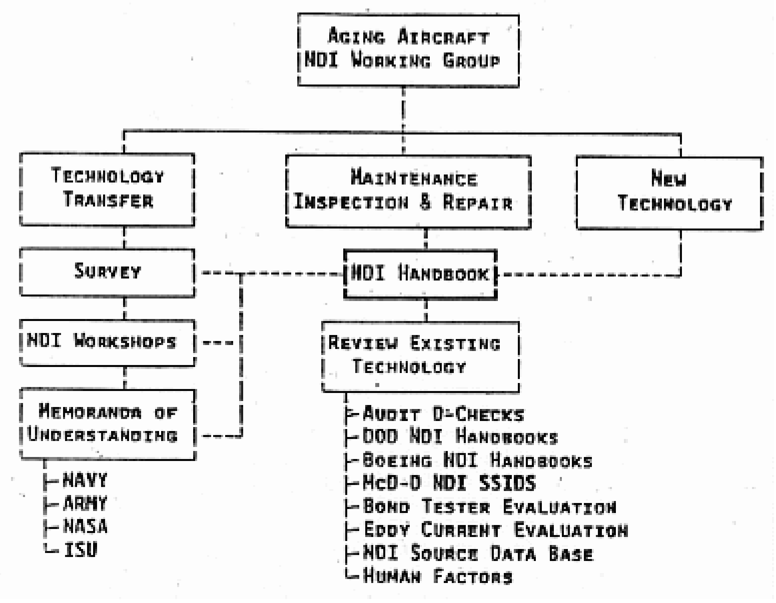


Figure 10 Aging aircraft NDI program.

Another activity of interest within the Aging Aircraft NDI Program is the audit of heavy maintenance checks accomplished by an FAA Audit Team. One part of this audit covers human factors issues including communications.

The Aging Aircraft NDI Program also is reviewing various NDI handbooks available to the industry. Individual evaluations of equipment and procedures are being made. All of this information is being distributed in the form of Advisory Circulars as appropriate and ultimately will be incorporated into the NDI Handbook.

A recent study by the Department of Trade and Industry of the United Kingdom focused on small manufacturing organizations, including small repair stations. They found that these facilities had limited NDI experience, usually residing in one person with outdated knowledge. These persons were unaware of current methods, equipment, and practices. NDI equipment was perceived to be expensive. NDI itself was viewed as an end-of-the-line inspection tool rather than as a quality assurance adjunct. Surveys in the United States indicate these same problems exist here. Smaller repair stations do have special communication needs which must be addressed.

In conclusion, non-destructive inspection must be used increasingly by the aviation industry to control problems with an aging fleet of aircraft. NDI equipment is becoming more and more capable and sophisticated. This eqipment can be of great value in the inspection process. For maximum benefit, however, proper communications procedures must be established so that the entire industry is fully informed concerning NDI and is fully capable of using this equipment proficiently.

Converting Technical Publications into Maintenance Performance Aids

Kay Inaba, Ph.D.
XYZYX Information Corporation

Effective maintenance performance requires optimum use of maintenance information. During the presentation, I will try to support the following arguments:

1. If you want to make maintenance effective, you must have usable information on the job. Technical information required by technicians to do their jobs effectively must be usable and available. But if that's all you do, you will have usable manuals but not necessarily any better performance.
2. Accountability is the key to motivating technicians to use information. Maintenance personnel must be held accountable for their performance. This means measurement and feedback.
3. To make information usable, you must do considerably more than make the text readable. The common measures of comprehension and readibility of text address only a small portion of the issue. There are many principles and guidelines for preparation of technical information which should be followed.

Lessons from the Past

Much of what is done today in the development of job performance aids is based on past studies and experience. For this reason, I will review some lessons learned from the past and discuss the peculiar and important role of information in maintenance. The initial set of studies of job performance aids with which I am familiar started from a concern by the Air Force over the high cost of maintenance. The studies indicated that the cost of manuals was miniscule compared to the high cost of ineffective maintenance. These costs were in the hundreds of millions of dollars per system. This is not the cost of maintenance; this is the cost of ineffective maintenance.

Maintenance errors are major contributors to maintenance ineffectiveness. There are four kinds of maintenance errors contributing to ineffective maintenance. These are (1) false removals, which is generally high whenever there is time pressure, such as with turnaround maintenance; (2) failure to isolate or failure to detect, which often occurs during inspection; (3) damage during maintenance, which studies have shown to range between 10 and 30 percent; and (4) time errors, which usually involves self-detected errors and simply extend the time to repair.

Maintenance is a labor-intensive system. Thus, anytime there is a maintenance problem, there will generally be personnel performance problems. Ineffective manuals and training are usually major contributors to the problem. Periodically, because of the high cost of maintenance and lack of understanding by higher management, these two (maintenance and training) are often the target of cost cutting efforts. Such cost cutting efforts have helped to reduce the usability of maintenance manuals.

Most important, manuals need to be usable on the job. Manuals that can be easily used on the job will help reduce error rates. Studies have shown that job performance aids (integrated with training) can reduce errors by as much as 90 percent of the existing rate. In addition, studies have shown a reduction in required maintenance time by around 50 percent can be realized with proper job performance aids.

In logic terms, we learned that providing information usable on the job is necessary but not sufficient. If you do not provide usable job information, your chances of improving maintenance effectiveness are quite limited. But given that you do, you still need to do more. Usable job information is very important, but the entire maintenance system must be addressed.

A second lesson is that higher level management attention to maintenance tends to be cyclical. This attention appears to run in approximately ten-year cycles. The reason is that maintenance is not a popular or glamorous subject. Maintenance is not a favorite subject of corporate executives. However, periodically executive attention is focused on maintenance because of the large cost consequences of ineffective maintenance. But the attention won't last long. Thus, if you are involved in maintenance and find you have the attention of management, take advantage of opportunity while it lasts.

When management does attend to maintenance, changes are often introduced -- some good, some not so good. These changes usually are short-lived. The result is usually a temporary improvement in some aspect of maintenance.

In order to make a permanent change, the change must be institutionalized. An example is the introduction of ATA-100, which helped standardize manuals in the airline industry. But it had its drawbacks in that institutionalizing also tends to stultify growth. Your manuals are now standardized, but are they usable? Have your manuals grown in usability? One way to overcome this resistance to growth is to make accountability an important item in maintenance because accountability focuses on performance.

Before concluding this discussion on lessons learned, I would like to share my favorite quotation regarding maintenance. The quotation is by Eric Hoffer, sometimes knows as the "blue collar philosopher." He states, "There is a phase of the war with nature which is little noticed but has always impressed me. To me there is an aura of grandeur about the dull routine of maintenance; I see it as a defiance of the teeth of time. It is easier to build than to maintain. Even a lethargic or debilitated population can be galvanized for a while to achieve something impressive, but the energy which goes into maintaining things in good repair day in, day out is the energy of true vigor." This expresses admirably why maintenance attention has such a short half life.

Maintenance is Information Demanding

- Maintenance is a stochastic system
- Frequent design changes
- Impact on maintenance technician
  - Large number of infrequent events
  - Multiple configurations
  - Numerous error opportunities

Figure 1 Information and Maintenance

The role of information in maintenance is a function of the unique nature of maintenance. Maintenance is a stochastic system driven by essentially random events. The combination of the stochastic nature of maintenance plus frequent changes in aircraft configuration result in a tremendous amount of information required. One Air Force study showed that approximately 80 percent of the work assigned a given technician consists of tasks that occur on the average (for a given technician) of once or twice a year. Obviously a technician cannot remember detailed maintenance information for all such tasks. This is a major reason why error in maintenance is generally accepted as a given.

Information to support maintenance is of two broadly different kinds, as shown in Figure 2. One is procedural, i.e., information to support operations. Procedural information usually is oriented toward corrective and periodic maintenance. The other kind of maintenance information is descriptive, which explains how a system (or equipment) works. This is the type of information technicians use to generate their own procedures at the worksite. Bear in mind that before one can perform, knowledge must be transformed into procedures. Performance problems start to appear when technicians use the descriptive, cognitive process to drive virtually all their tasks rather than rely on manuals.

