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.

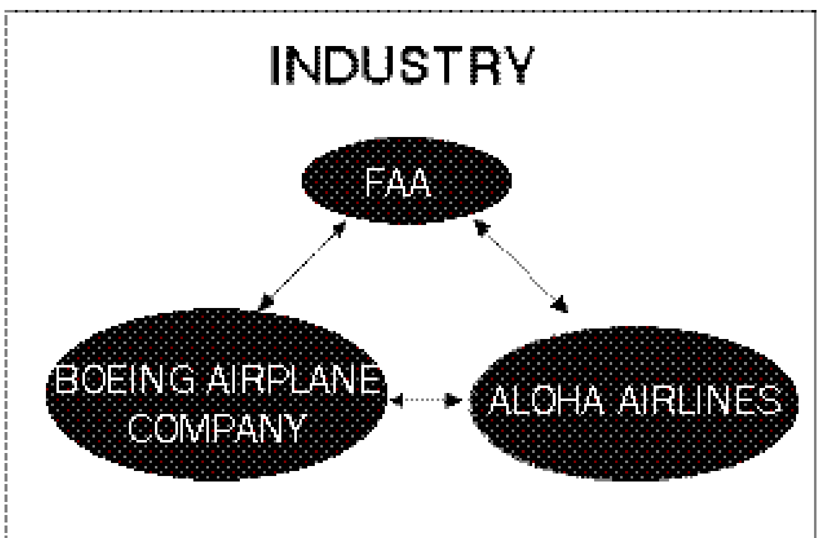

Figure 1

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.

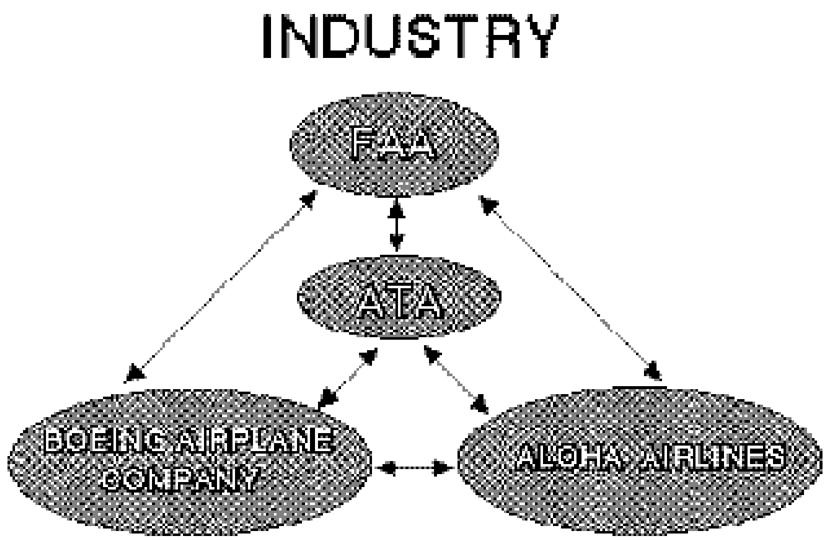

Figure 2

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.

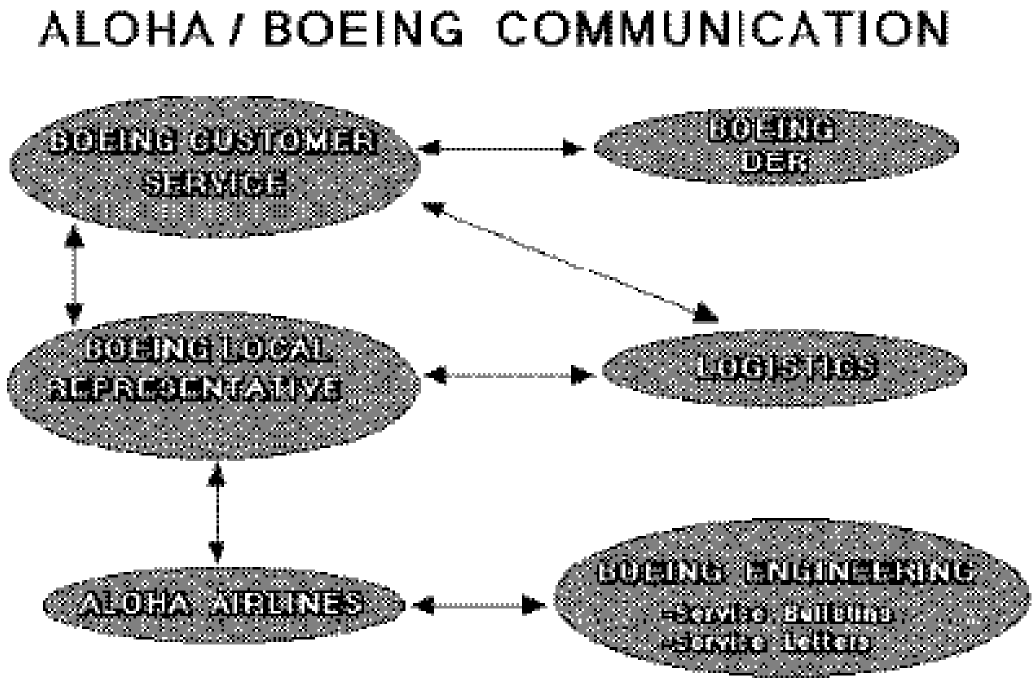

Figure 3

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.

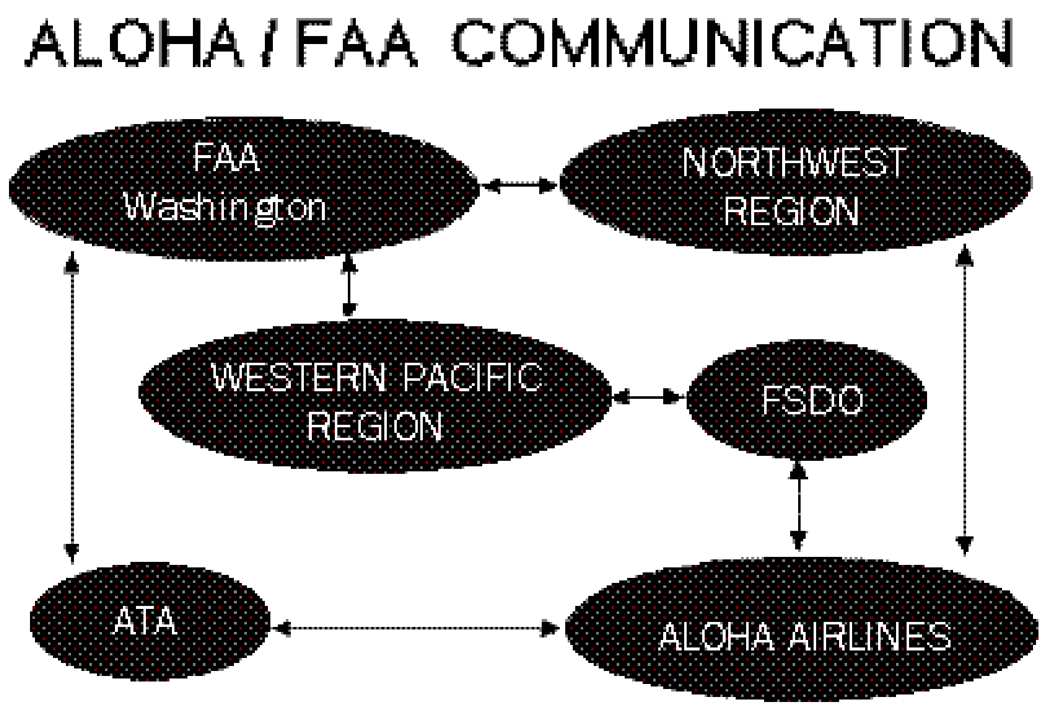

Figure 4

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.

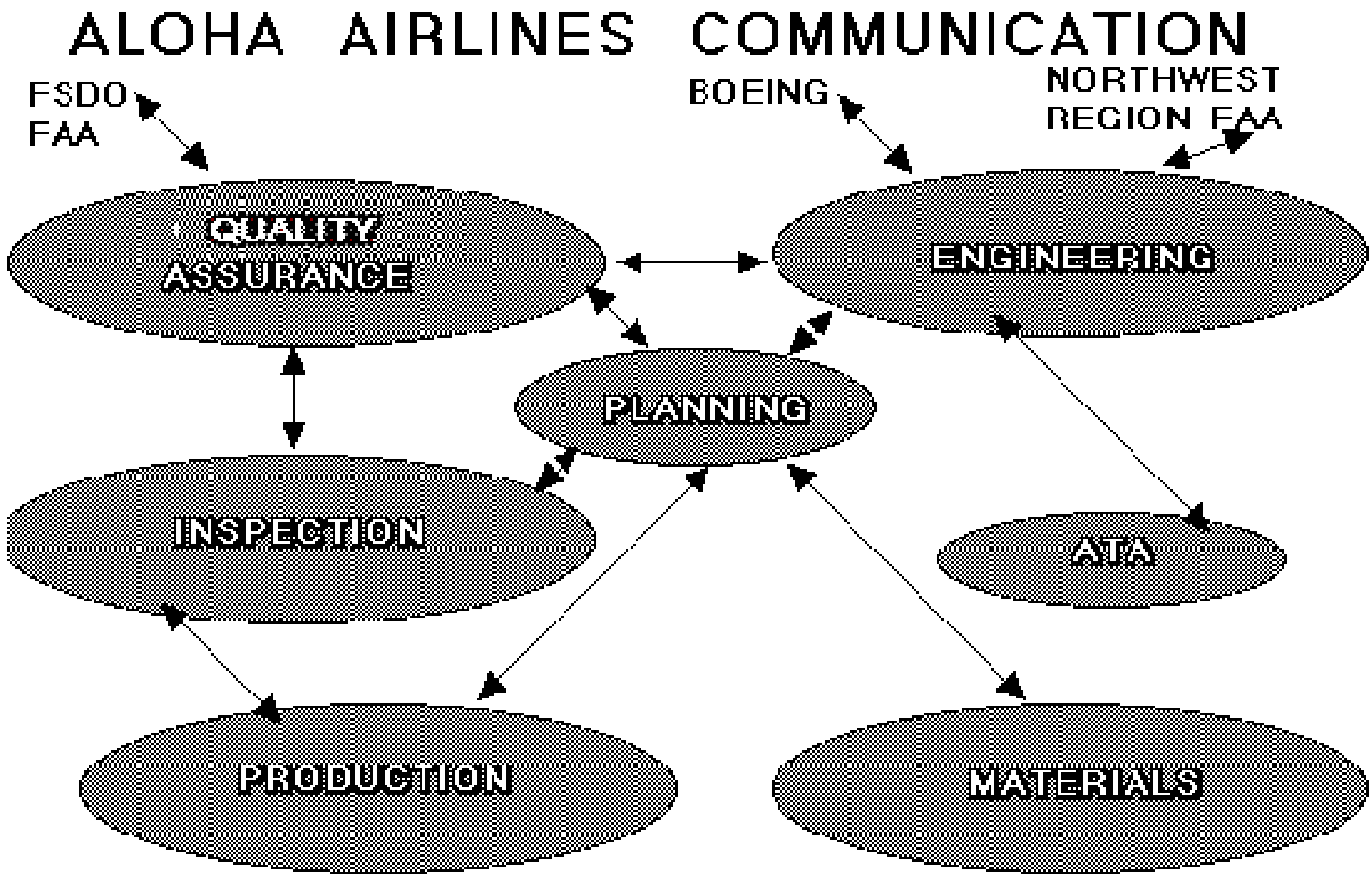

Figure 5

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.

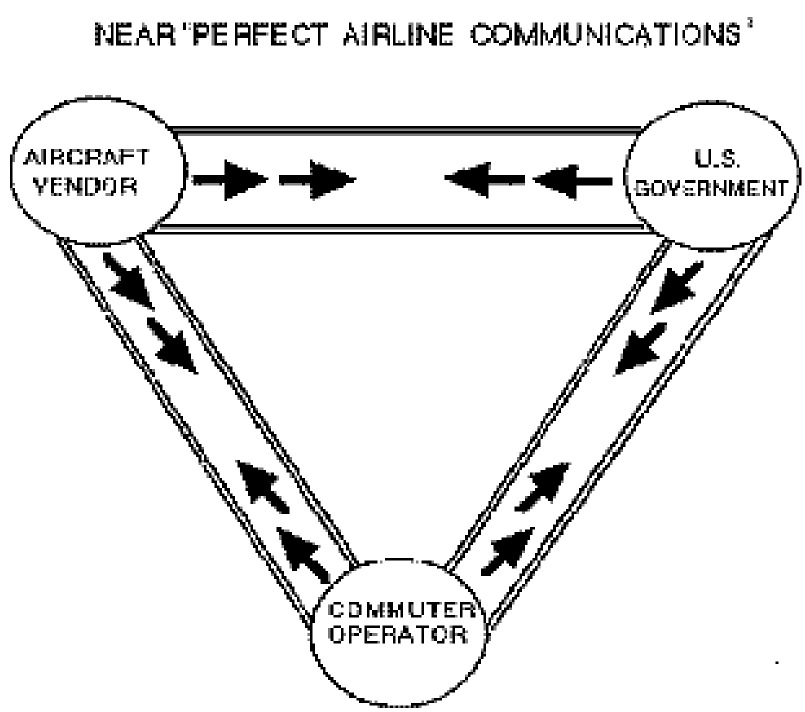

Figure 1

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.

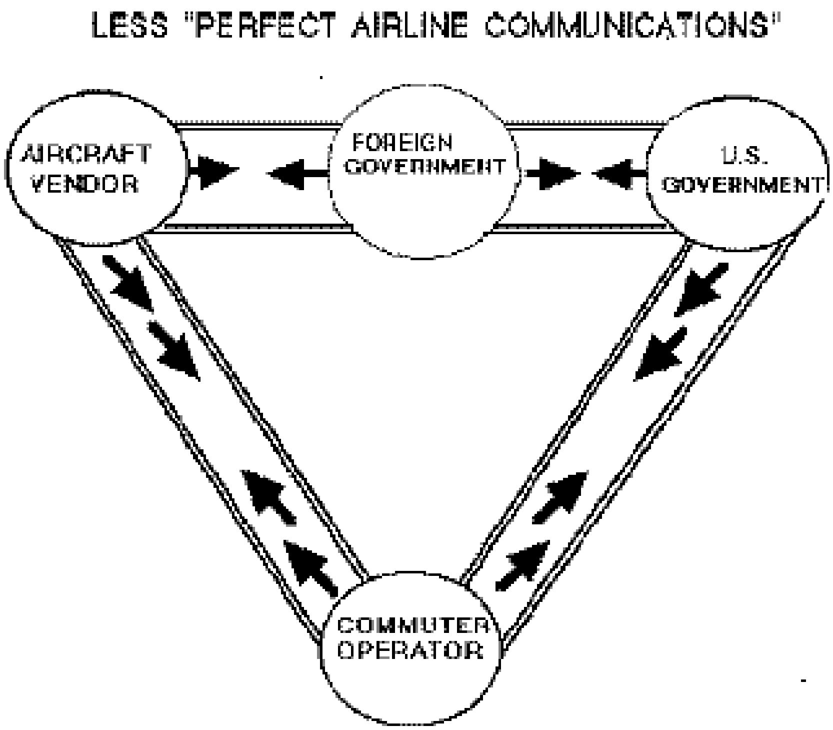

Figure 2

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.