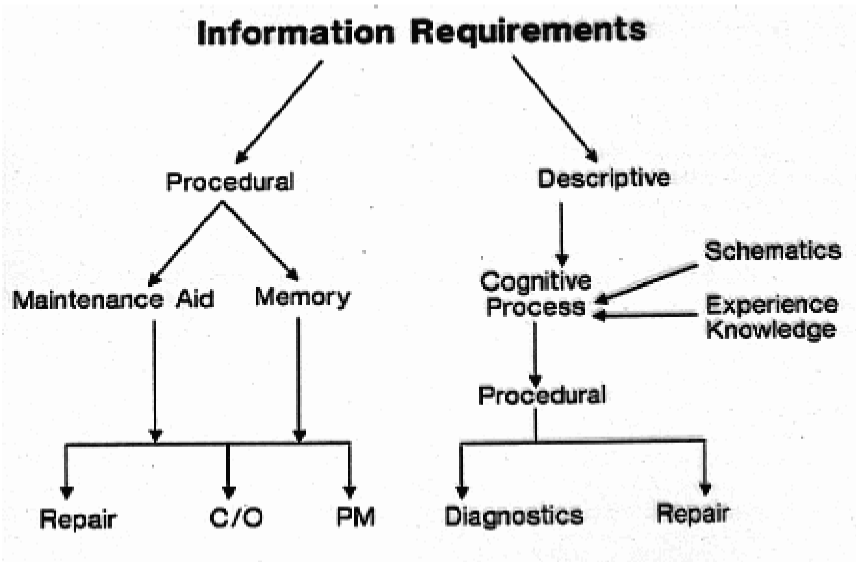


Figure 2

As a rule, technicians tend to rely on their memory or "cognitive" capabilities, or ask their peers. Maintenance manuals tend to be used as a secondary source of information. Air Force research has shown that those who do use manuals tend to be the most experienced. The reason appears to be that the inexperienced can get information from their peers or supervisors. The experienced technician has no other place to go, so he uses the manual.

Procedural information can be partitioned into a number of information items, as shown below:

- What to do
- How to do it
- Sequence -- the order of task performance
- Location -- where work is to be done
- Identifications/context -- the specific item to receive the action
- Tolerance -- how the equipment is to respond to the task

Descriptive information also can be considered in terms of smaller units, as shown:

- Systems context -- how the system fits within a larger system
- Functional relationships -- relation to other system components
- Physical-functional relationships -- the physical unit that is to be manipulated, adjusted, replaced, or repaired
- Physical characteristics -- features relevant to diagnostics such as location of test points

Use and Usability

The use and usability of information are two separate but closely related issues. Several factors affect use of information. When emphasis is placed on accountability in performance, technicians will tend to use information more than when accountability is not a factor.

If the usability of information is high, it will also foster (but not guarantee) usage. The less energy required of a technician to use information, the greater the likelihood he will use the information. This concept applies whether one is speaking of manuals or computerized presentations.

Use policies also are important, with most policies so broad as to be of essentially no use. For example, directives at some military facilities state that "All maintenance personnel are required to use manuals." Experience has shown such directives to be of little or no use because management usually does not enforce such broad directives. Peer pressure is another major reason why in most situations technicians do not use manuals. One tends to work as the others around him work.

A number of factors affect manual usability. A listing of the more important includes:

- Accessibility
    - Work breakdown structure
    - Package
- Portability
- Completeness
- Accuracy
- Flexibility of use
- Presentation

Most items above are obvious in their importance. However, a brief discussion is in order about two of these: (10) Flexibility of use and (2) Presentation.

As a technician gains experience in a particular type of work, his need for information changes. Information systems/packages should be designed so that they will fit the more experienced person as well as the inexeperienced. This is difficult to do with paper systems but somewhat more manageable with computer-based systems.

Presentation principles deserve considerable attention. Such principles are perhaps the most important factor underlying the effectiveness of technical manuals designed to be used on the job. These presentation principles, or guidelines, are based on past research in four fields. These are:

1. Short-term memory research. Short-term memory appears to last for 15 to 30 seconds. Thus, if information can be imparted to a user in these 15 to 30 seconds, one will get an accurate translation of that information into performance.
2. Scanning research. This research provided guidelines on the amount of information to present on a page or in a graphic.
3. Audiovisual research. While we have learned that presenting information in an audiovisual mode is generally not cost effective, the research did provide valuable data concerning the relative importance of text versus graphics.
4. Learning research. This research gave valuable guidance concerning proper ways to treat descriptive information.

Presentation principles are divided into two broad categories -- one for procedures and one for descriptive materials. Most principles concern procedures, and we break these into principles related to text-graphics, text, and graphics. Text-graphics will be addressed first.

A cardinal principle for the use of text-graphics is that the text material and the graphics should be presented "together." This means, for paper, on the same page or facing pages. For cost reasons, this principle at times is not followed. As a compromise, the graphics may be placed at the end of a procedure. In some cases, graphics may be placed at the end of the chapter. In either case, however, expect a degradation of usability. The rule remains: The more energy required to obtain information, the less likelihood the information will be used.

The role allocation of text and graphics is important. The following listing presents the optimum allocation of text and graphics material:

Information Type **Presentation Type**

What Text

How Text

Sequence Text

Location Graphic

Identification/Context Graphic

Tolerance Text

The what, how, and sequence are best presented in text form. Attempts have been made to present what and how graphically, but we have seen no data to indicate that this helps the user. The best allocation is to use text to show what, how, and sequence, and use graphics to present location of equipment items and its identification. Tolerance should be in text form.

Figure 3 shows an attempt to present location and identification information by straight text alone. This approach has two disadvantages. First, considerable text is required to describe the location and appearance of the equipment. Second, the instructions themselves get quite extensive.

NOTE

A coupler is located at each end of car, on the centerline, below the anticlimber and underframe. The mechanical coupler has a rounded nose and recessed face to allow secure engagement with the corresponding recessed face and rounded nose of the opposing coupler. Bolted to the underside of the mechanical coupler is an electric portion protected by a contact shutter door.

1. Hold curved edge of coupler face gage against coupler face so that:

   * Rounded protrusion on gage is within indentation on coupler.

   * Rounded protrusion on coupler is within indentation on gage.

   * Scribed marks on gage are aligned with center-punched marks on top of coupler.

Figure 3

Figure 4 shows the same information presented in Figure 3, but in a text-graphic format. Note that only a very simple text statement is required. Most of the information is presented by the graphic.

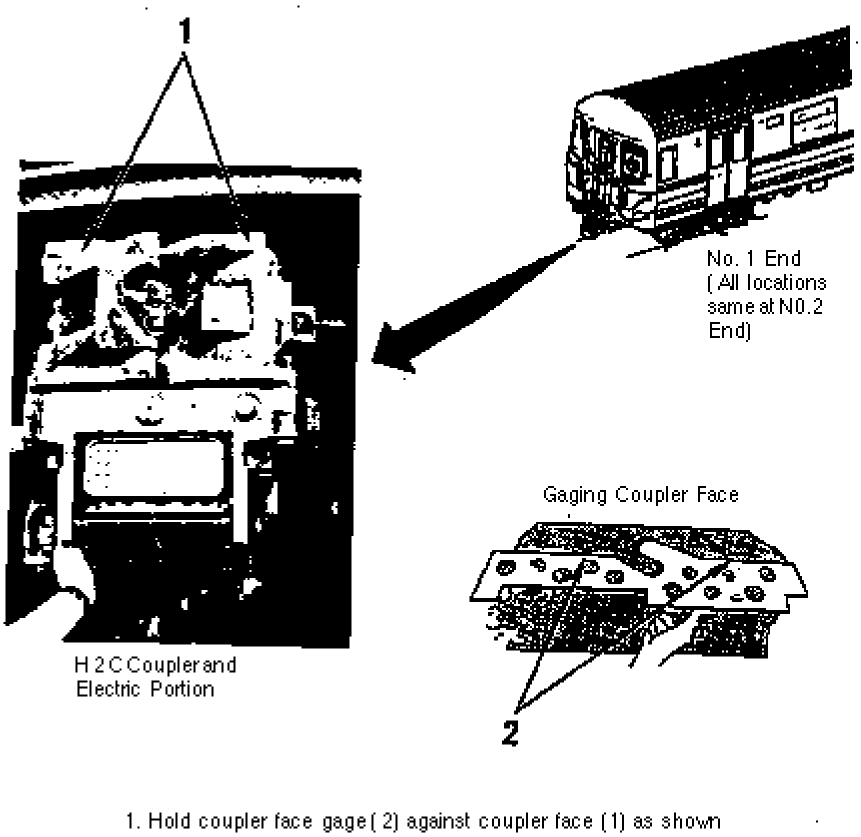


Figure 4

Use of graphics, however, raises another issue. This is the issue of fidelity of graphics. The greater fidelity one attempts to introduce, especially in black and white presentations, the more expensive the manual. We have found that fidelity itself is not the key item. For instance, in Figure 4 the call-out of No. 2 tells you the shape of the tool to be used. No. 1 shows where it should be placed. This call-out is not entirely clear, but the important feature is that if the technician is located beside the equipment item, the shape of the equipment itself will tell him exactly where the tool is to be placed.

Several clear-cut principles apply to the presentation of text, shown in Figure 5.

Presentation Principles for Text

- Fixed syntax
- Mimimal number of words
- Standardized command verbs
- Standardized nomenclature
- Two - three related actions per step

Figure 5

Syntax is simple. For procedures, use the command form. The reader is always the "you," so the subject (for the sentence) can be eliminated. Key components of the syntax are the action verb, (i.e., the command verb) and the object of the action verb. For the principle of "minimal number of words," we allow 25 words at most. If more than 25 words is required for one sentence, something is wrong. For standardized command verbs, a maximum of 100 should be completely satisfactory. Even for complex sets of maintenance tasks, we find 80 percent will be covered with 20 verbs or less. Standardized nomenclature obviously is important in text. While not as important with graphics, we recommend standardized nomenclature to improve acceptance and reduce ambiguity. Finally, two to three related actions per step will keep the instruction within short-term memory capacity.

The term "related action" is important to understand. For example, the instruction "remove ten bolts, remove cover" is acceptable even though it exceeds the two to three related actions per step. The reason is that when the technician removes the ten bolts, the cover is loose and he then remembers that he should remove it also. On the other hand, the instruction "close valve 236A and valve 767C" is not acceptable. By the time the technician finds the first valve and closes it, the probability that he will forget the second valve is too high.

Figures 6, 7, 8 and 9 illustrate the use of the basic syntax. In Figure 6, the word "loosen" is the command verb, with "clamp" the object, and "from scuppertube" the qualifier for this action. At times, the qualifier can be eliminated since it may not add information. When the clamp is shown in proper context in an accompanying graphic, "remove clamp" is adequate.

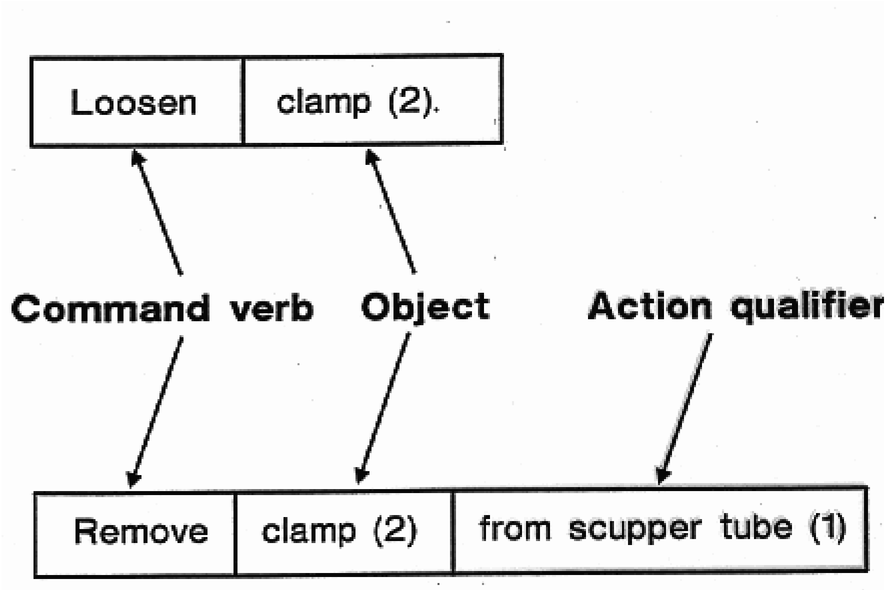


Figure 6

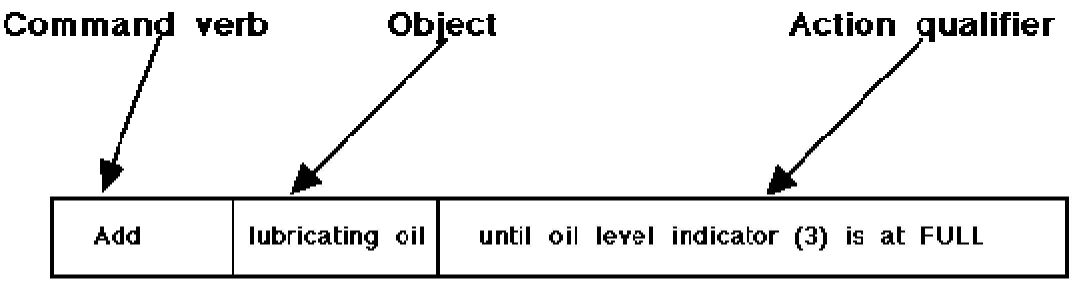


Figure 7

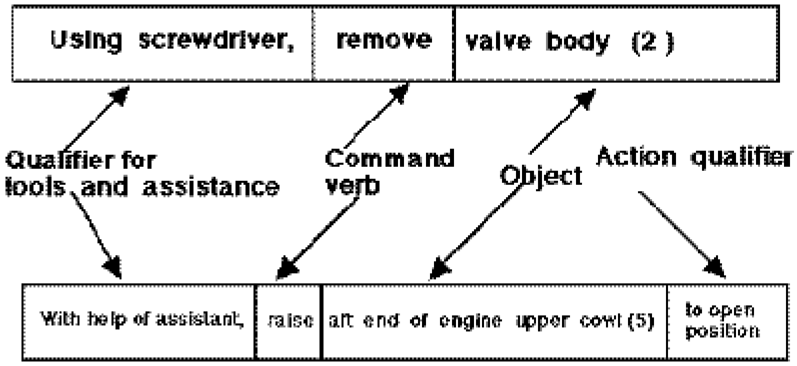


Figure 8

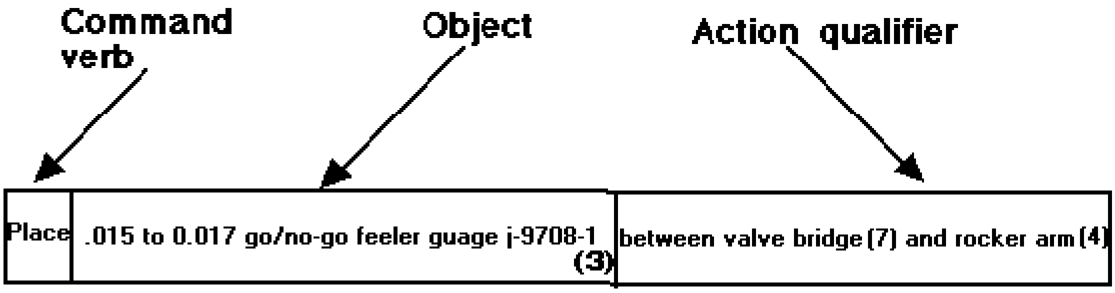


Figure 9

At times, qualifiers are essential to the meaning. For example, in Figure 7, the qualifier "until oil level indicator is at FULL" is essential because it qualifies the action. It tells you the tolerance.