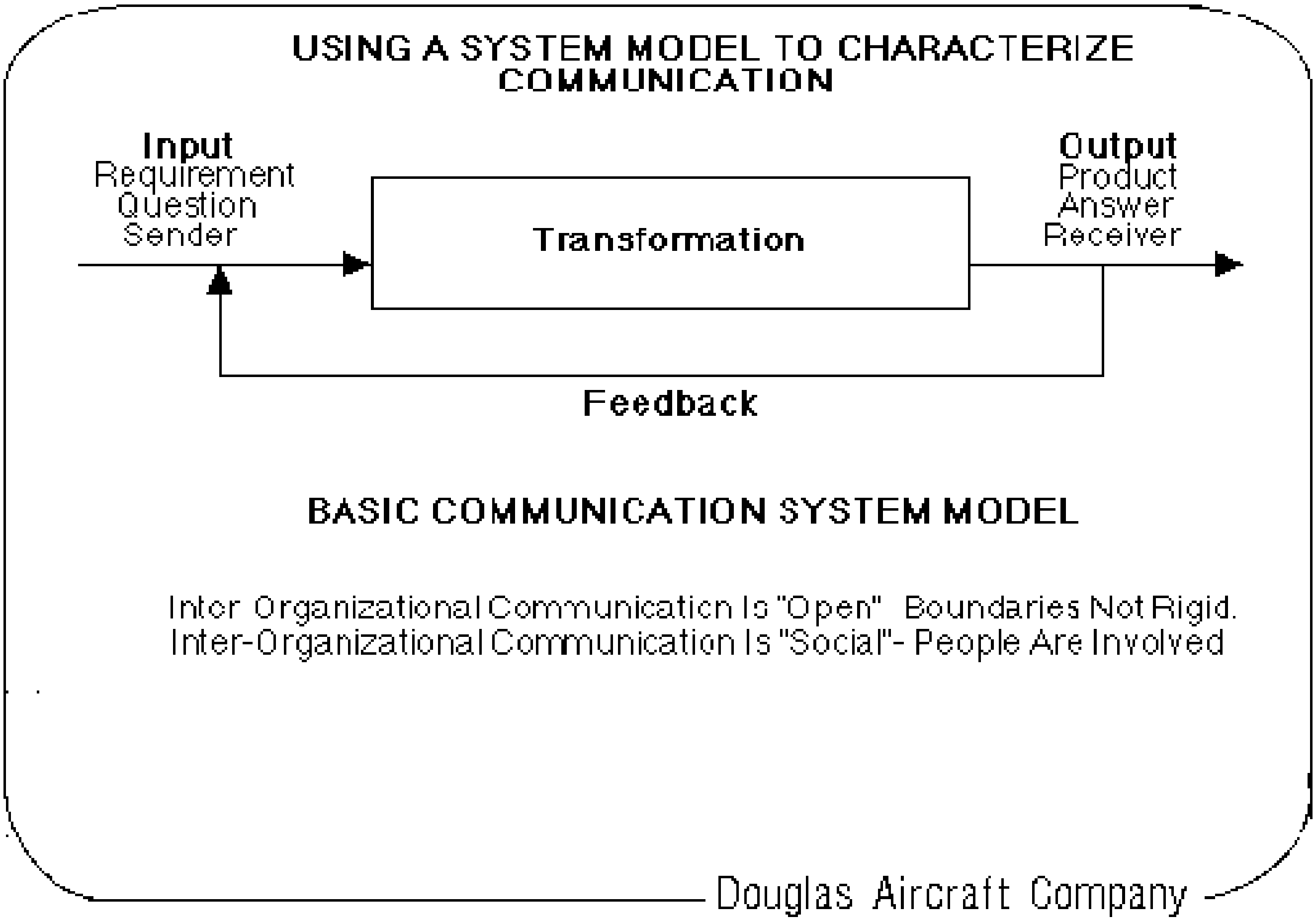

Figure 1

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.

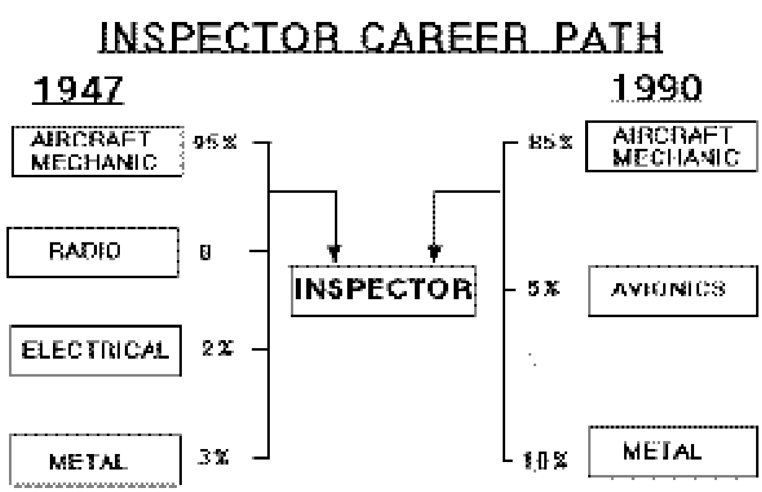

Figure 1

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.

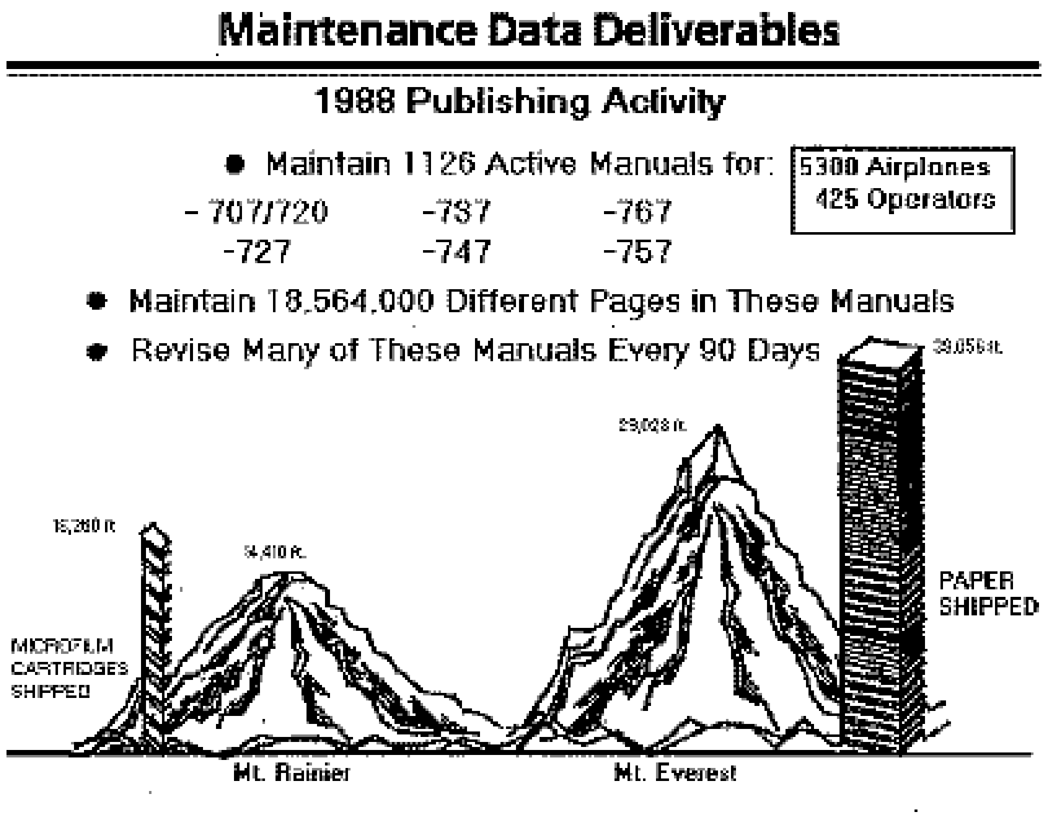

Figure 2

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.

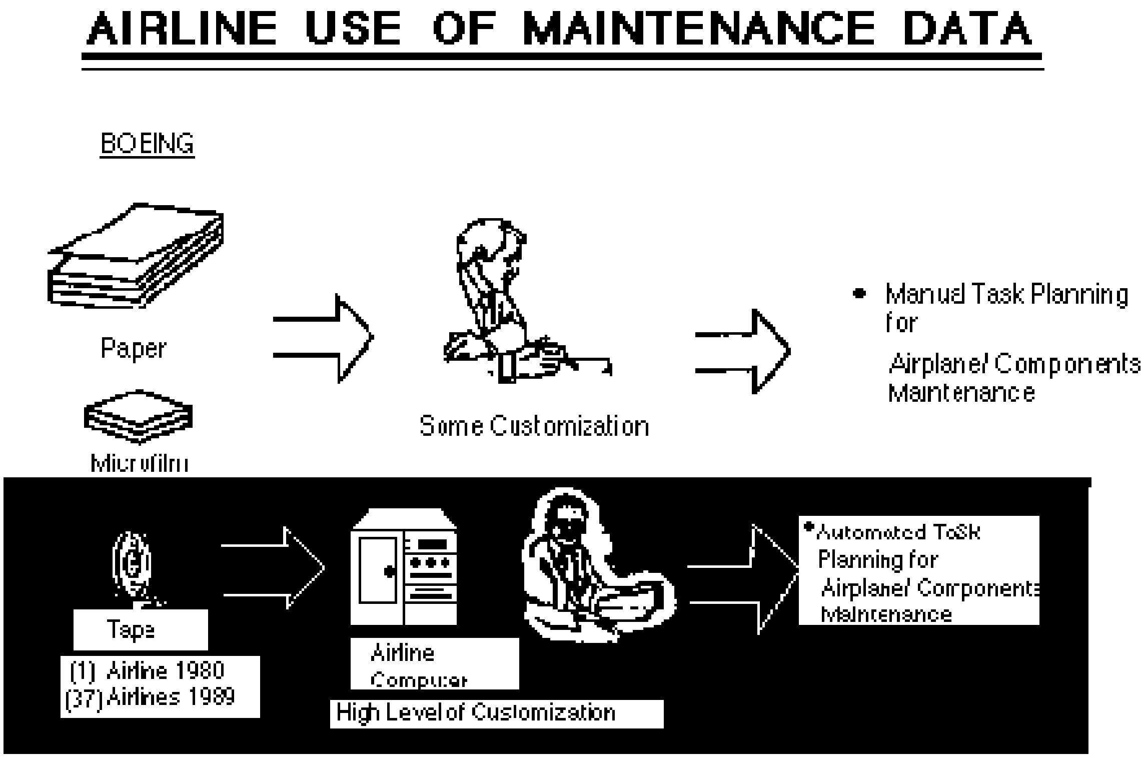

Figure 3

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.

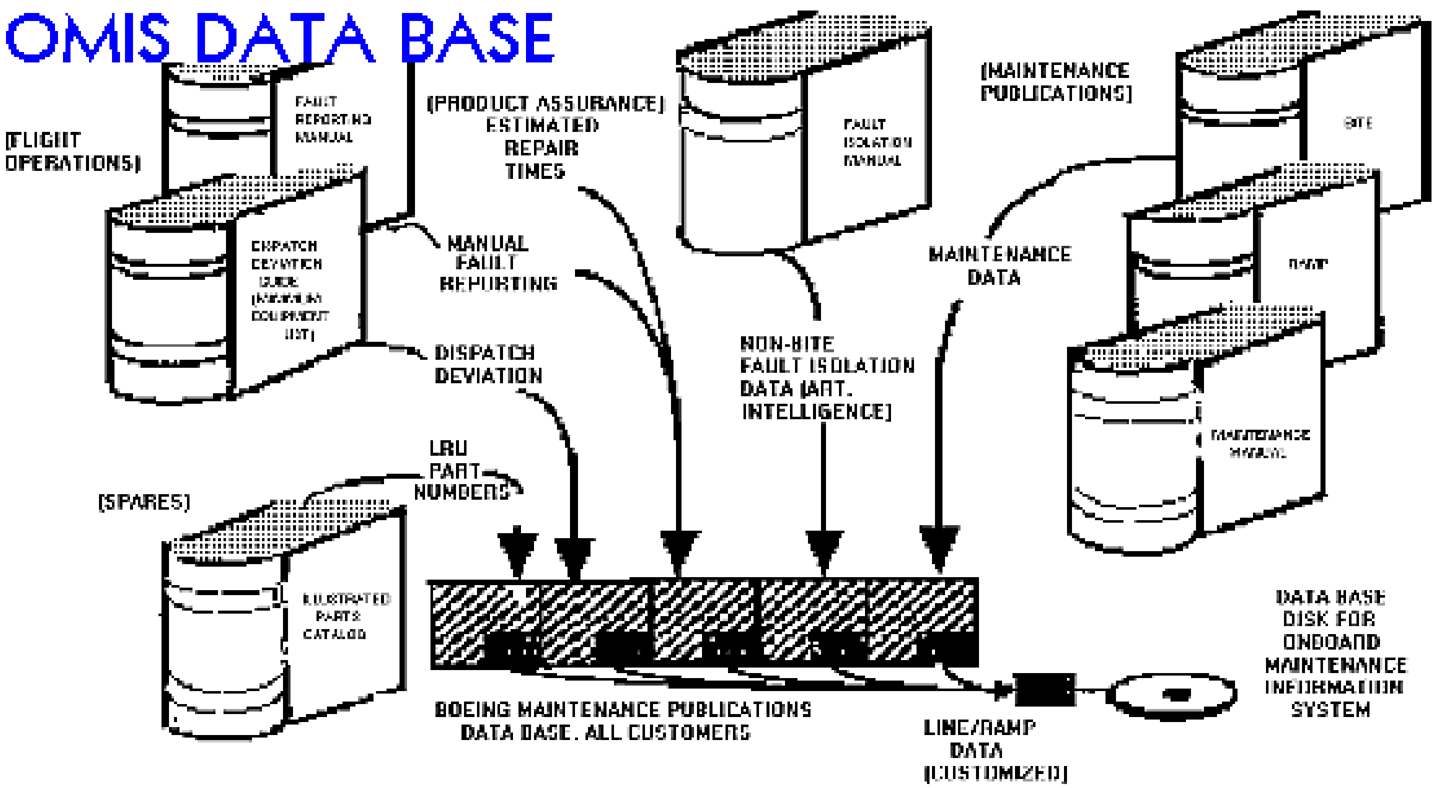

Figure 4

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.

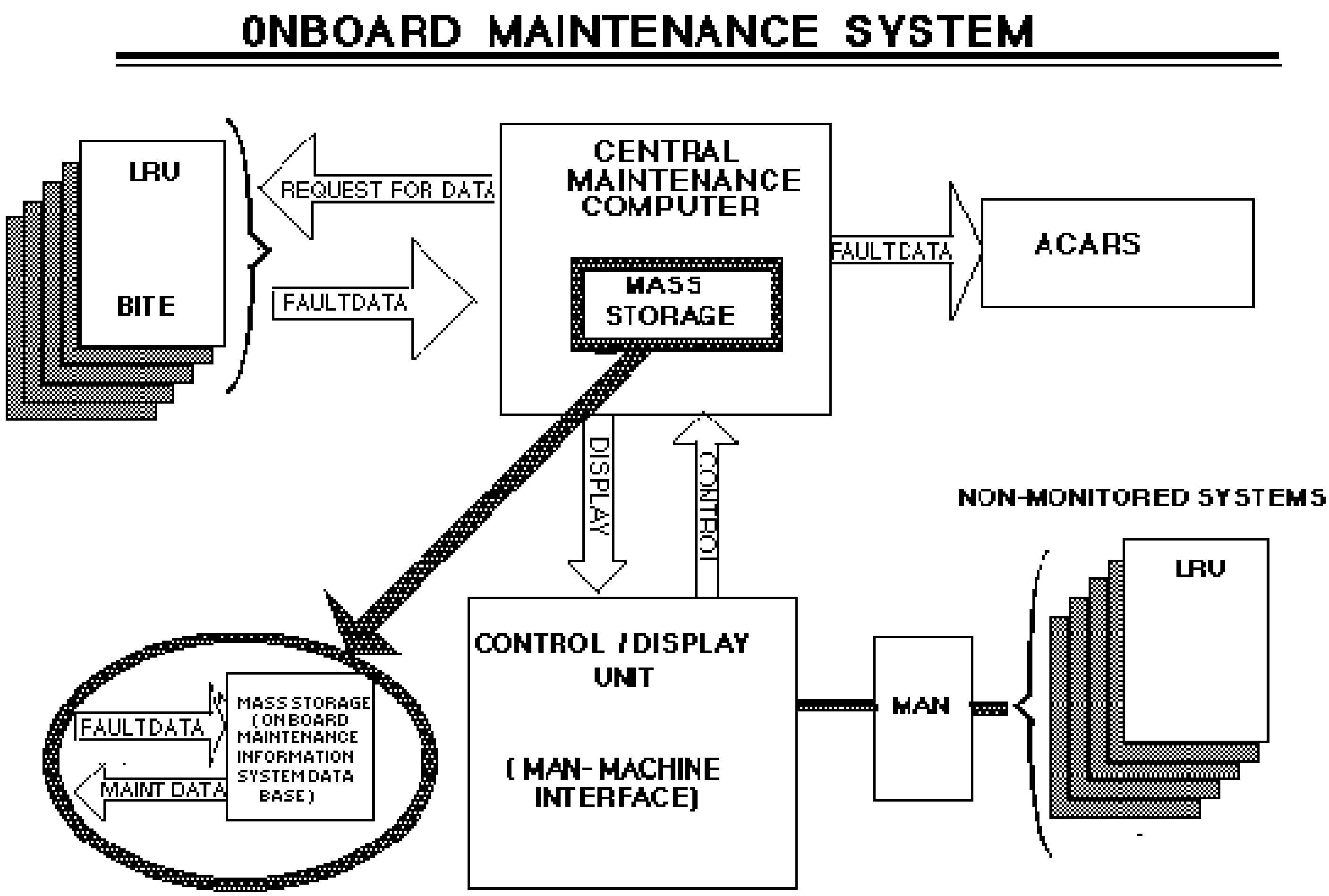

Figure 5

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	Get workcard and

and understand area eddy current
to be covered equipment, calibrate

2. Access Locate area on Locate area on
aircraft, get into aircraft, position
correct position self and equipment

3. Search Move eyes across Move probe over each
area systematically. rivet head. Stop if
Stop if any indication. any indication.