The current list of action verbs we are using is shown in Figure 10. This list may be adjusted somewhat from project to project but, in general, in its entirety would not exceed 120 action verbs. We refer to these as required verbs. We do not allow synonyms. If we use the verb "raise" for an action, it is always raise. It is never "lift;" it is never "elevate," It is always "raise." To work with these verbs requires a different kind of discipline and a different style of writing, one closer to programming computers than to writing text.

add	estimate	make sure	save
allow		mark	scrape
apply	feel	measure	see
ask	fill	mix	set...to
avoid	find	move	shake
	follow		soak
be		note	start
bend	go	notify	stay
blow	get	open	stop
	guide		
carry		perform	take
check	handle	place	tap
clean	have	polish	tie
close	hold	pour	tighten
compare		press	touch
connect	increase	pull	try
continue	inflate	push	turn
cover	inspect	put	
cut	install		use
		raise	
decrease	keep	read	wait
deflate		release	wash
determine	listen	remove	watch
dip	look	repeat	wear
discard	loosen	replace	wipe
disconnect	lower	return	wrap
do (not)		rinse	write
drain			
dry			

Figure 10

Figure 11 presents principles relevant to graphics. The key point in use of graphics is to present a context and show the items in that context. This applies to the use of graphics in both procedural and descriptive materials.

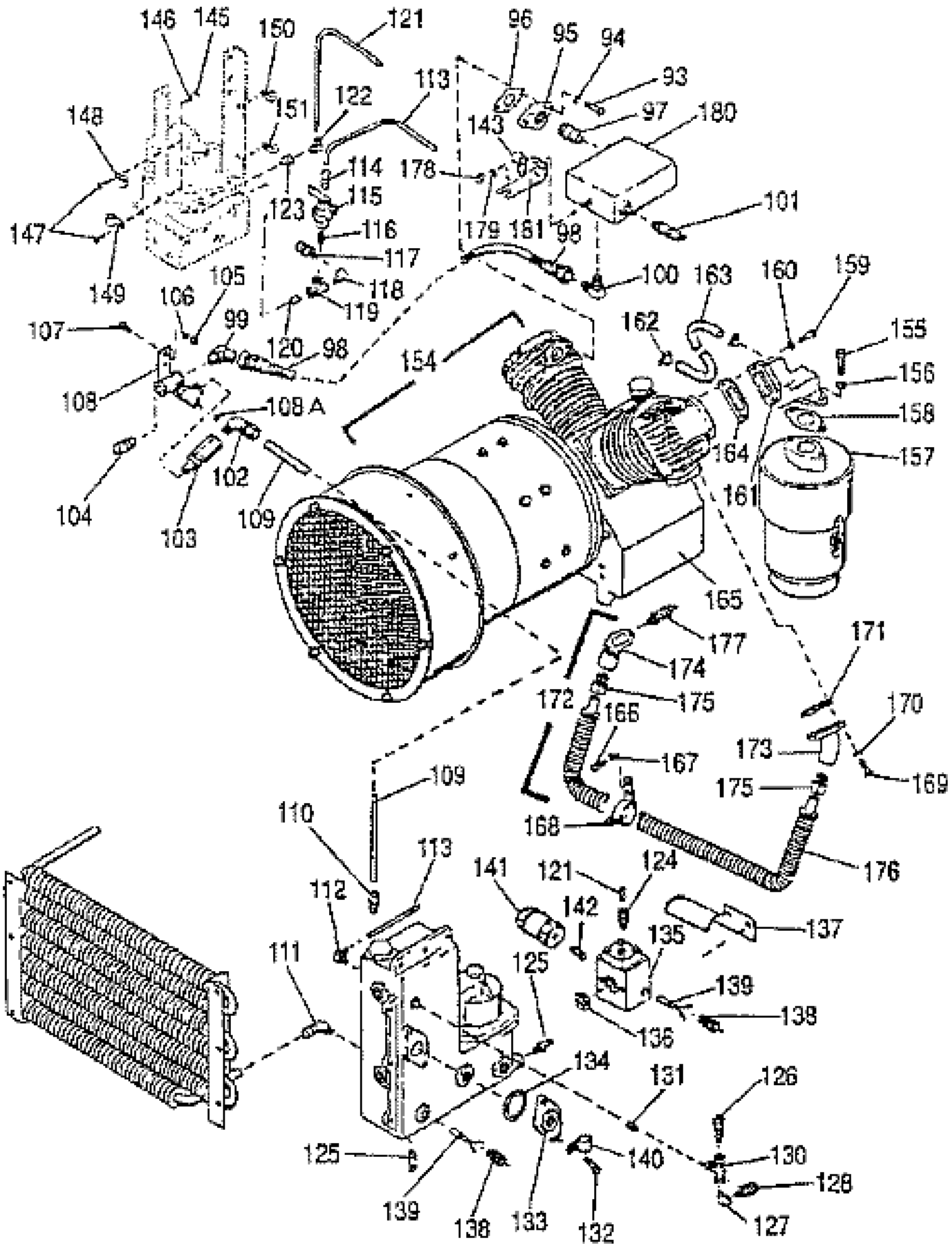
Presentation Principles for Graphics

- Provide context
- Show in context (for location and identification)
- Reduce items not relevant to task/subject (Avoid clutter)

Figure 11

It is quite important to avoid clutter in graphics, which again raises the issue of fidelity. Many designers of manuals try to use actual pictures, which of course have high fidelity. However, studies show that line drawings are superior to pictures. The basic reason is the negative effect of clutter found in pictures. For example, a line drawing of a circuit breaker board, holding a number of circuit breakers, does not need to show circuit breakers as such. The illustration can simply show circles. The key for the graphics is to provide some clue that the technician can use to find a specific circuit breaker. The clue can be the right corner, the left corner, or a line running through the center. The entire board does not have to be shown. The technician relates relative position on the board (e.g., a specific breaker) to a known point (e.g., the upper right corner).

Extensive use should be made of call-outs in graphic presentations of technical information. Scanning principles should be followed in the use of call-outs. Figure 12 is a sample of a graphic which is not particularly effective. I defy anyone to find the number 129 within a few seconds. Yet this is not an unusual drawing for a manual.



AIR COMPRESSOR EXPLODED VIEW

Figure 12

The use of words rather than numbers for call-outs is shown in Figure 13, with considerably less clutter presented than in Figure 12. The greater clarity of Figure 13 will reduce scanning time. However, scanning time can be further reduced and accuracy increased if call-outs are shown as numbers rather than words, as seen in Figure 14. Words must be read; one cannot scan them very effectively. Numbers, in some sequence, can be scanned more rapidly. The specific sequence is not important. It also is not important whether the sequence proceeds clockwise or counterclockwise -- left to right or right to left. What does matter is that the sequence is quickly recognizable and that one can locate "6" quickly after passing "5."