4. Decision Making Examine indication against Reprobe while
remembered standards. closely watching
eg. for dishing or corrosion. eddy current trace.

5. Respond Mark defect, write up Mark defect, write up
repair sheet or if no repair sheet, or if
defect, return to search. no defect, return to
search.

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

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

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.

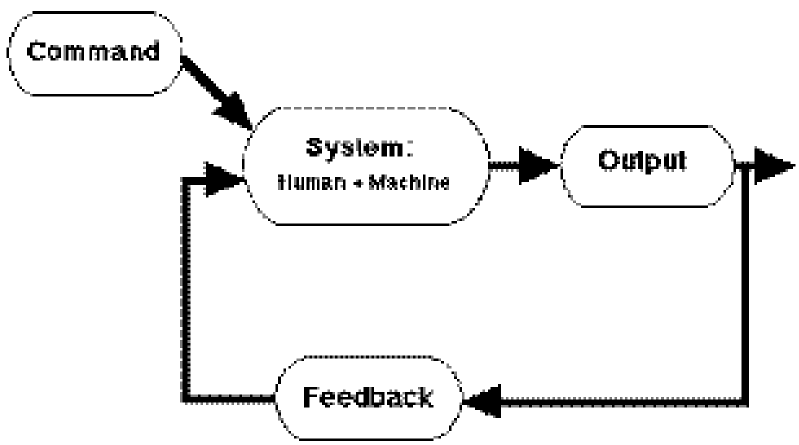

Figure 1 Closed-Loop Control

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.

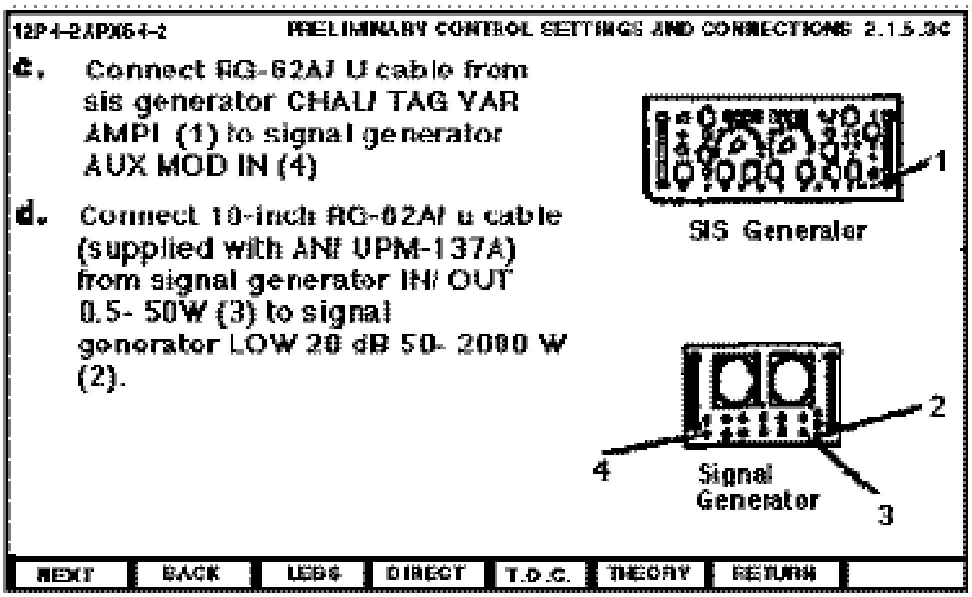

Figure 1 IMIS Prototype

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.

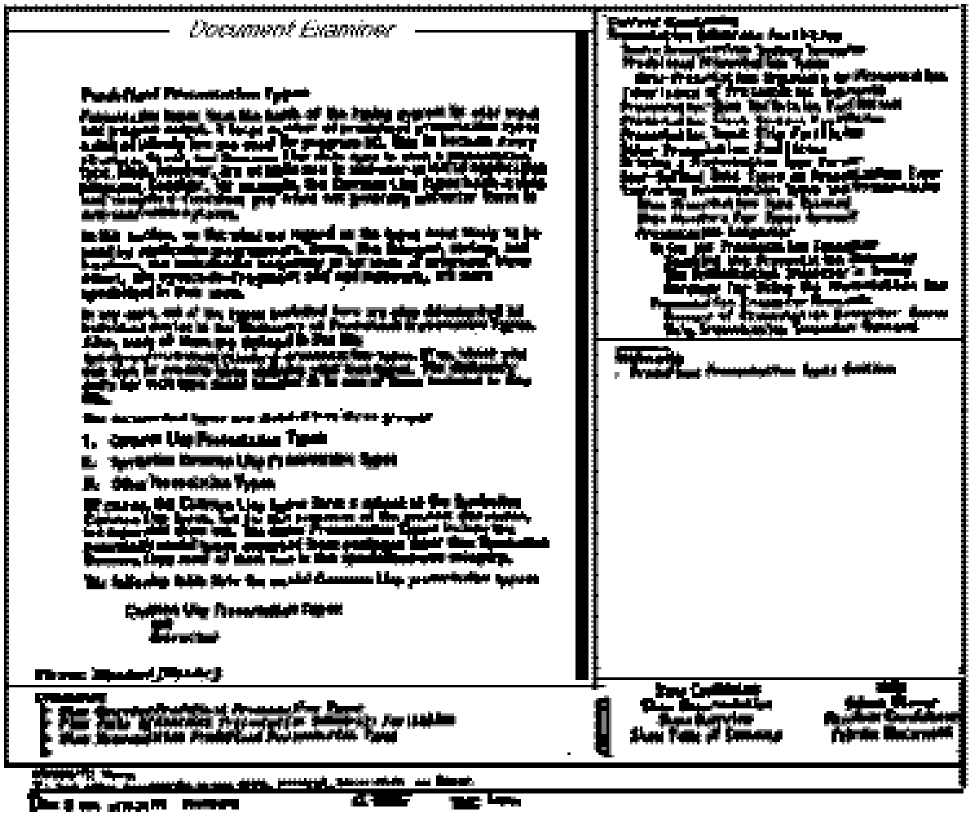

Figure 2 Document Examiner

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.

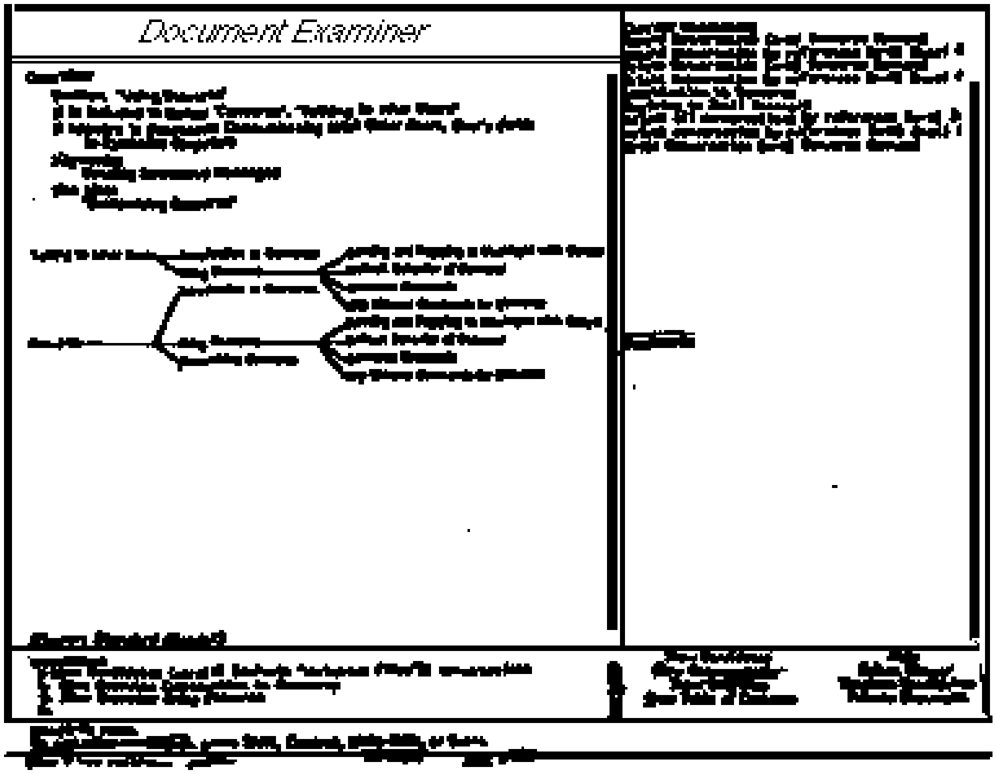

Figure 3 Document Examiner - Graphic Map

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.

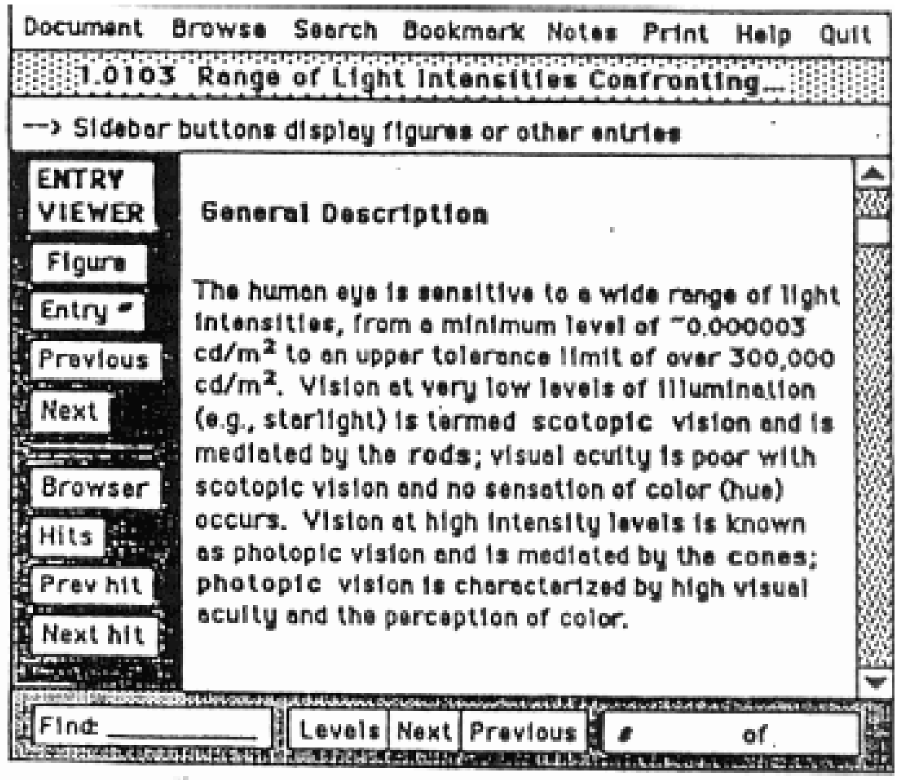

Figure 4 Engineering Data Compendium

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.

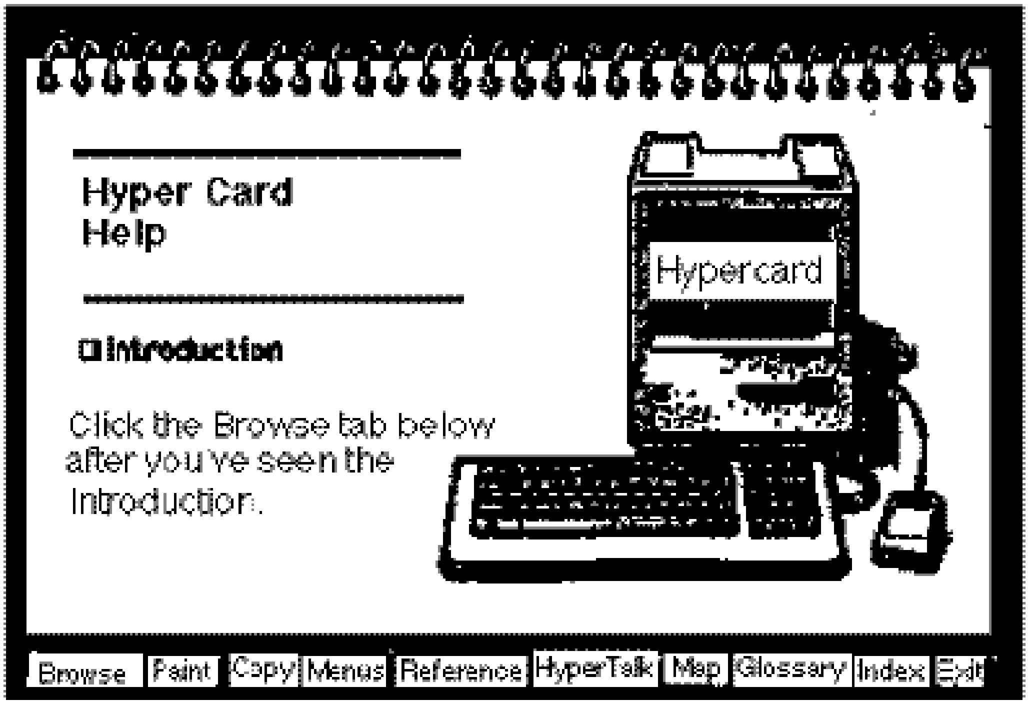

Figure 5 HyperCard Help

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.

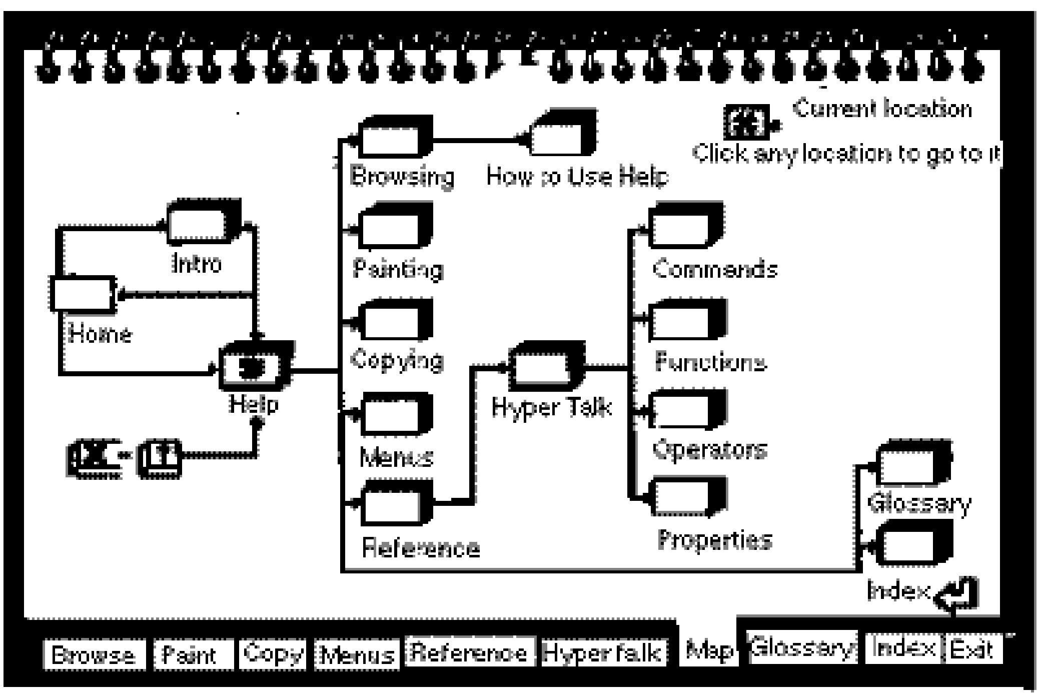

Figure 6 HyperCard Help - Graphic Map

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.

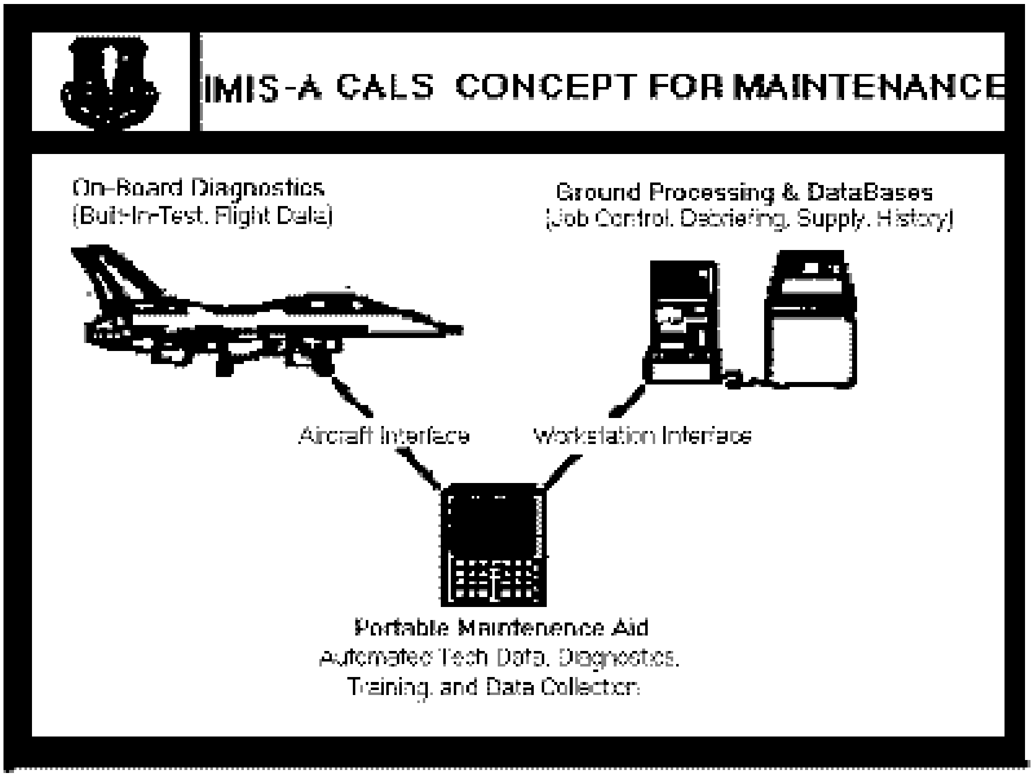

Figure 1

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.

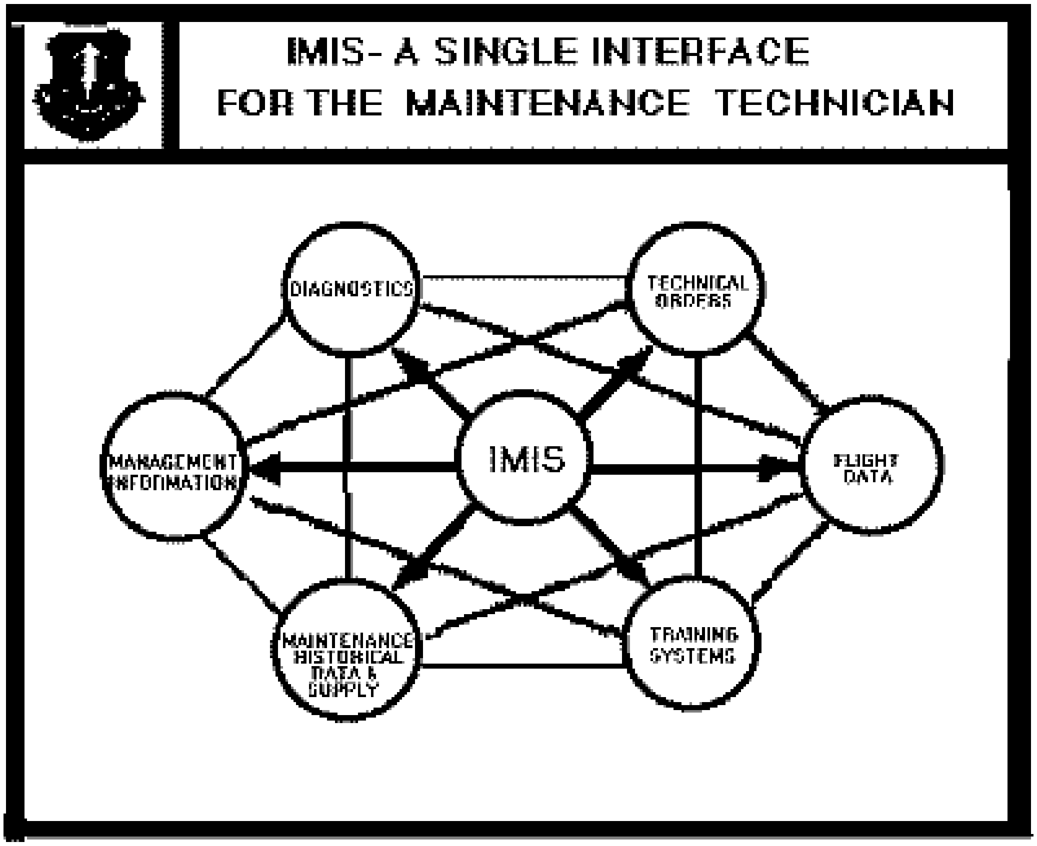

Figure 2

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.

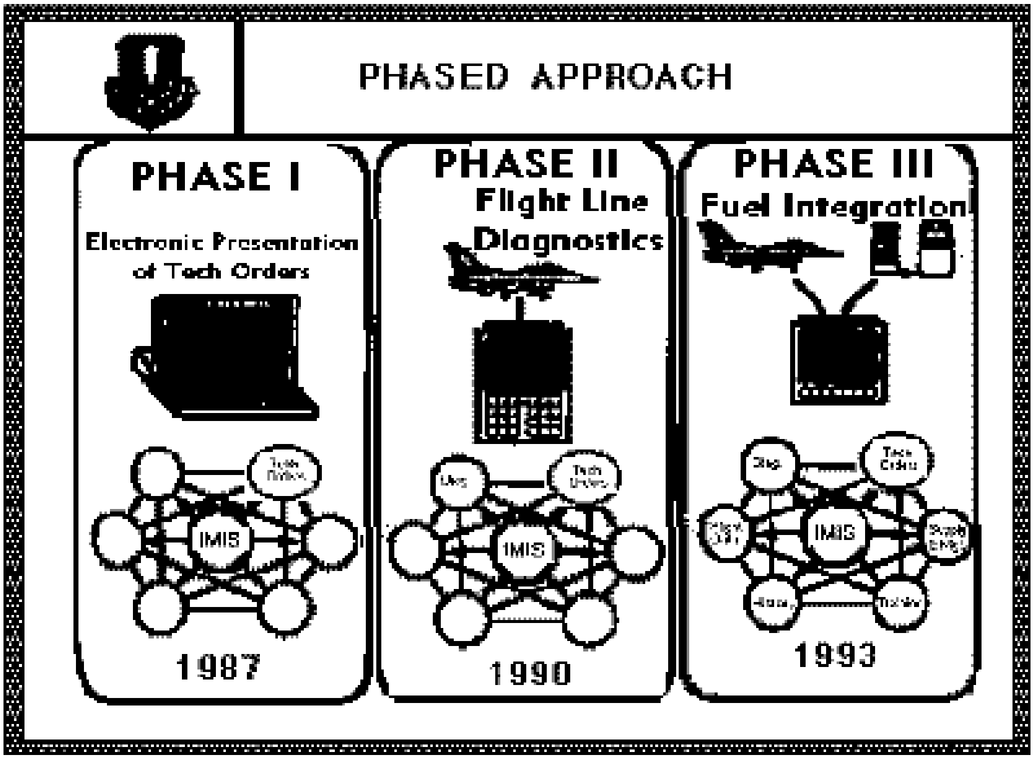

Figure 3

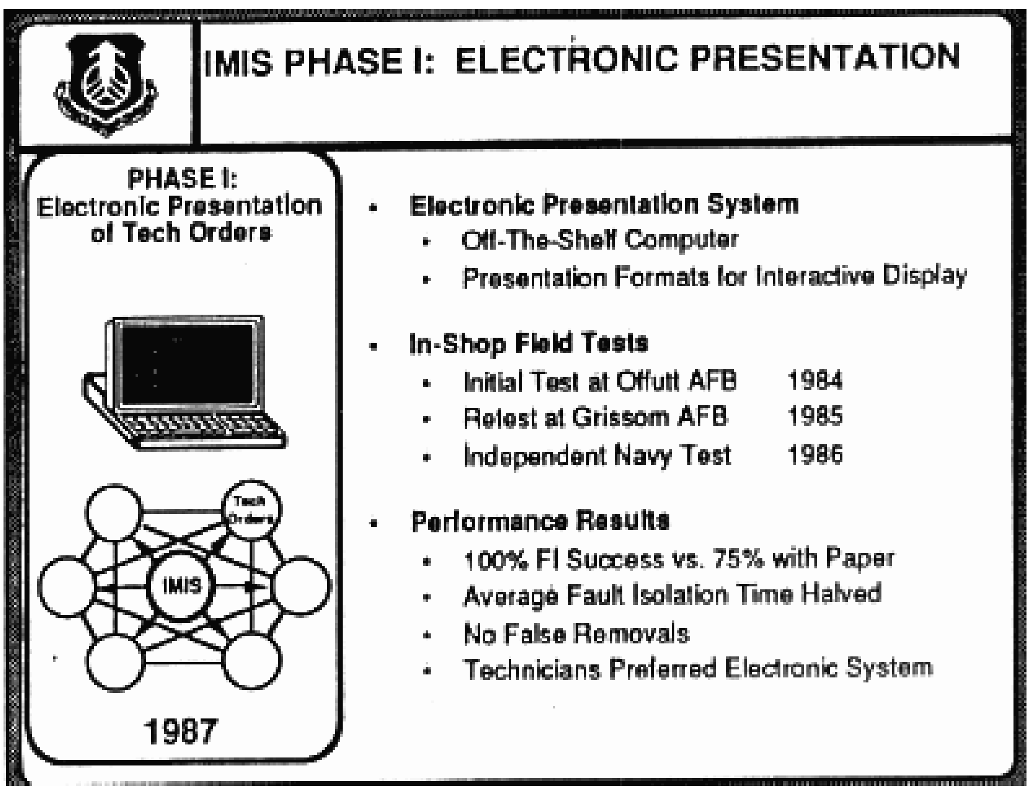

Figure 4

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.

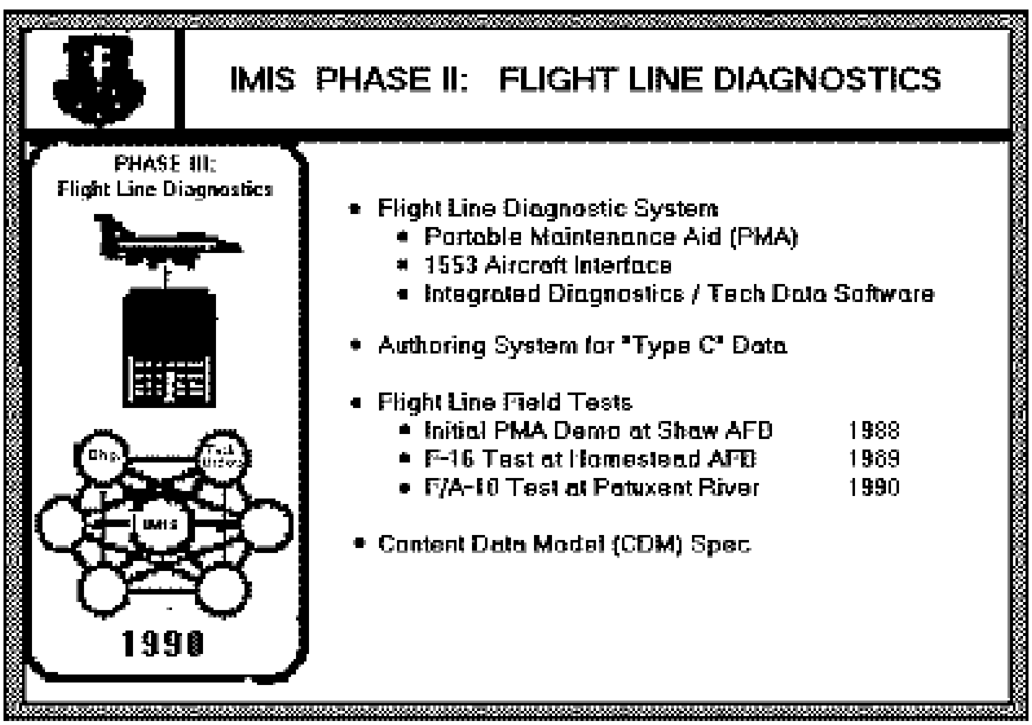

Figure 5

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.

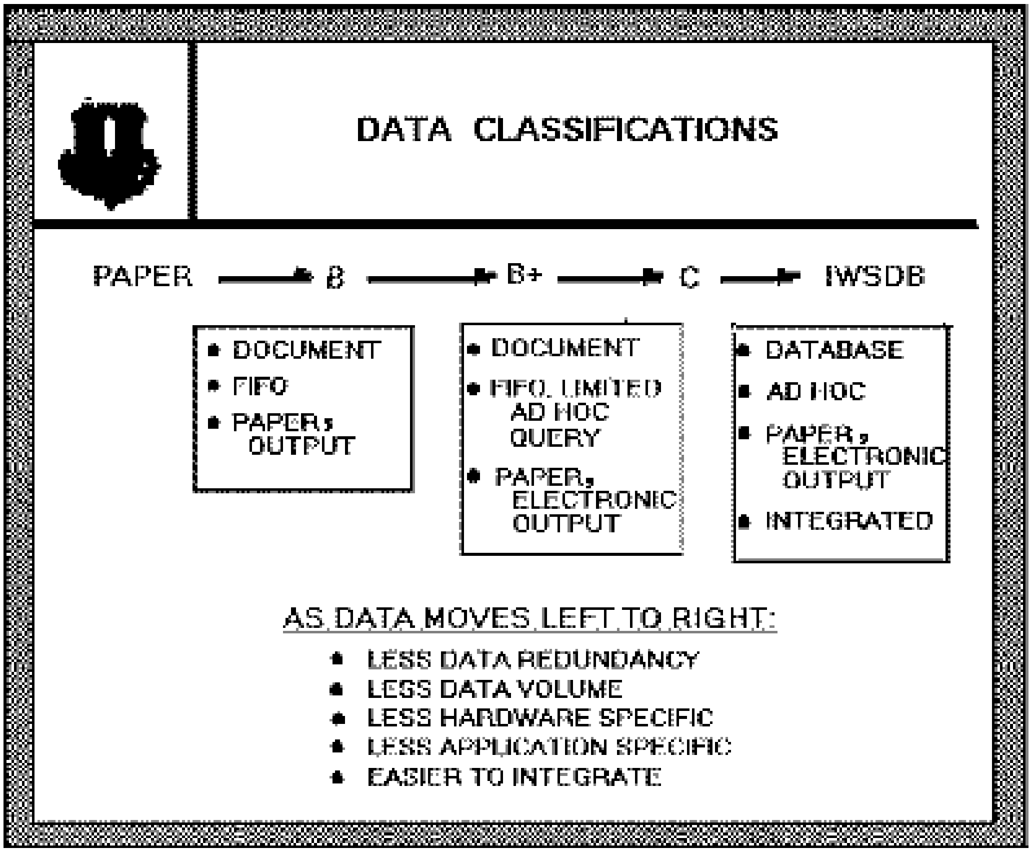

Figure 6

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.