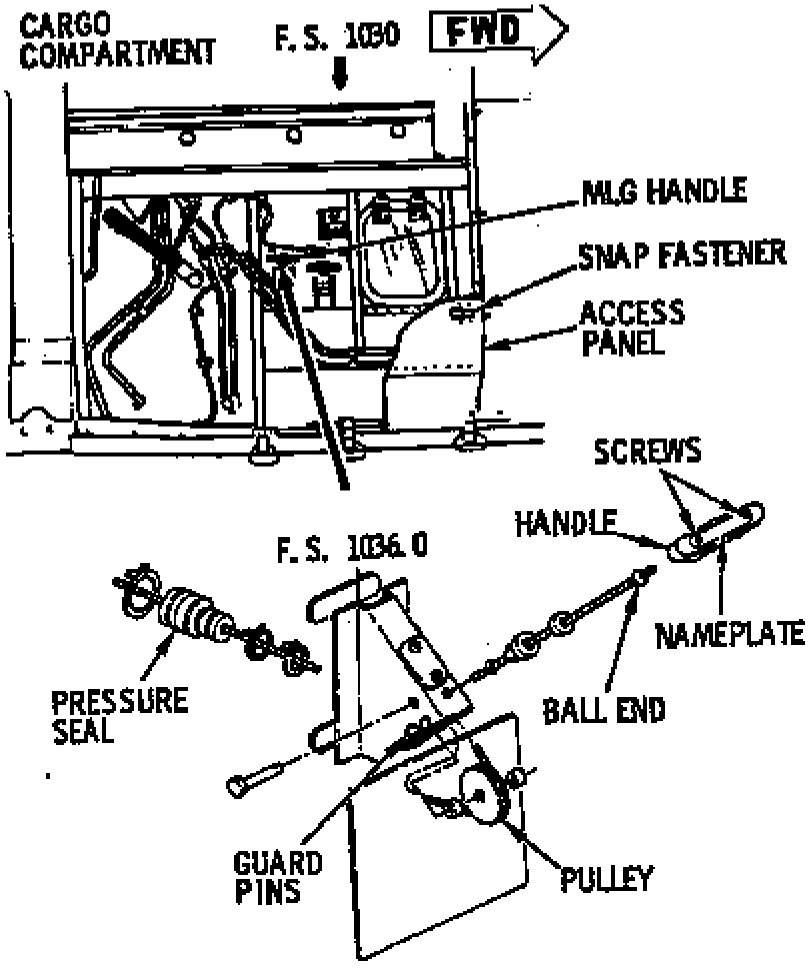

CARGO
COMPARTMENT
F. S. 1030
FWD
MLG HANDLE
SNAP FASTENER
ACCESS
PANEL
SCREWS
HANDLE
F. S. 1036.0
NAMEPLATE
PRESSURE
SEAL
BALL END
GUARD
PINS
PULLEY

Figure 13

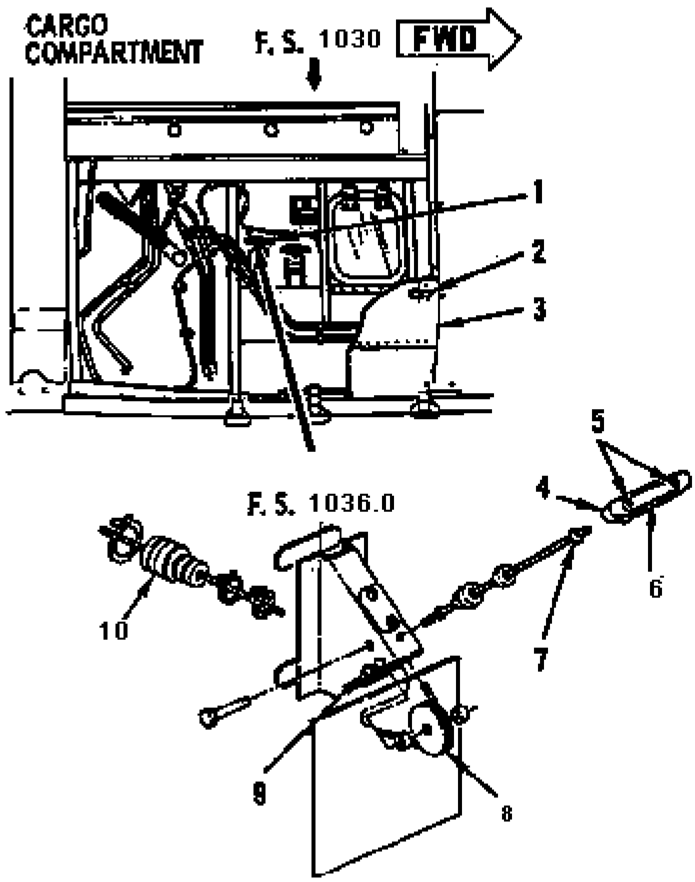


Figure 14

Figure 15 presents an example of a basic format recommended for use. This combines text and graphics with numbered call-outs. It does not matter whether the text is below, above, to the left, or to the right of the graphics. The important point is that the graphic is keyed to the text.

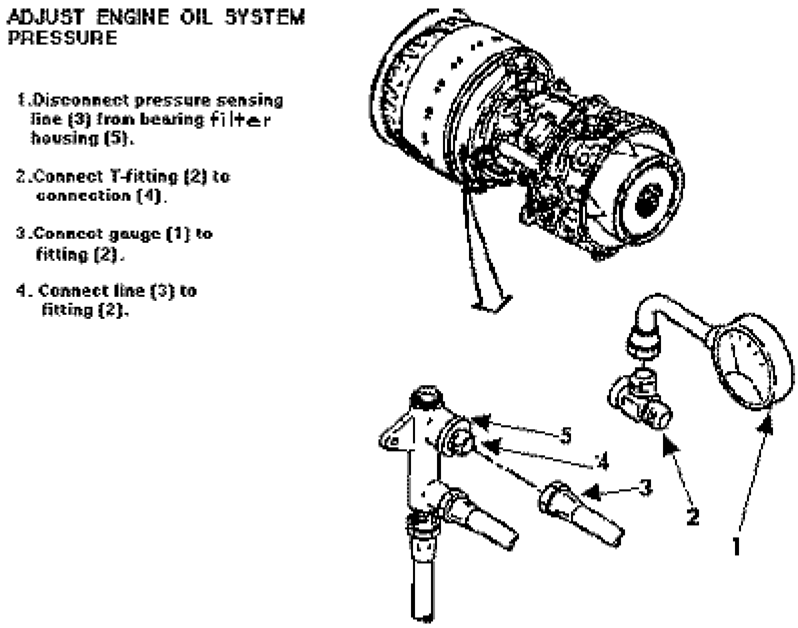


Figure 15

Presentation principles (Figure 16) for descriptive materials are not as clearly defined as those for procedural information but are nonetheless useful. Descriptive information provides a description of equipment operation or systems operations. Descriptive information taps the long-term memory capability of the reader. A technician has to retain the information and apply it to the job usually months after he first reads it. In providing this information, the preferred hierarchy is whole-to-part-to-whole. The whole provides the context and is presented first; the particular activity or detail is described next; and the activity then is related again to the context. Information presented in the context of some known whole will have a better chance of being acquired and retained. Acquisition also will be improved if a graphic is used to provide the context, with associated text speaking to the graphic.

Presentation Principles for Descriptions

- Whole-to-part-to-whole (Graphics)
- Functional context (Graphics)
- Text-graphic integration

Figure 16

Another principle for descriptive materials is that of "functional context." According to this principle, derived from learning research, acquisition and retention of information will be enhanced if new information is presented in the sequence in which people do the work, even though one is describing equipment, or the sequence in which the process takes place in the equipment.

Another principle concerns density. How much information should be presented per unit of presentation? In print form, we treat the paragraph as the basic unit of presentation. According to the principle, the presentation should be restricted to no more than three to four related system actions per paragraph, e.g., sends a signal, processes the signal, transmits a signal, etc. When you exceed the limit, the reader tends to move on without understanding the content.

The final principle is that of language control. The material should be described in terms known to the reader. Technical jargon should be avoided, unless the terms are defined as part of the learning/descriptive process. Unfortunately, there is not much by way of guidance in the literature concerning how to curtail "language" of technical materials in a systematic manner. Therefore, one must rely far more on writing skills of those preparing the descriptive parts of technical manuals than we like. We find that it helps to start with a limited number of basic words and then use these words to describe new words as the needs arise. In this manner, you can achieve a measure of standardization of the "language" in the manual.

Measurement and Development

Common measures of readability are not very useful for measuring the effectiveness of technical information. As indicated in this presentation, there are numerous factors that contribute to the acquisition and retention of technical information. You will find that only a small portion are covered by common measures of readability such as the Flesch count. While use of the Flesch count should not be discouraged, improving the usability of manuals and technical information requires more than simply fixing the text. What needs to be communicated cannot be accomplished effectively by text alone.

A recommended procedure for measuring the effectiveness of technical documents is to first use specifications based on the presentation principles just discussed. Then, determine the extent to which a communication or manual complies with the specification.

Deviations from the specifications should be allowed. As noted, a major problem with specifications is that they stultify growth. Too often authorities demand 100 percent compliance to specifications because it is simply too hard to train people to be flexible. The consequence, I believe, is far worse than trying to train people to be flexible.

Deviations from the specifications (in the preparation of technical information materials) should be based on the principles described above. However, the final judge of usability should be whether the technicians can actually use the information on the job. A measured relationship between maintenance information and performance on the job should be determined. Only with such a measurement capability can we realistically evaluate the information systems being used and/or considered in aviation maintenance.

Growth of Job Performance Aid Utilization

Daniel J. Berninger
Galaxy Scientific Corporation

Introduction

I am not sure what to call this talk and "Growth of Job Performance Aid Utilization" is a compromise that I am still not entirely happy with. We are conducting a study on behalf of the Federal Aviation Administration of what we call Job Performance Aids (JPA). Initially we set out to survey the state of the art in these systems. The long term objective of the research is to help integrate existing and future systems with human factors considerations. We seek to develop an awareness of the applications of JPA's, and address some of the reasons these systems are often unpopular and ineffective.

The term Job Performance Aid has been mentioned several times during this conference and it seems to mean different things to different people. We learned from Mike Mulzoff of Pan Am that in 1945 the mechanic had little more than a pen knife to work with. In a strict sense that pen knife was a JPA. In the initial phase of our research we are focusing on computer processing based JPA's. It is a type of JPA that seems to have a lot of potential, but also seems to cause the most consternation among users. Most airlines have utilized the computer for some aspect of their maintenance effort, from parts tracking and maintenance scheduling to on-line databases with aircraft procedures. There is a whole new generation of systems that have be developed for the military that will lead to the use of computers for many more elements of maintenance. Our research effort is designed to facilitate the transition of this technology to civil aviation, and identify the changes that will be necessary before that can happen.

I said I was not entirely happy with the title of this talk. The reason is that although we have seen a growth in the use of JPA's in the last 10 years, what has struck us the most about our initial research are the challenges facing maintenance in the next ten years. It seems likely that these challenges will make JPA's an essential part of all maintenance operations.

Challenges of the Coming Decade

Let me talk briefly about this sense of urgency that we have observed. At one time the maintainer of the aircraft was the pilot and the designer as well. He was a single resource for information on design, flight conditions, service history, diagnosis and repair procedures. Importantly, since that person was the pilot, he was able to get immediate feedback on his performance as a maintainer. All of these factors are still very important in aircraft maintenance, but no single person is capable of handling the bulk of information that is required to adequately maintain an aircraft. The sheer volume of information has increased so much that hundreds of people are required to perform the task of maintenance on a single aircraft today. Yet it is desirable for these hundreds of individuals to act as one, each sharing information as required.

Today's maintenance technician can only know a small subset of the information that is needed overall; not giving him a lot of unnecessary information becomes important, as does his ability to communicate what he knows at the appropriate times. Maintenance technicians are very much dependent on their coworkers and the equipment (job performance aids) that are available. This is the dynamic that is the focus of my talk, and, in fact, the focus of this conference. The tasks that one person performed at the outset of aviation now require hundreds, and the task of maintaining the flow of communication between those people is daunting.

Not only has the complexity of aircraft increased, but the number of aircraft to be maintained has grown. This growth has just begun. There is now a five year backlog for most types of commercial aircraft. In fact, there are as many aircraft on order as there are in service. There is a corollary push to extend the serviceable life of aircraft now in service. The term "economic life" means that retirement of an aircraft is postponed until maintenance is economically unfeasible. Given the price of new aircraft and shortage of aircraft in general, retirement is rare.

At one time, most airlines could afford to keep a spare aircraft available to press into service as a replacement for aircraft going in for maintenance. This, in combination with less rigorous schedules, provided some breathing room for the maintenance of aircraft. Aside from the heavier C and D checks, most maintenance on aircraft must now be done late at night or during a handful of days on the ground.

So far we have established that the task of aircraft maintenance is becoming more challenging because aircraft are more complex; the number of aircraft is increasing; the timeframe to carry out maintenance is decreasing; and communication of hundreds of people is essential. Needless to say, all of this would give us plenty to think about, but there is one more dynamic. There will be almost a complete turnover in the workforce in the next ten years. I am sure most people in the audience have heard the statistics. Over the next 10 years, 40,000- of the current 65,000-strong maintenance workforce will qualify for retirement. This is the group of highly experience maintenance workers who joined aviation in the early boom years of jet aviation in the late 50's and early 60's. All of these experienced workers will be lost, while the need for maintenance technicians is expected to grow to 95,000 by the year 2000. At one time this amount of loss might have been made up by experienced people from the military, but now the military is expected to be the chief competition in recruiting people. What this means is that the new work force will be young and inexperienced. There will not be enough graduates of the A&P schools to meet the demands, so a large number of people will be learning on the job.

This group of new maintenance personnel will have to make up in energy what they lack in experience, and they will be far more dependent on Job Performance Aids than their predecessors. On the other hand they will have some advantages over their more experienced coworkers. They will be far more comfortable with technology and the use of the ever present computer. I will talk about some of these systems and the future trends today.

The Youth Attack

Given my youthful appearance, I assume you may have wondered what a young fellow can teach you about the future of maintenance. Well my introduction should give you a hint as to what I can tell you. Although I am not as young as I look, I am definitely a representative of the generation that will be ubiquitous in aviation in 10 years time. I can give you some indications of what will be good and what will be not so good about having this type of transition in the workforce.

Perhaps the youth of the workforce will help us in some ways. Even at my age I am "over-the-hill" when it comes to computers. To give you some perspective on how fast technology is progressing, consider that when I started college data entry was handled by punch cards. Computer terminals were not widely available until I was a sophomore. Radio Shack was the big computer supplier when I was a junior, and Apple did not come into prominence until I was nearly finished. I was finished with my master's degree by the time IBM had the idea to market a personal computer. Computers are basically a mystery to me compared to the entry-level engineers who are starting with our company today. Can you imagine what growing up with computers will mean to those going through school today. My three-year old daughter is already playing with computers. She uses a Sesame Street program that I loaded on the computer at home.

Job Performance Aids

Now, I have said enough about the computer as a stand alone item. As many of you know, it is not as easy as just giving everyone a terminal. During the 1980's, computers started to have a presence on the maintenance floor. Although no one would be able to go back to the way things were, it is not clear that everything about the introduction of the computer was positive. It is also clear that data was often collected simply because the computer could provide it. In some cases, it became unclear whether the computer was aiding the human or the human was aiding the computer.

Our initial research has demonstrated that this is indeed the time for action, but by no means is it a time for panic. From what we have seen, we have more reason for optimism than dread of the future. This sense of optimism only comes after viewing all sides of the issues. I would like to highlight one aspect of our findings that addresses another side of an issue that has come up several times during this conference. The issue is still human factors, but not the human factors of the worker, it is the human factors of the designer.

Several talks and subsequent questions addressed to speakers have raised concerns about the integration of computers on to the maintenance floor over the past decade. A number of horror stories were related and it was clear from the discussion that some of these systems were more hinderance than help. First I will say that is, indeed, consistent with our findings. We have not come upon a system that will be the "savior" of maintenance. Further we can confirm the finding that the main problem is the lack of human factors consideration.

The next step is to understand why this is the case and how to avoid it in the future. We want to answer the question of why the systems that have been implemented so far have such short comings.

First one needs to understand the design process of these systems. It is easy to criticize complex systems, once they are built and operational because limitations are self-evident. Unfortunately for the designer, the entire design and implementation process must take place with relatively little opportunity to observe operation. Even at junctions when observations can be made, changes are impractical unless they relate to the basic functionality of the system. These observations are typically known as "niceties" by designers, and are unaffordable, since it is a struggle just to get the basics running. Although there are some exceptions, human factors considerations are almost always put in the nicety category, and thus are missing from the final product. It is now becoming apparent that for systems used by humans, nicety is probably not a good definition of these elements.

It is a difficult problem to solve, because human factors issues are difficult to identify up front and nearly impossible to implement midstream. The final product is almost entirely dependent on the original effort at setting requirements. The requirements are made too early in the process to be complete.

The message is that poor human factors design is not due to a conspiracy by equipment designers. It is due to a limitation of the traditional design process and the body of knowledge that they have to work with.

Where human factors has been taken up in places like Boeing and Douglas the groups are treated more in an advisory capacity. Someone else designs the component and the human factors group simply gives a "go" or a "no go" to the design. The people who understand human factors and the people who design equipment need to work together from the beginning.