IMIS PROGRESS

• INTERMEDIATE LEVEL TO DATA FIELD TEST-GRISSOM AFB, IN	1985
• NAVY/AF/MARINES I-LEVEL FIELD TEST	1986
• ORGANIZATIONAL LEVEL TO DATA FIELD TEST-MACDILL AFB, FL	1988
• F-16 FLIGHT LINE DEMO AT HOMESTEAD AFB	1989
• PORTABLE COMPUTER, AND UPGRADE	1987-1990
• AUTHORING SOFTWARE TESTS BY INDUSTRY, GOV'T	1987-1991
• DATA INTERCHANGE STANDARDS	1988-1990
• CONTENT DATA MODEL DEVELOPMENT AND TEST	1988-1990
• F/A-18 FIELD TEST	1990
• MAN-MACHINE INTERFACE	ON-GOING
• FULL UP SYSTEM DEMONSTRATION	1993

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

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Transportation Systems Center

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.

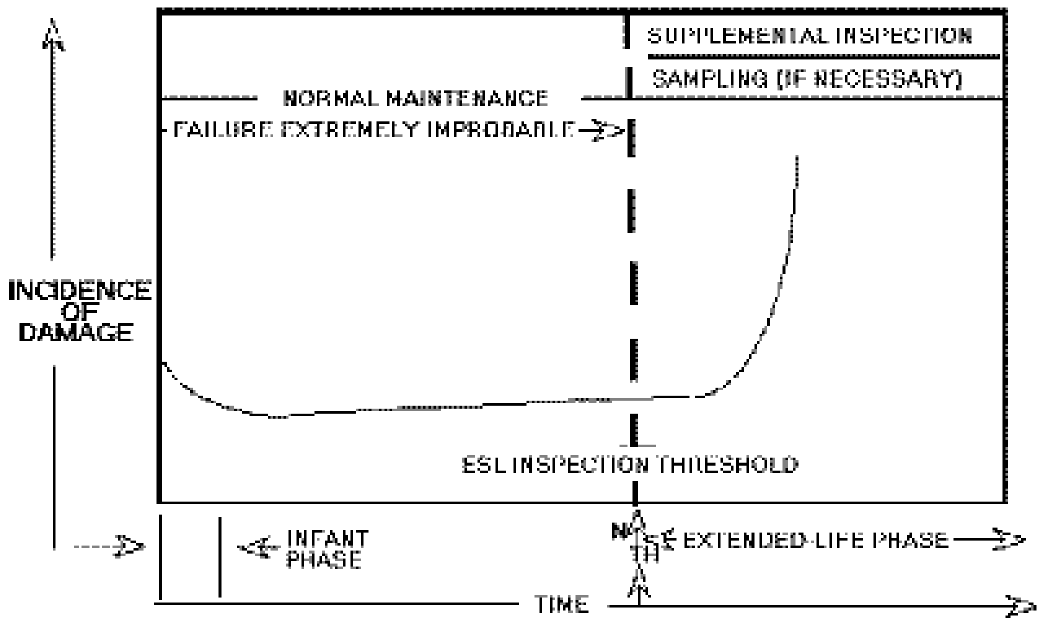

Figure 1 When in the life of an aircraft does damage occur?

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.

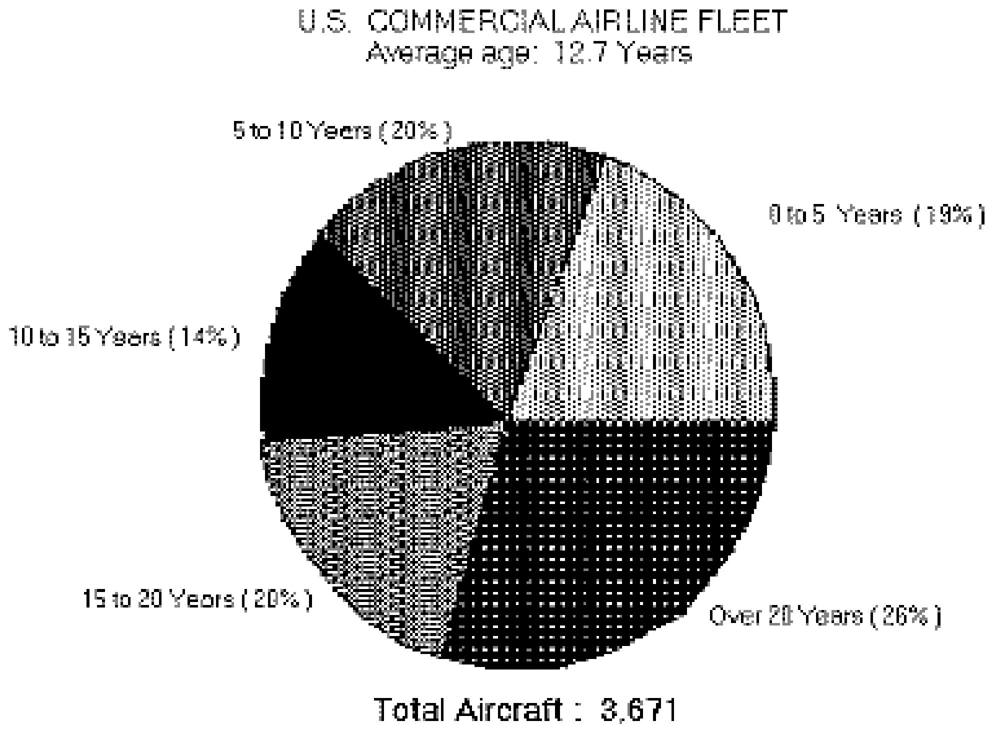

Figure 2 Estimated age of the commercial airline fleet.

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.

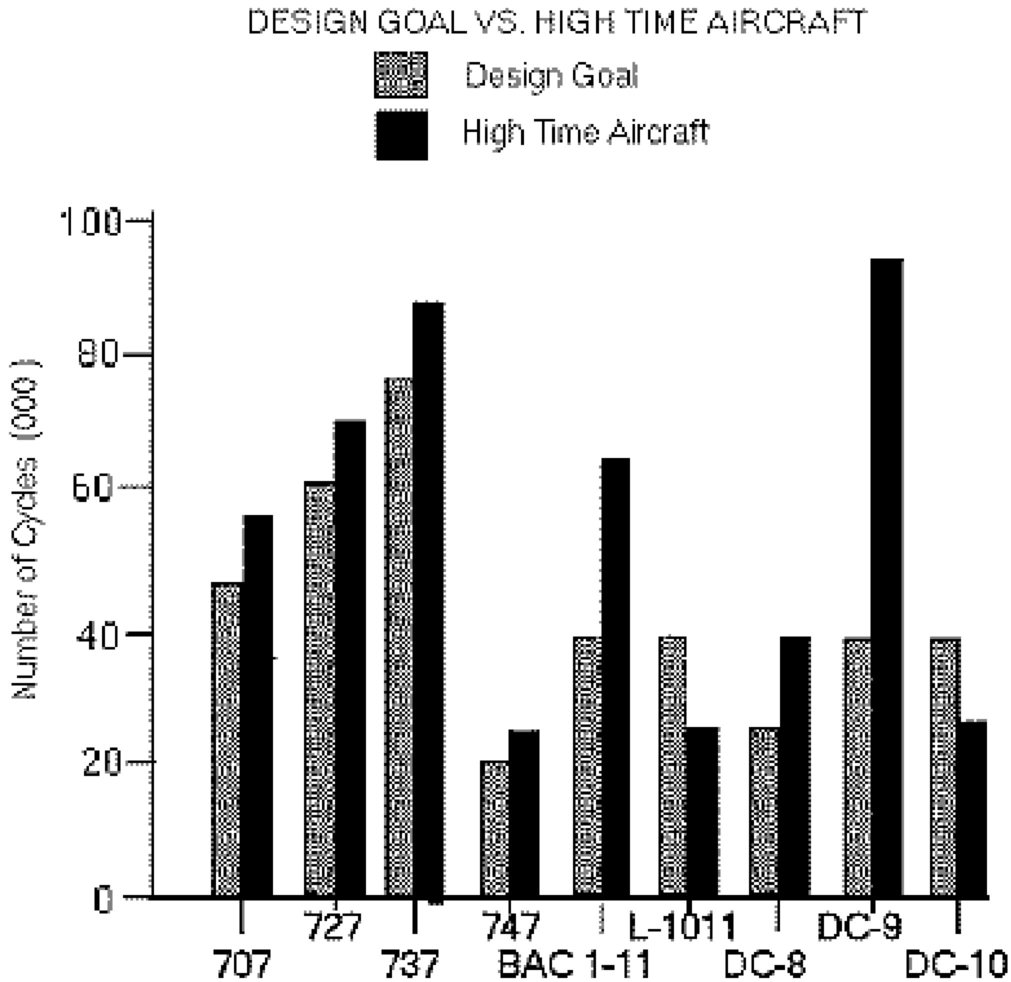

Figure 3 Comparison of design age with actual age of highest time aircraft in fleet

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.

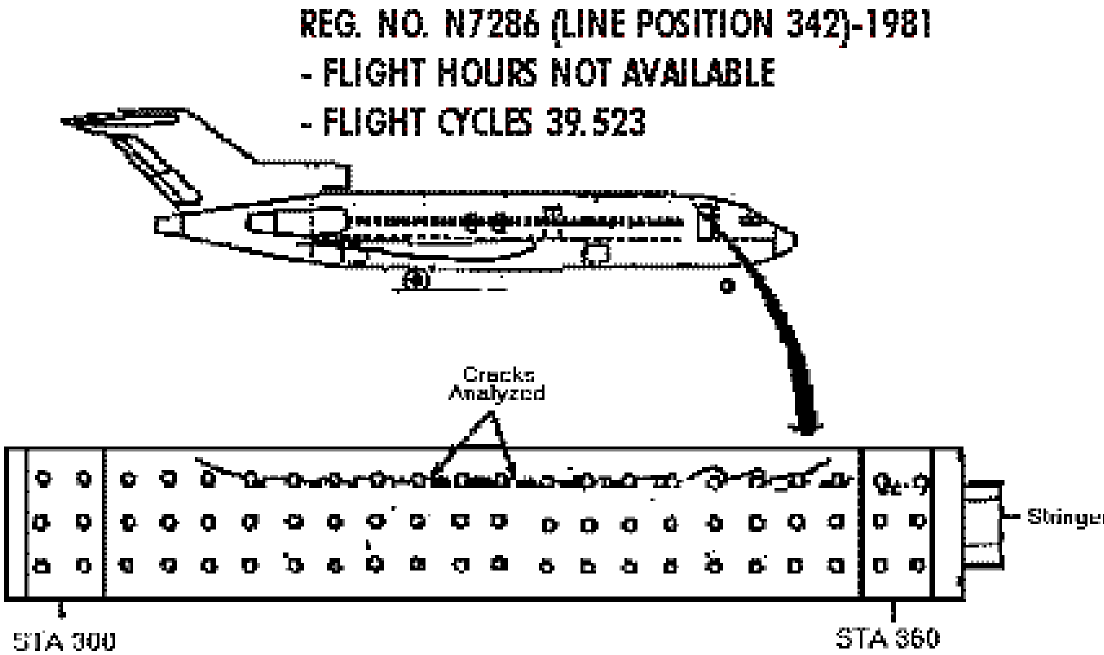

Figure 4 Example of multiple crack elongation

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.

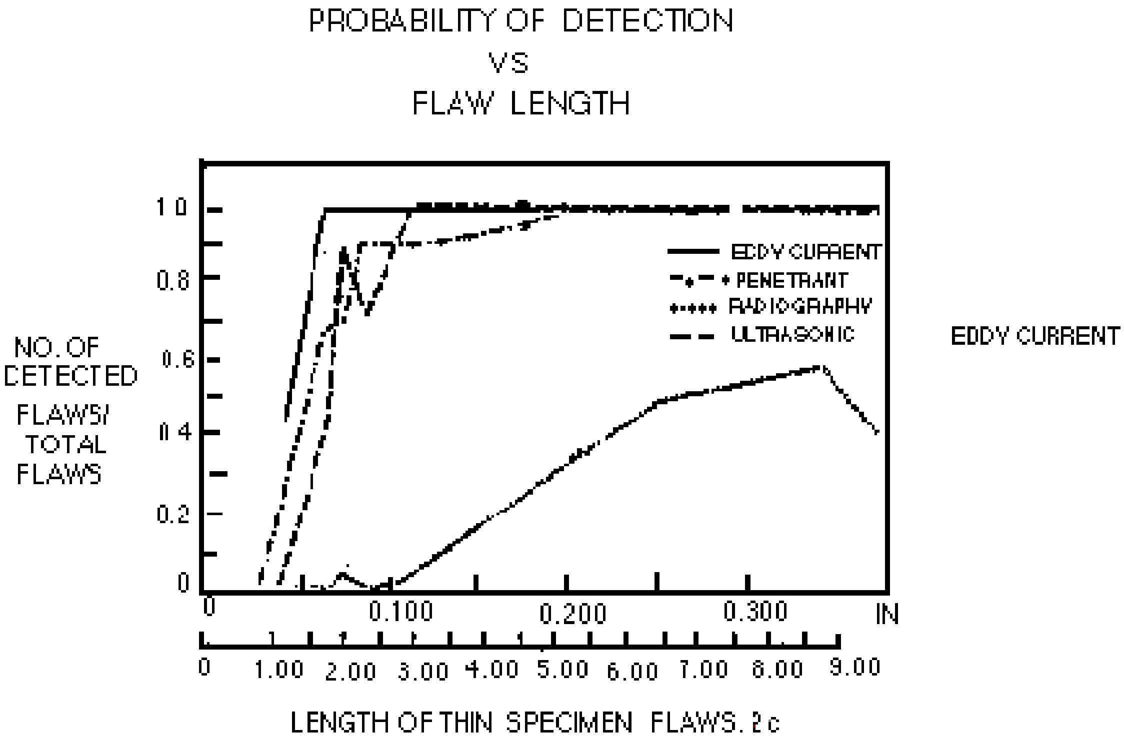

Figure 5 Detection probability curves for four NDI procedures.

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.