So what can be done? The jury is still out on that, but the Human Factors Research Program of which this conference is a part is attempting to bridge those gaps in understanding. The one common denominator to meeting the challenges of the future will be the need for cooperation and communication at all levels. No one group can operate independently. Designers of equipment will have to talk with the maintenance community to identify requirements and also the human factors community to address human factors issues.

The FAA has taken this approach in putting together a diverse team of researchers for its Aging Aircraft Human Factors Research Program.

The point being that just because some of our efforts to utilize advances in technology have been awkward and frustrating, that does not have to be the rule for the future.

Job Performance Aids

So now let me talk a little about some of the existing systems we have identified. One of the systems talked about today, IMIS, is an excellent example of a job performance aid. Currently we are looking at this system and others that have been implemented in aviation or a related field. The value of this effort can be viewed from the perspective of a typical maintenance department. If you are responsible for carrying out the duties of maintenance on a day-to-day basis, you do not have time to keep up with all of the technology that exists or evaluate all of the technologies that are brought to your attention. Currently, only the larger and more profitable airlines can afford the investment of time and money to investigate utilization of performance aids. Our effort is designed to make this information accessible to everyone who is interested. Our effort will also provide background on what it takes in terms of labor and overall cost to implement a job performance aid, and an awareness of the down side issues as well. Managers can then make informed decisions on the application of new technology.

I have selected a few representative examples from our initial research to give you a flavor of what is possible today. Most of the systems are designed to provide the mechanic with a better source of information. This is not a surprise since mechanics point out that they spend up to 70 percent of their time just looking for the correct information.

We were surprised at the number of systems, approaching 60 at varying levels of development and complexity. One of the common denominators is the use of expert system technology. I will talk about expert systems in more detail in a few minutes. As I mentioned, most of the technology has been developed and tested by the military. I have pulled six systems out to describe. IMIS (Integrated Maintenance Information System) is one of the best examples of a job performance aid, but you have already heard about it today so I will not go into it any further.

A large portion of the systems we uncovered revolve around maintaining the engines. After engines, avionics were the most common systems. The maintenance aids that we are looking at fall into a several basic categories. There are systems that (1) support diagnosis, (2) information delivery, and (3) training.

TEMS: Turbine Engine Monitoring System. TEMS is representative of one of the earliest applications of technology to the maintenance process. As the name implies, its focus is to monitor engine performance parameters seeking to predict when and what maintenance is required on the engine, thus achieving on- condition maintenance. There are a number of systems that vary in how engine performance data is collected and the number of engine performance parameters observed. Some systems collect the information automatically and record it, and recently American Airlines has set up systems for real-time collection and transmission. Some systems require the flight crew to manually record the data that is then analyzed when the aircraft is on the ground. All of the systems use the information in the same way, by continuously monitoring the trends to spot anomalies. The end result is increased aircraft availability and lower overall engine maintenance costs. TEMS and its family of systems is used by the U.S. Air Force to track its entire fleet of engines.

TEXMAS: Turbine Engine Expert Maintenance Advisor System. TEXMAS is utilized in conjunction with monitoring systems like TEMs. Rather than having humans do all of the analyses, TEXMAS uses human-like reasoning to achieve the same end. It takes the raw data and carries out functions such as engine performance measurement, event monitoring, and life monitoring. TEXMAS can also be used to walk an inexperienced mechanic through the process of diagnosis. TEXMAS is based on expert system technology, which can be thought of as an alternative approach to programming computers. I will talk about it in more detail at the end, but in effect one comes up with rules that can be applied to different situations and when the proper conditions are met.

VSLED: Vibration, Structural Life and Engine Diagnostics. VSLED is representative of the latest generation of performance aids in that it is integrated into the aircraft itself. It is unusual because it extends the familiar engine monitoring to the aircraft structure. This is done by monitoring parameters and analyzing trends as with engine monitoring. In the case of the structure, there are sensors on the aircraft that sense stress and vibrations. The goal VSLED has in common with other systems is to reduce the overall maintenance hours. VSLED takes several systems and brings them together. It continuously monitors parameters and has automatic detection of limit exceedance. In addition, it can take the data and perform fault isolation. VSLED is the on-board maintenance system for the new generation of V-22 Helicopters.

AIMES: Avionics Integrated Maintenance Expert System. AIMES takes the monitoring idea and combines it with real time diagnosis. This is important for avionics problems, because a substantial percentage of the problems that occur cannot be repeated on the ground. Thus, the knowledge of the mechanic is coded on the computer in the form of rules, and the AIMES system does fault isolation while the aircraft is still in operation.

CITEPS: Central Integrated Test Expert Parameter System. This system was developed by the U.S. Air Force Wright Patterson Aeronautical laboratory for the B-1B. CITEPS utilizes information from the monitoring systems and built-in-test (BIT) systems to perform fault isolation. It is also expert-system based, using rules that are developed from talking with experienced maintenance personnel.

XMAN: Expert Maintenance Tool. This system was developed by Systems Control Technology Corporation for the USAF A-10A. This was designed to be a user interface to the maintenance database created by systems like TEMS. It is an aid designed to automate diagnostic and trouble shooting procedures. Since it can communicate to the user the sequence of conclusions in the diagnostic procedure, it can be used for training.

Most of these system and others such as the BIT systems for the new AIRBUS aircraft underwent a rocky implementation process. It turns out that getting built-in-test to function properly and the expert systems to make an accurate diagnosis is extremely challenging. To make matters more challenging, even 90% accuracy is not sufficient when it comes to gaining the confidence of the maintenance workforce. One can imagine that even if the machine is correct 9 out of 10 times, spending a shift or two on a "wild goose chase" can make you think twice about using the system next time. In the world of aircraft maintenance there are few simple procedures, so accurate diagnosis is essential.

Expert Systems

Expert Systems will be an essential part of aiding a young maintenance workforce. It is not a coincidence that most of the system listed previously utilize this technology to some extent. The reason is that maintenance is dependent on knowledge. Knowledge of history, condition, failure mode, and remedies. Expert systems were developed for this purpose.

Expert System technology is one of the few widely successful products of the field of Artificial Intelligence. Expert systems were first proposed over 15 years ago, and commercial applications have been appearing in bulk for 5 years. The basic technology is about as mature as any computer technology. The expert system is well suited for applications where performance is dependent on a very narrow body of information. Expert systems work well in areas of aircraft maintenance and medicine, but not so well in modelling common sense.

The process of implementing an expert system is shown by the Expert System Model chart (Figure 1). You need a few "ingredients" for a successful implementation. First you need an expert. The field of Knowledge Engineering has developed to handle the task of converting the individual's experience into a series of rules. The rules have the following format: "if these conditions are present, then the following conclusions can be made." It is surprising that our knowledge can indeed be summarized by a rather small number of rules. A typical domain can be modeled with on the order of 250 rules and very large systems rarely require more than 1000 rules. The knowledge of several human experts may be combined into a single rule system. Additional rules are also created using the technical reference manuals that a human may utilize in the course of his work.