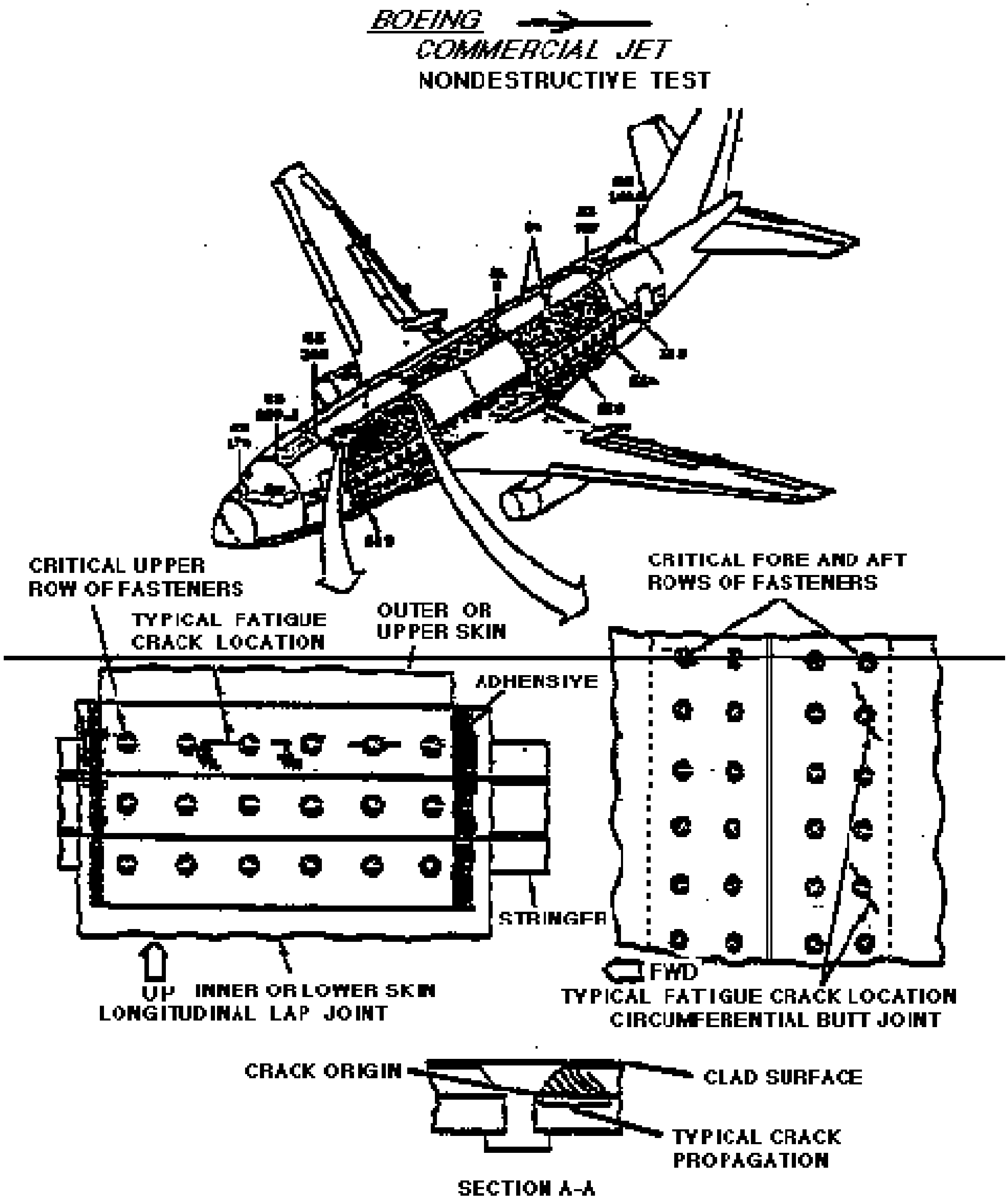

Figure 6 Typical fuselage skin joint configuration and crack orientation.

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.

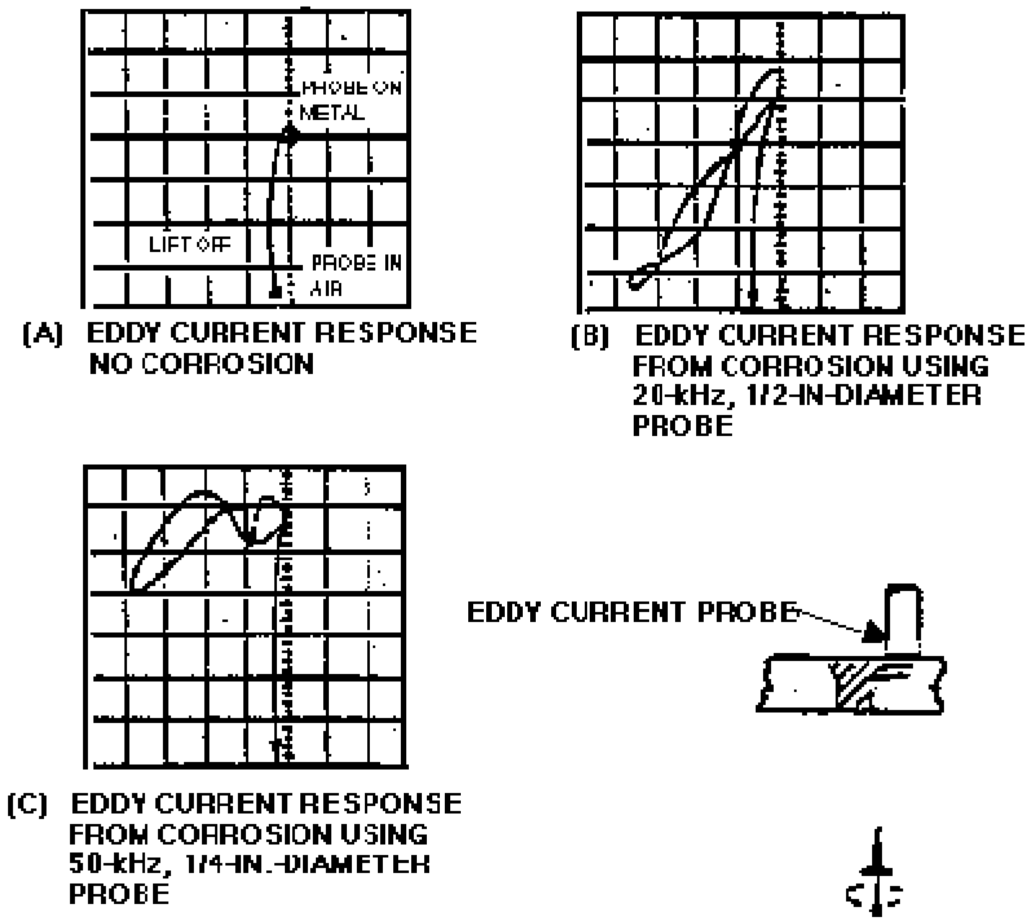

Figure 7 Eddy current impedance-plane responses for exfoliation corrosion around fastener holes in wing skins.

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.

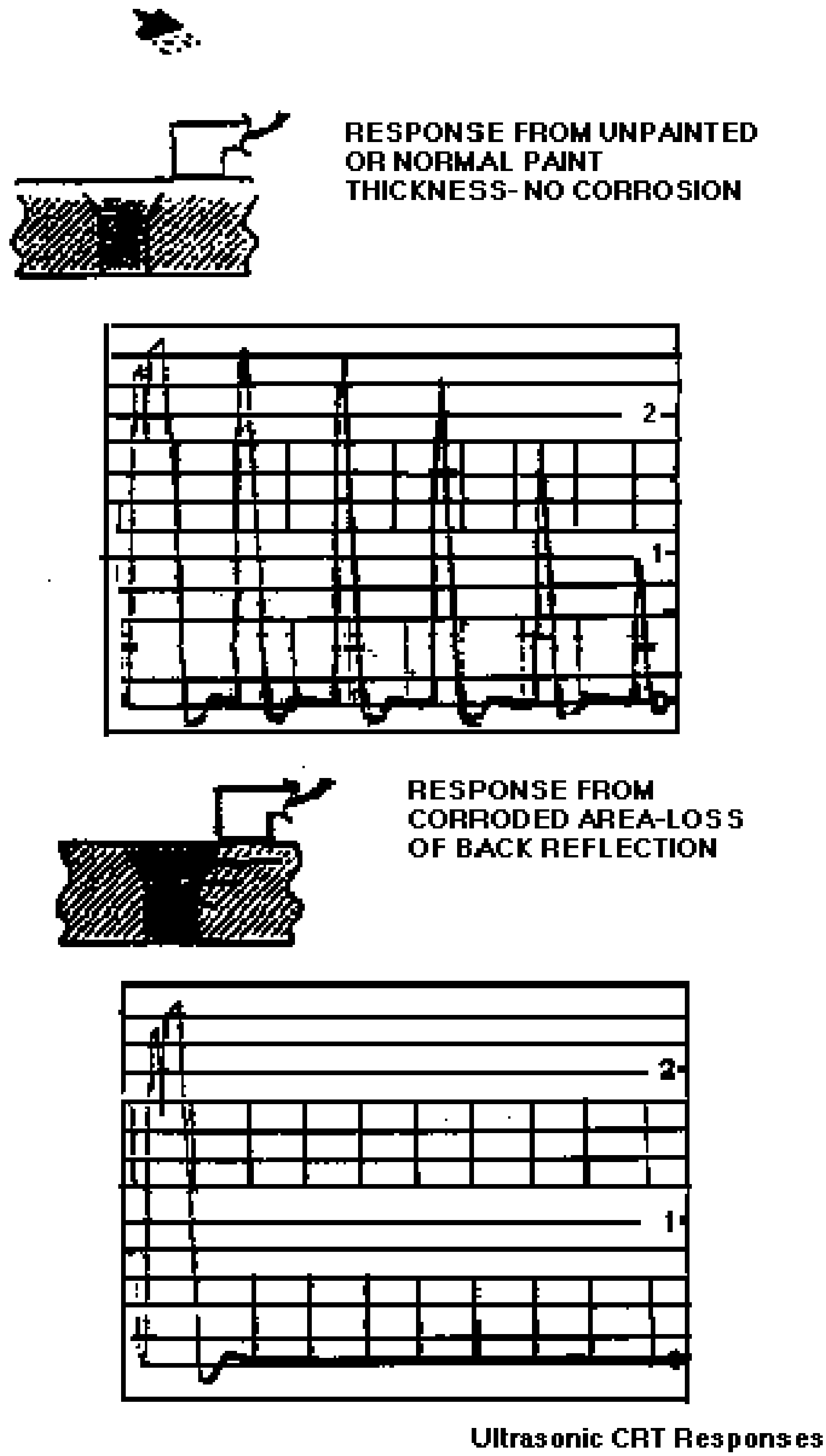

Figure 8 Contact ultrasonic CRT responses

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.

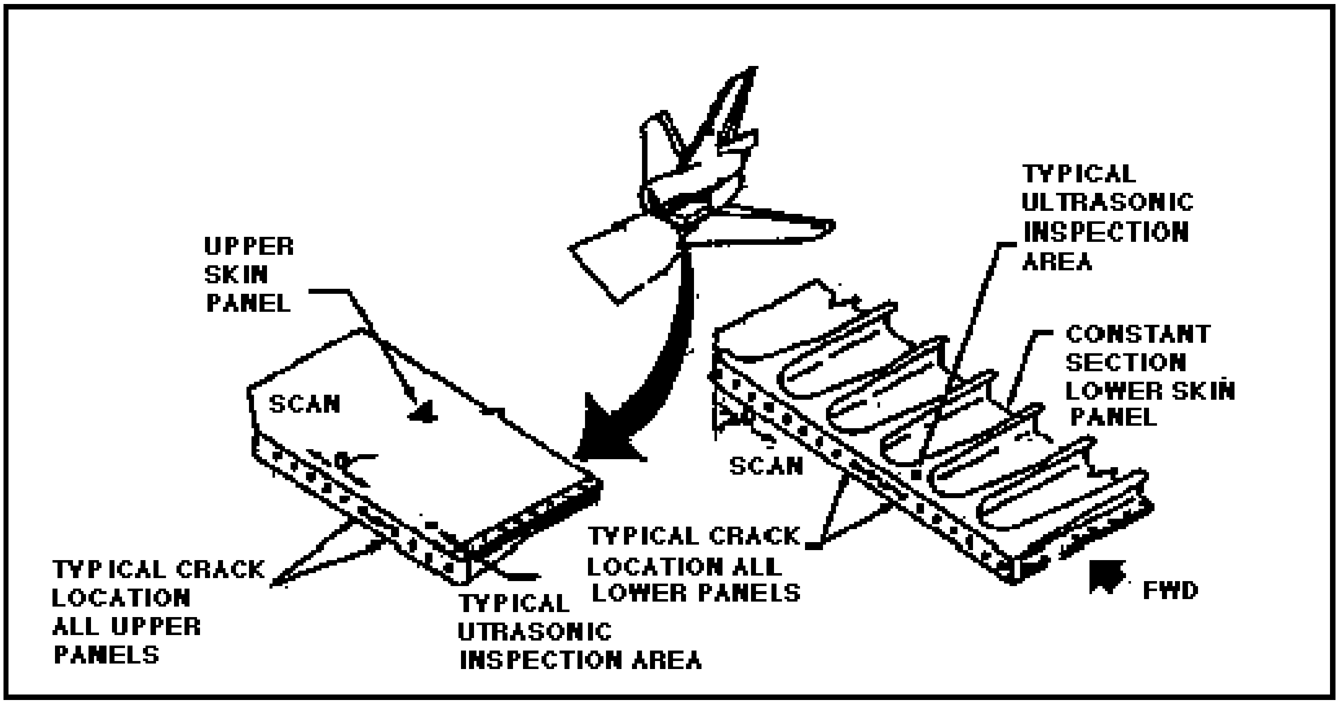

Figure 9 Typical crack environment for ultrasonic inspection.

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.

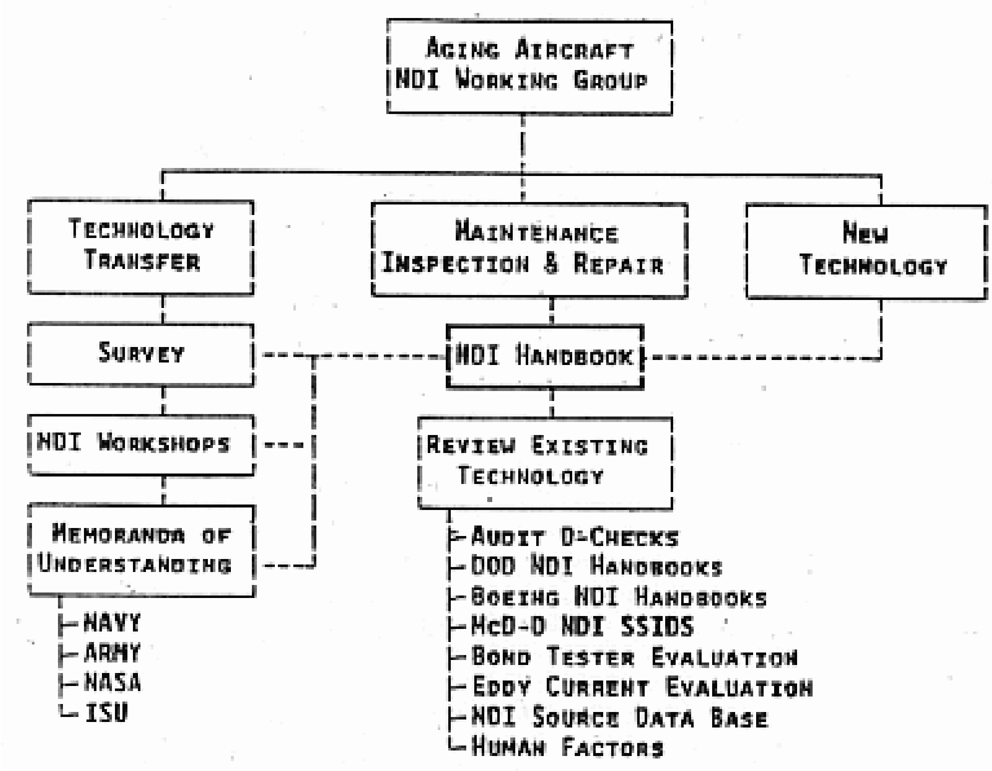

Figure 10 Aging aircraft NDI program.

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

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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 <u>usable</u> 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 <u>ineffective</u> 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 <u>ineffective</u> 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 <u>usability</u> 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.

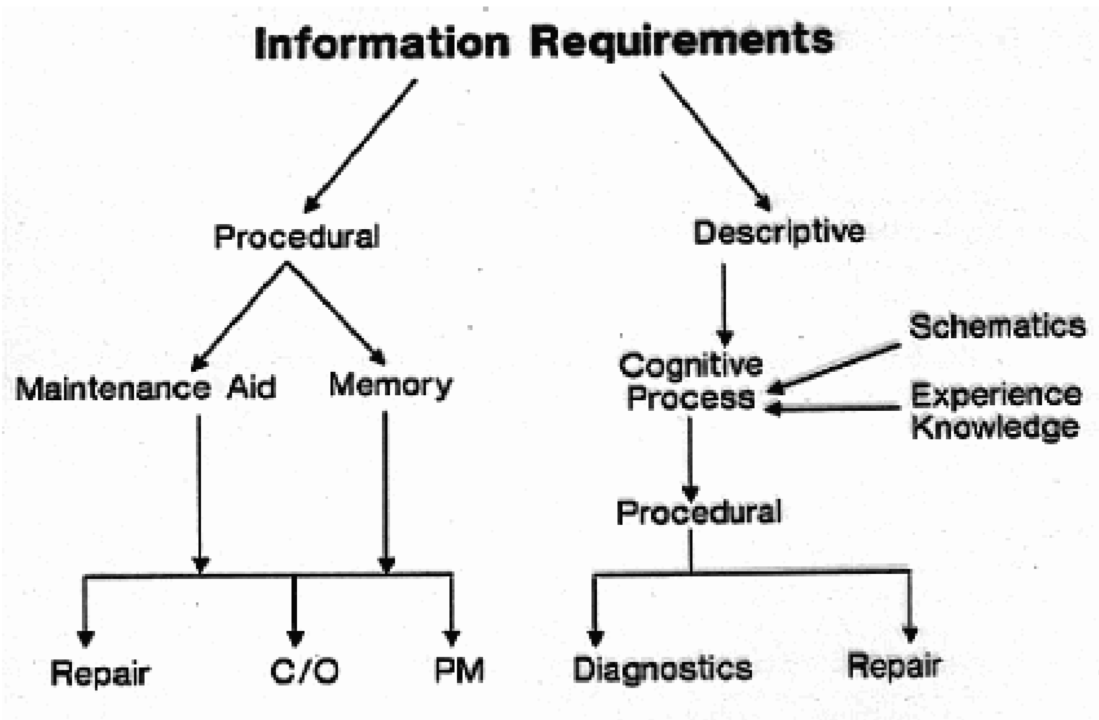


Figure 2

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.

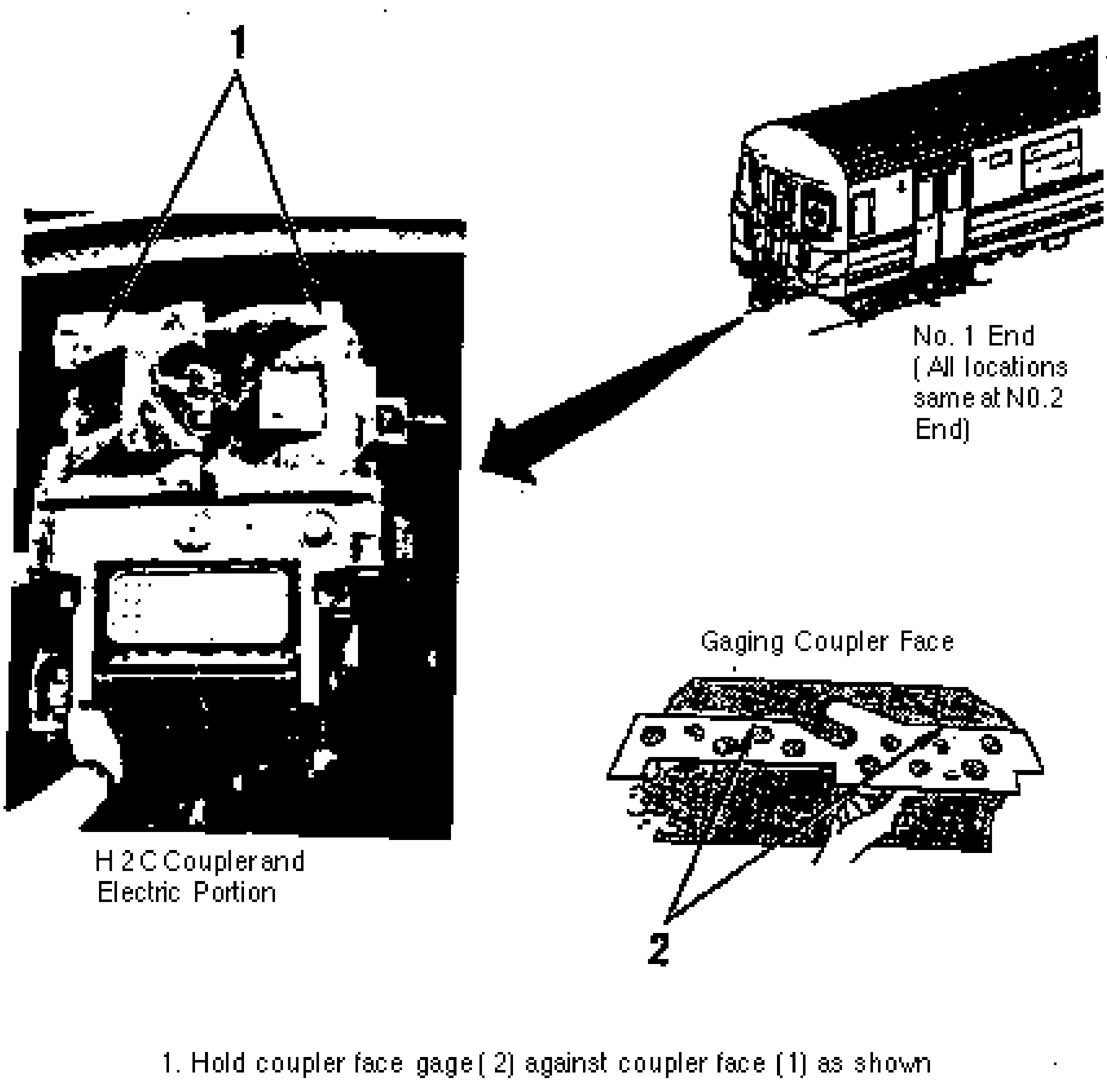


Figure 4

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.

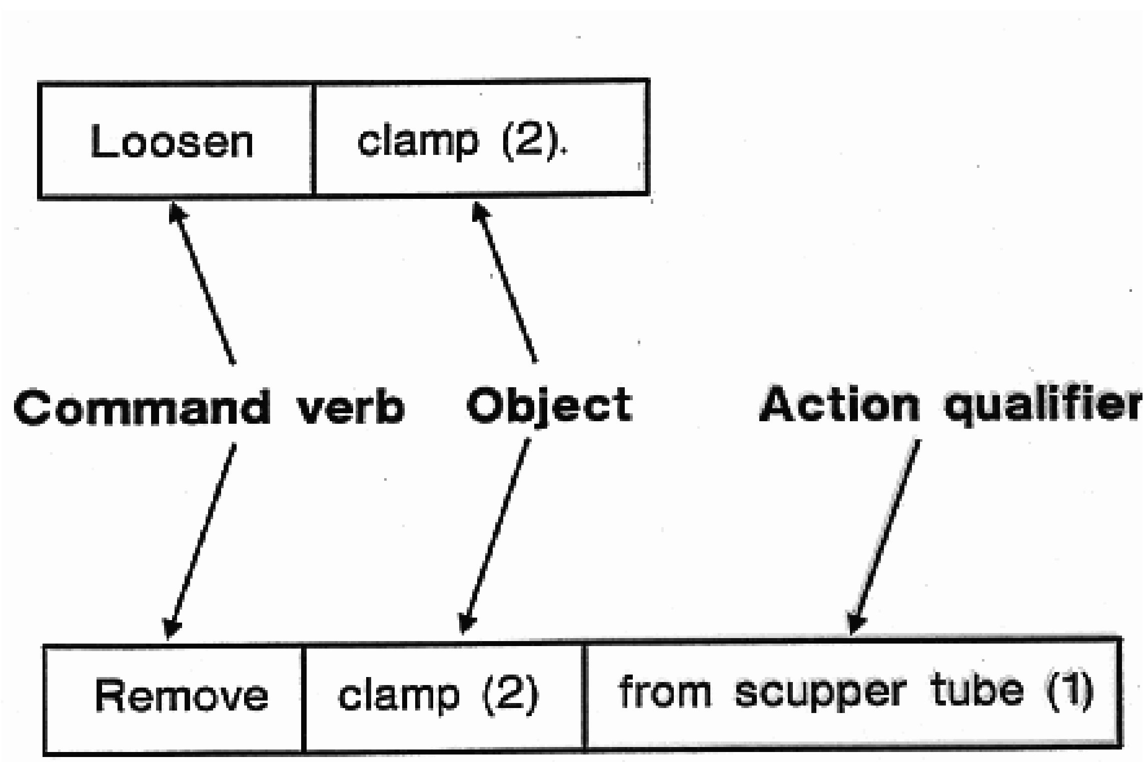


Figure 6

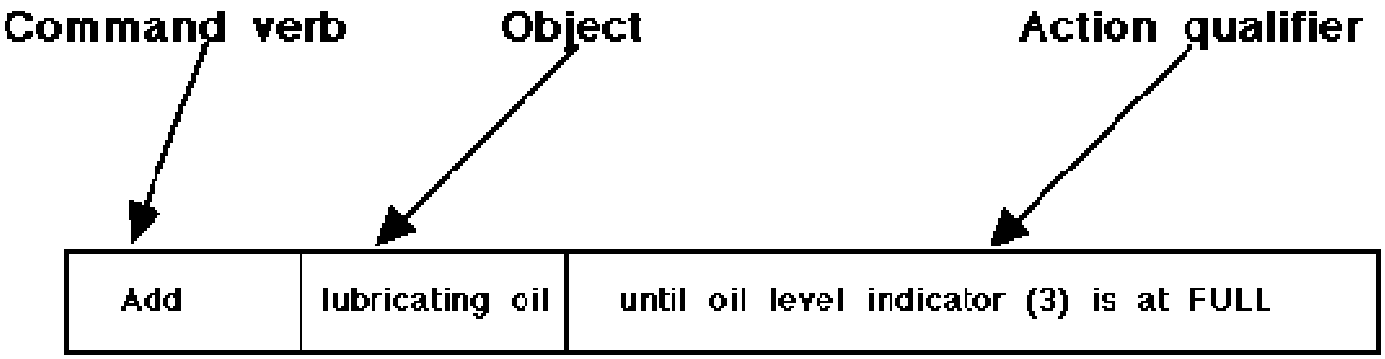


Figure 7

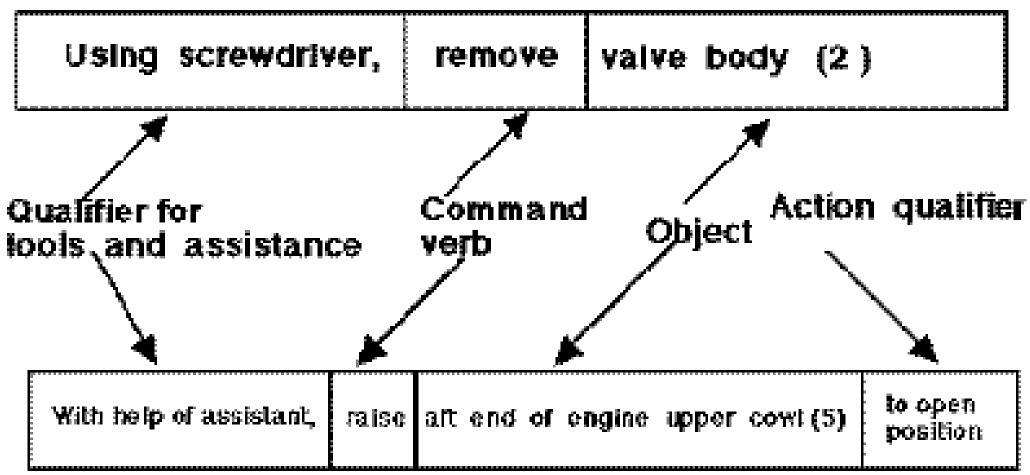


Figure 8

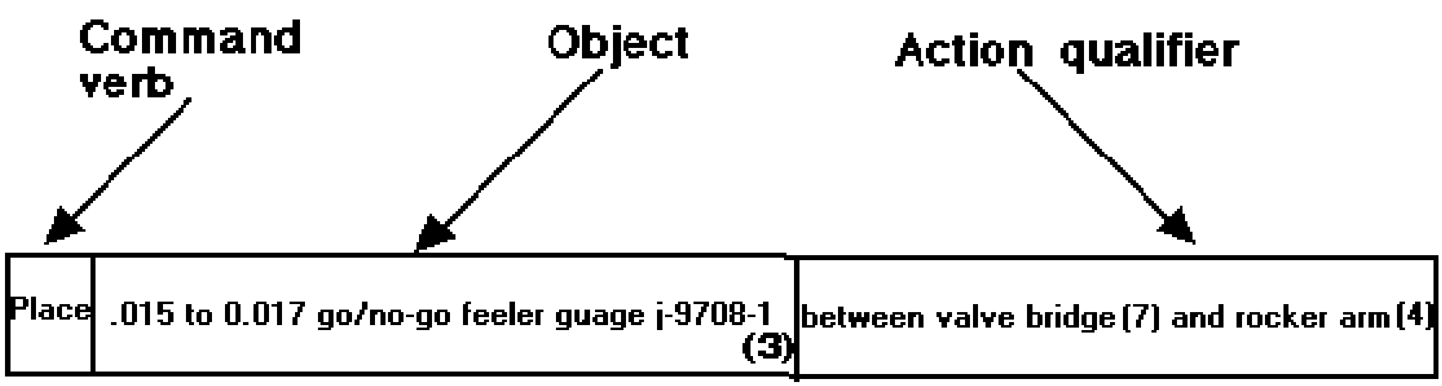


Figure 9

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.

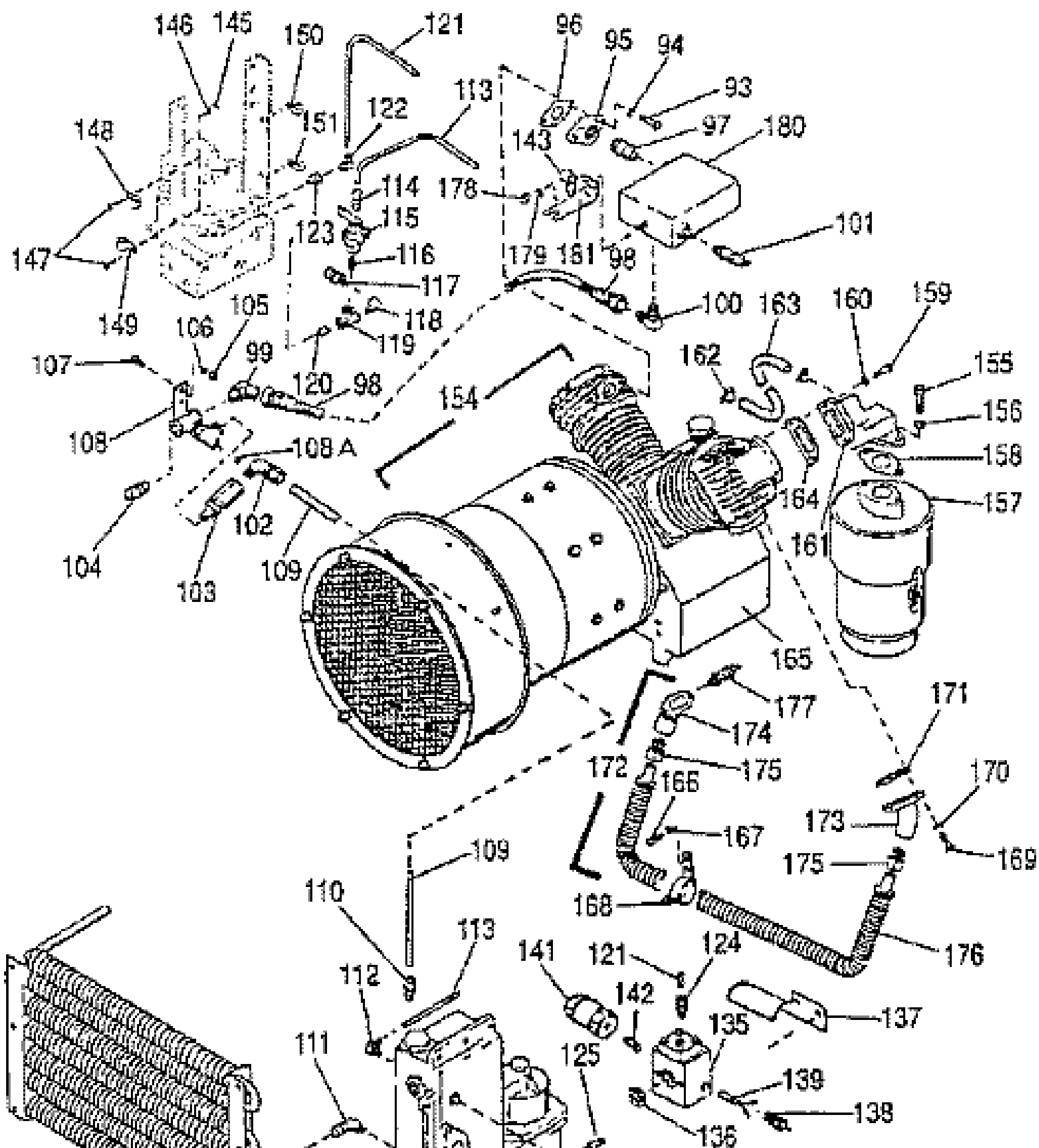
Presentation Principles for Graphics

- 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.