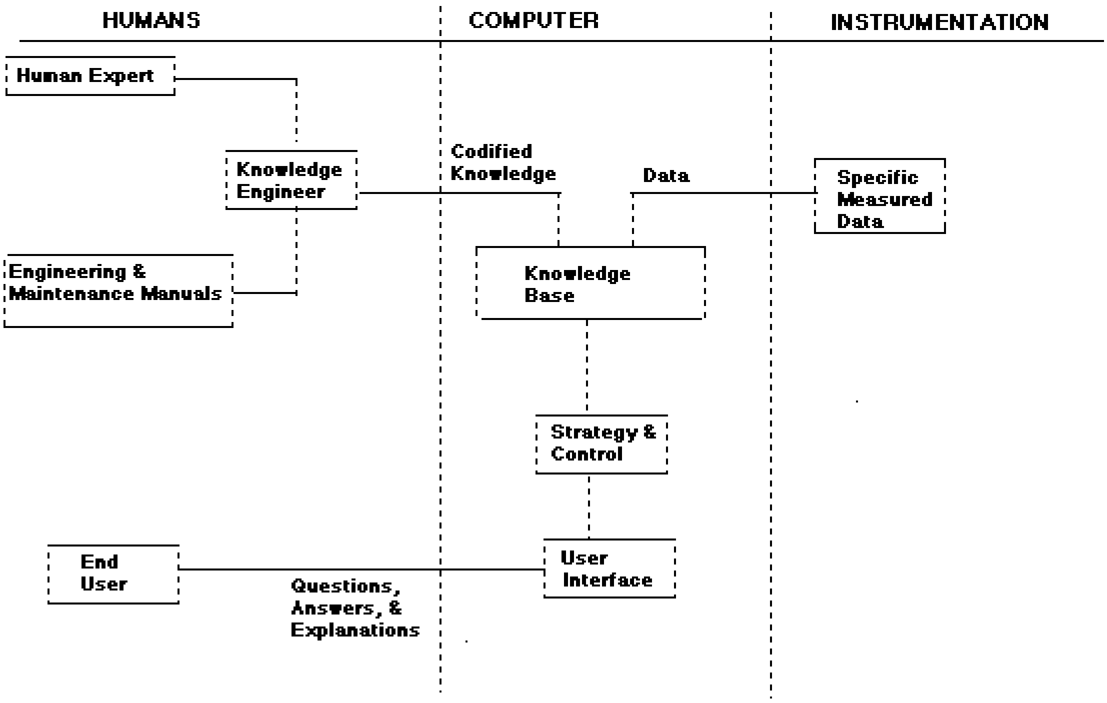


Figure 1 Expert Systems Model

These rules will be the knowledge of the final product. The expert system has two other major components. The expert system must manipulate the rules based on current information. This is achieved via a Strategy and Control Section. The control section simply takes current information, including any measured data, and compares it to the rules.

The final section is a user interface. This puts information into a form that can be understood by the user. In addition, the user interface provides the user with the line of reasoning that was used to reach a conclusion.

Emerging Technologies

A number of technologies that are now emerging that have not yet been integrated into a system. There is a developing capability in the area of voice recognition and speech technology. This is important for the maintenance world, because communication via speech is hands free. One such system is called "Dragon Dictate," by Dragon systems. It is a board that allows automatic transcription of speech into a PC. It has natural language speech recognition, adapts to any voice, has unlimited vocabulary, and is easy to use.

Another technology that could be utilized to facilitate access of information is a portable video display screen that fits over the user's eye. It can be incorporated into a baseball cap. It provides the illusion of a 12" screen that is 18" from the eye. The screen is only about three quarters of an inch square and is called the "Private Eye." It was designed by Reflection Technologies and is now starting production. The key is providing the mechanic with information at a remote location.

Still in the initial phase of our project, we are continuing to investigate and evaluate existing and emergent job performance aids and the related systems. We are continuing to pursue airline participation for our field research, and points of contacts within the airlines. Your comments and questions will be useful, too, and I invite your remarks. Please feel free to contact me at Galaxy Scientific Corp., Mays Landing, New Jersey.

Thank you.

Appendix B: Meeting Agenda

Second Meeting
on
Human Factors Issues in Aircraft Maintenance and Inspection
"INFORMATION EXCHANGE AND COMMUNICATIONS"

13-14 December 1989

Old Colony Inn

Alexandria, Virginia

Office of Aviation Medicine

FEDERAL AVIATION ADMINISTRATION

Washington, DC

Second Federal Aviation Administration Meeting on

Human Factors Issues in Aircraft Maintenance and Inspection

Wednesday Morning, 13 December 1989

Ballroom A & B

7:45 a.m. Registration and Coffee

INTRODUCTION/ORIENTATION

8:30 a.m. Meeting Welcome *Anthony J. Broderick* Federal Aviation Administration

9:00 a.m. Meetings Objectives/Update *William T. Shepherd, Ph.D.* Federal Aviation Administration

INFORMATION EXCHANGE AMONG KEY ORGANIZATIONAL ELEMENTS

9:30 a.m. FAA Overview of Maintenance-Related Information Exchange *Dennis Piotrowski* Federal Aviation Administration

10:00 a.m. Break

10:15 a.m. Major Air Carrier Perspective *Clyde Kizer* Air Transport Association

11:00 a.m. Mid-Level Air Carrier Perspective *Thomas Derieg* Aloha Airlines

11:45 a.m. Hosted Lunch (Ballroom C & D)

Wednesday Afternoon, 13 December 1989

1:00 p.m. Commuter Airline - Vendor Communications *Fred Giles* Continental Airlines Commuter Division

1:45 p.m. Aircraft Manufacturer Perspective *Anthony Majoros, Ph.D.* McDonnell-Douglas

2:30 p.m. Facilitation of Information Exchange Among Organizational Units Within Industry *James Taylor, Ph.D.* University of Southern California

3:15 p.m. Break

INFORMATION REQUIREMENTS FOR M&I PERSONNEL

3:30 p.m. Information Needs of Aircraft Inspectors *Michael Mulzoff* Pan American Airlines

4:15 p.m. Better Utilization of Aircraft Maintenance Manuals *Richard G. Higgins* Boeing Commercial Airplanes

5:00 p.m. Adjourn

5:30 p.m. to Informal Social Hour

7:00 p.m. (Ballroom D)

Thursday Morning, 14 December 1989

7:45 a.m. Registration and Coffee

INFORMATION REQUIREMENTS FOR M&I PERSONNEL

8:30 a.m. The Information Environment in Inspection *Colin Drury, Ph.D.* SUNY Buffalo

INFORMATION SYSTEMS AND DATA BASES

9:15 a.m. Data Base Support for Maintenance Requirements of the Nuclear Power Industry *Thomas G. Ryan, Ph.D.* U.S. Nuclear Regulatory Commission

10:00 a.m. Break

10:15 a.m. Applications of CD-ROM and Hypertext for Maintenance Information *Robert J. Glushko, Ph.D.* Search Technology, Inc.

NEW TECHNOLOGIES

11:00 a.m. An Integrated Maintenance Information System (IMIS): An Update *Robert C. Johnson* Wright-Patterson AFB

11:45 a.m. Informal Buffet Lunch (Outside Ballrooms A & B)

Thursday Afternoon, 14 December 1989

12:30 p.m. Communication and Transfer of NDI Data *Stephen Bobo* DOT Transportation System Center

1:15 p.m. Converting Technical Publications Into Maintenance Performance Aids *Kay Inaba, Ph.D.* XYZYX Information Corporation

2:00 p.m. Growth of Performance Aids Utilization *Daniel Berninger* Galaxy Scientific Corporation

MEETING CLOSE-OUT

2:45 p.m. Audience Discussion/Q & A Period

3:30 p.m. Adjourn

Appendix C: Meeting Attendees

Second Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection
13 - 14 December 1989
INFORMATION EXCHANGE AND COMMUNICATIONS

MEETING ATTENDEES

Richard Acquavita, Pan American World Airways, Inc., JFK International Airport Jamaica, NY11430

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Paul Bursch, Honeywell, Inc., 3660 Technology Drive, Minneapolis, MN 55418

Frank Celona, Machinist's Union, 1300 Connecticut Avenue, Washington, DC 20036

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

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Douglas R. Harris, Ph. D., Anacapa Sciences, Inc., P.O. Box 879, Santa Clara, UT 84765

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Juerg Michel, Manager, Technical Flight Safety SwissAir TQS, 8058 Zurich, Switzerland

Gil Miller, Continental Airlines 8450, Travelair Building 2, Houston, TX 77061

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Ramon Raoux, Transport Canada Building Place de ville, Ottawa, Ontario, Canada K1AON8 Attn: AARDG

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Thomas G. Ryan, Ph.D., U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research M.S. NL/N-316, Washington, DC 20555

Bob Scoble, United Airlines Aircraft Inspection SFOIQ San Francisco International Airport, San Francisco, CA 94128

Edward Sewald, Northwest Airlines M.S. C4260, Minneapolis/St. Paul Int'l Airport St. Paul, MN 55111

Valerie Shalin, Ph.D., Honeywell Systems Research Center, 3660 Technology Drive, Minneapolis, MN 55418

William Sharkey, Maintenance and Engineering Dept. Aer Lingus Dublin Airport, Dublin, Ireland

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