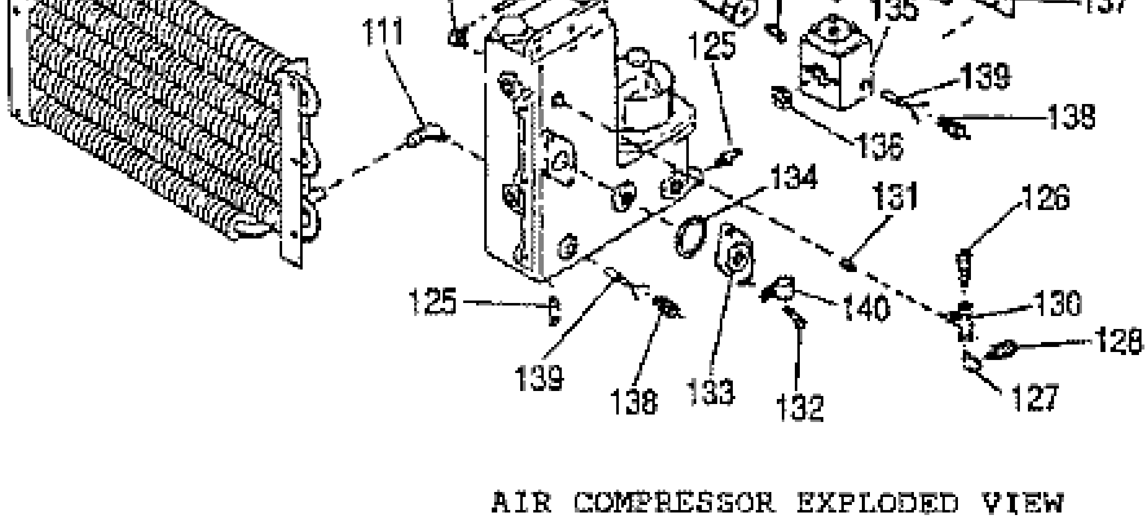


Figure 12

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."

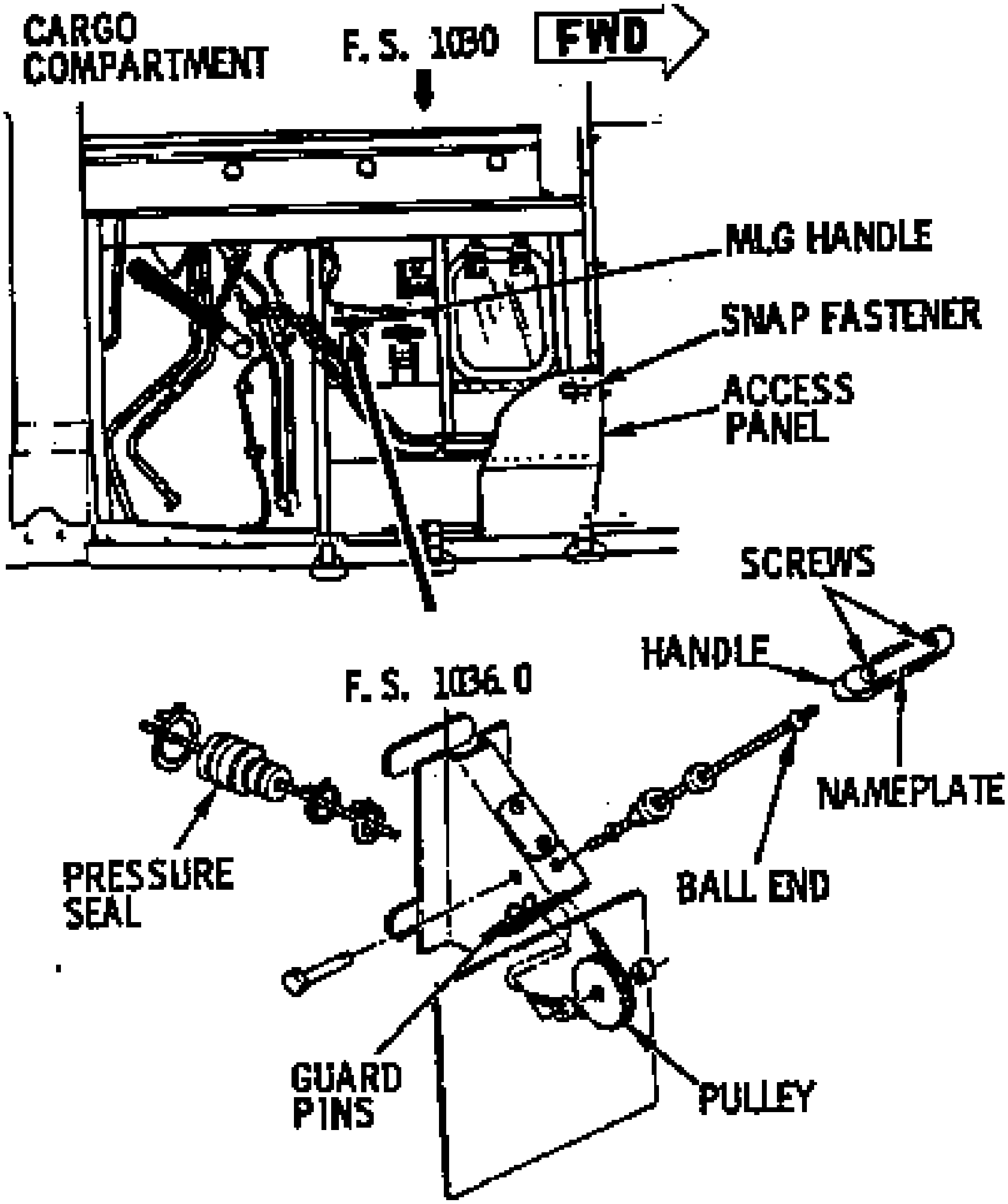

CARGO
COMPARTMENT
F. S. 1030
FWD
MLG HANDLE
SNAP FASTENER
ACCESS
PANEL
SCREWS
HANDLE
F. S. 1036.0
NAMEPLATE
PRESSURE
SEAL
BALL END
GUARD
PINS
PULLEY

Figure 13

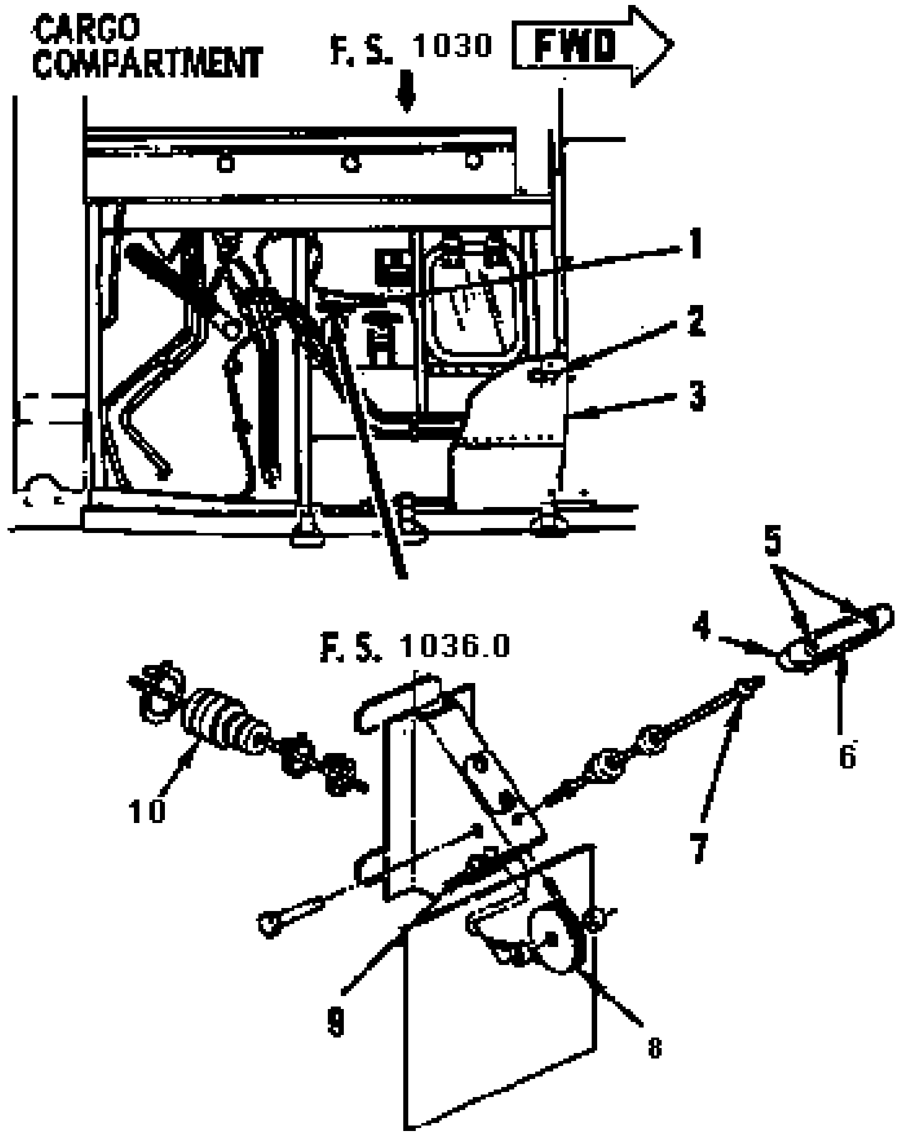


Figure 14

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.

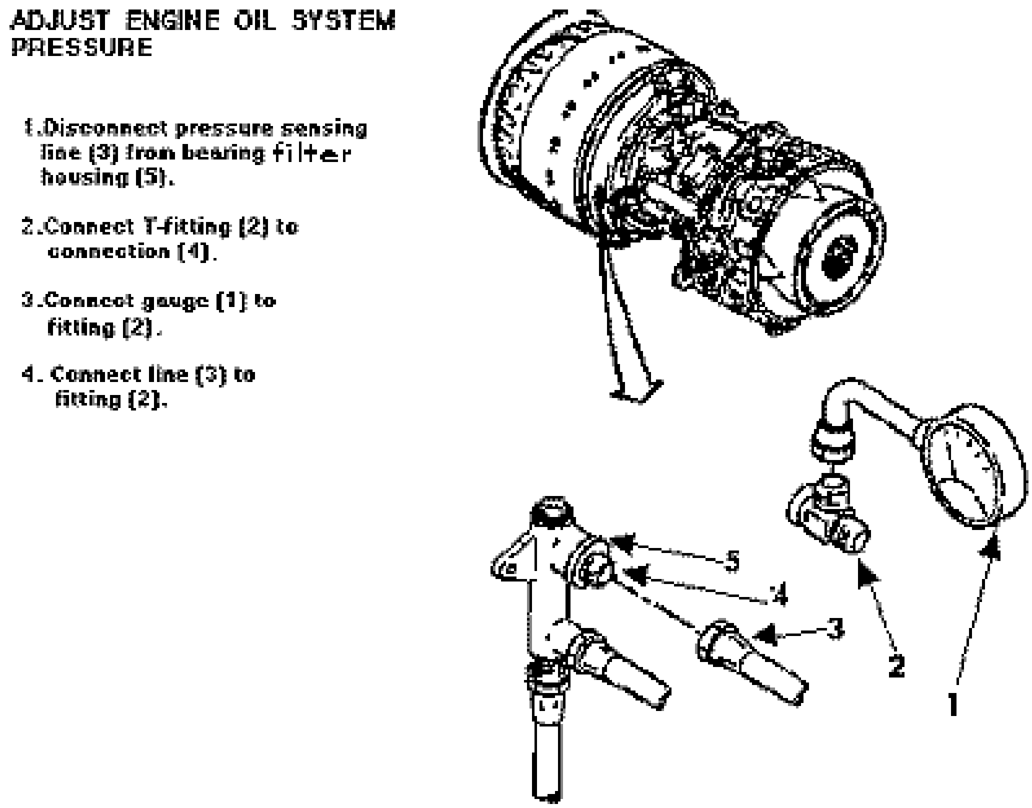


Figure 15

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.

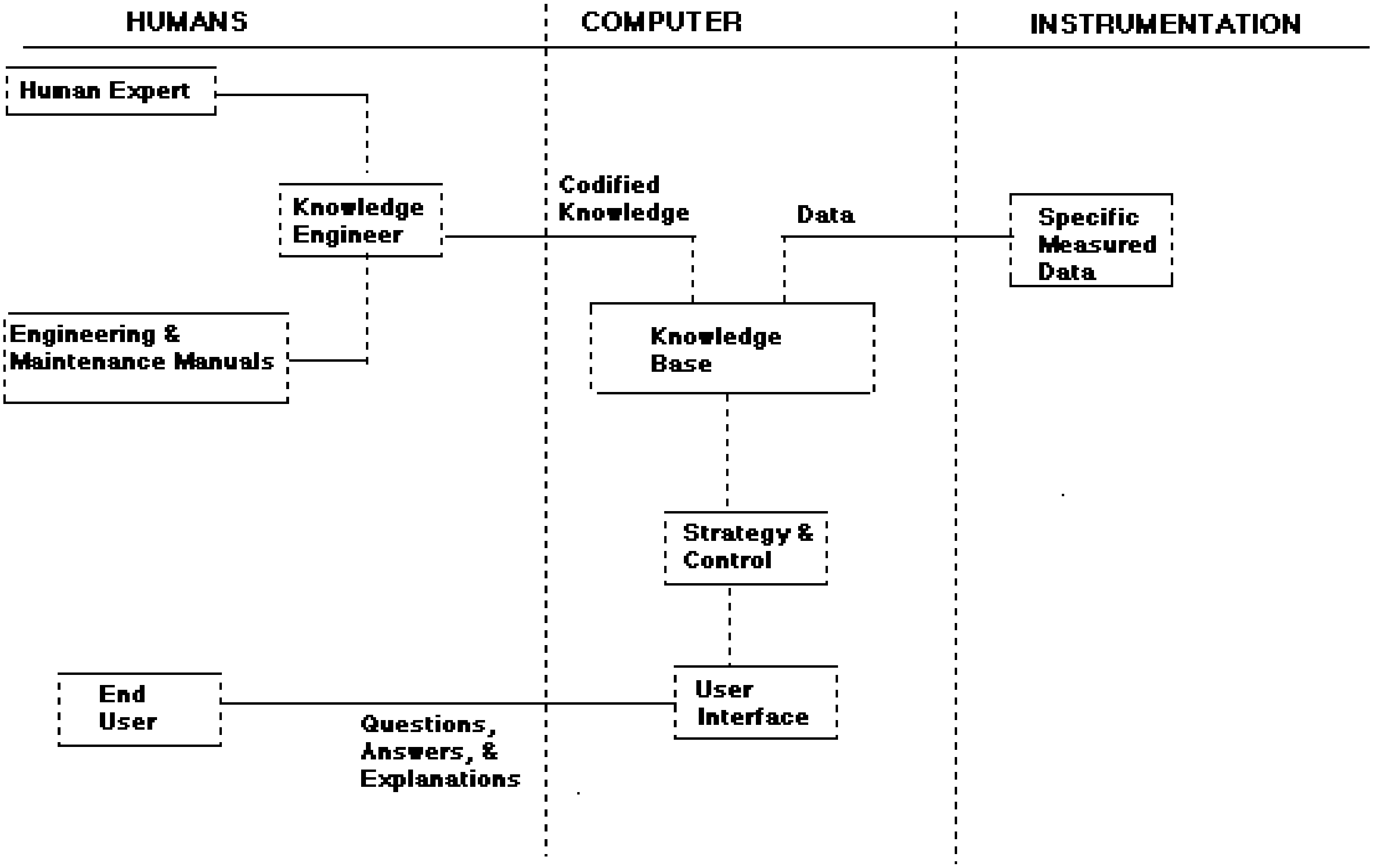


Figure 1 Expert Systems Model

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.