Appendix A: Meeting Presentations

CHANGING AIR CARRIER MAINTENANCE REQUIREMENTS

Joseph Vreeman
Air Transport Association

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

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

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

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

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

Our maintenance requirements are directly affected by our business position. Last year we lost $1.3 billion as an industry in the United States. In 1990, we lost even more. It was about $4 billion. We cannot continue to survive in a business, as usual posture. Midway, Eastern, Pan Am, and others have proved that won't work. We need to create a safer and a more productive aviation system. We need to focus on improved service with the aim of becoming competitive and staying in business. No longer can we depend on government regulations, treaties, or the like, to guarantee staying in business. Our industry is rapidly becoming global. Under these conditions, the way you stay in business is by providing a better service at a lower cost than the competition. The traveling public is our customer. They want better service. They want cheaper tickets. If they don't get that, they will go someplace else, maybe to another airline or maybe to high speed trains.

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

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

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

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

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

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

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

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

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

There is a never-ending search for improved safety. This is the focus of our efforts each year and we need to find some way to break through the plateau that we have established. There are many areas and different disciplines that need to be involved in making that happen. Suffice it to say, each year we at ATA take the time and trouble to list initiatives, this year 21 different initiatives, that we all agree would positively impact safety. The ATA initiatives list **--** our safety agenda **--** has been given to each of you.

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

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

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

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

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

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

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

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

Cost. Maintenance costs need to go down. We need to be spending less of our resources maintaining airplanes. We need to eliminate waste. Maintenance costs have increased from about $1.4 billion in 1970 to about $9 billion in 1990. This is a tremendous increase during twenty years, up 635 percent. A lot has happened in those twenty years -- deregulation, large number of airplanes, etc. Try to normalize that statistic. Look at available seat miles and look at available ton miles. The available ton miles has been increased by only 260 percent. Maintenance costs went up by a factor of six, and the amount of capacity that we had only increased by a factor of 2.5. Taking into account inflation, it doesn't look all that bad. Today we are paying 7.7¢ for available ton mile. In 1970, if we adjust for inflation, we were paying more. Then we were paying 10.5¢ for available ton mile. That trend needs to continue. To be successful, we need to provide a better product. We need to provide it at a lower cost. We need to stop the losses our industry has had over the last two years and make a reasonable return on our investment.

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

AIRCRAFT DESIGN FOR MAINTAINABILITY WITH FUTURE HUMAN MODELS

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

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

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

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

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

Human Models

There are five major types of human models:

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

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

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

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

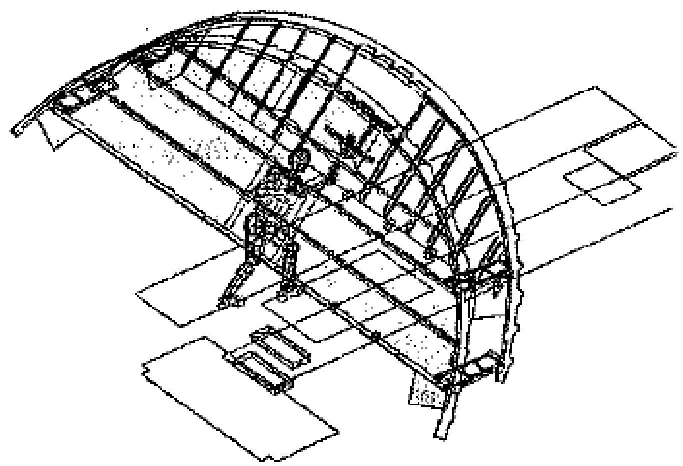
This matter of understanding the system is not as mysterious as it sounds. Think for a minute of how your refrigerator at home may work. In reflecting, you are relying on a mental model, an internal representation of your view of refrigerators. There are two temperature compartments in most refrigerators.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

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

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

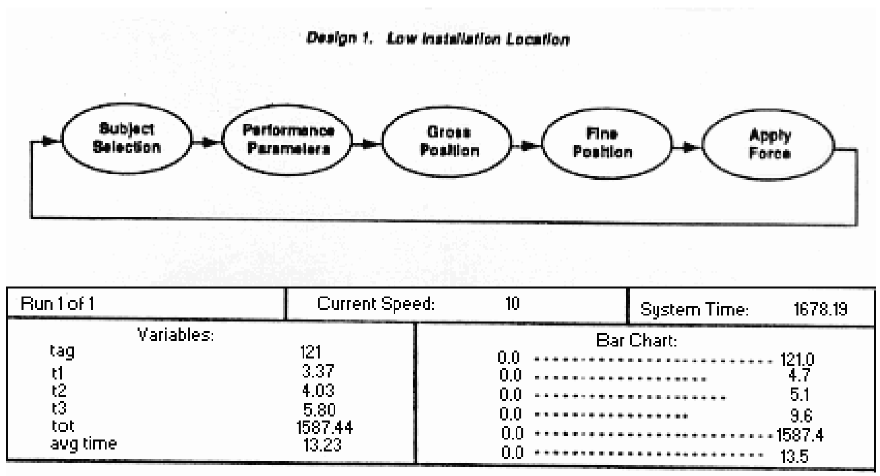
The final performance model type, knowledge based models, are related to expert systems and artificial intelligence. They are based on explanations on how people decide what is to be done and how they solve problems. Fault diagnosis for repair on aircraft can consume 60 percent of the aircraft repair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

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



Bulkheads in Assembly Jig

Figure 1



Simplified Micro SAINT Simulation Model of Elements in Hand Drilling Task, Design 1

Figure 2

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

- visual acuity - the effect of exposure time;
- tactile short-term memory;
- probability of correctly reading meters; and,

- characteristics of humans as decision makers.

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

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

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

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

The fool-proof design characteristic especially sounds unlike anything that would be derived from human performance literature: "Equipment items shall be designed so they cannot be mounted improperly." The objective of this statement is, of course, to prevent improper installation in the field or interchange of units that are not functionally interchangeable. However, apart from anecdotes of human errors, there is no set of data in the human performance literature that could be classified as "foolish," in the sense that by reading human performance data one would know how to design equipment to preclude its improper installation.

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

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

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

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

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

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

Use of Human Performance Models

<u>Figure 3</u> is a representation of how a work station with an embedded future human model might function. On the left is a box labeled "Examine Existing Information." On the right is a section labeled "Generate New Information." A graphics computer is used both to examine existing information and to generate new information. A personal computer is used to supplement the generation of new information in the workstation. In a workstation like this, users would be able to create structure files and port them to and from an electronic development fixture. Rather than a physical prototype, or a physical mockup, we would work with an electronic development fixture.

WORKSTATION FUNCTIONS FOR DFM ANALYSIS INDICATE HOW FUTURE MODELS COULD BE USED

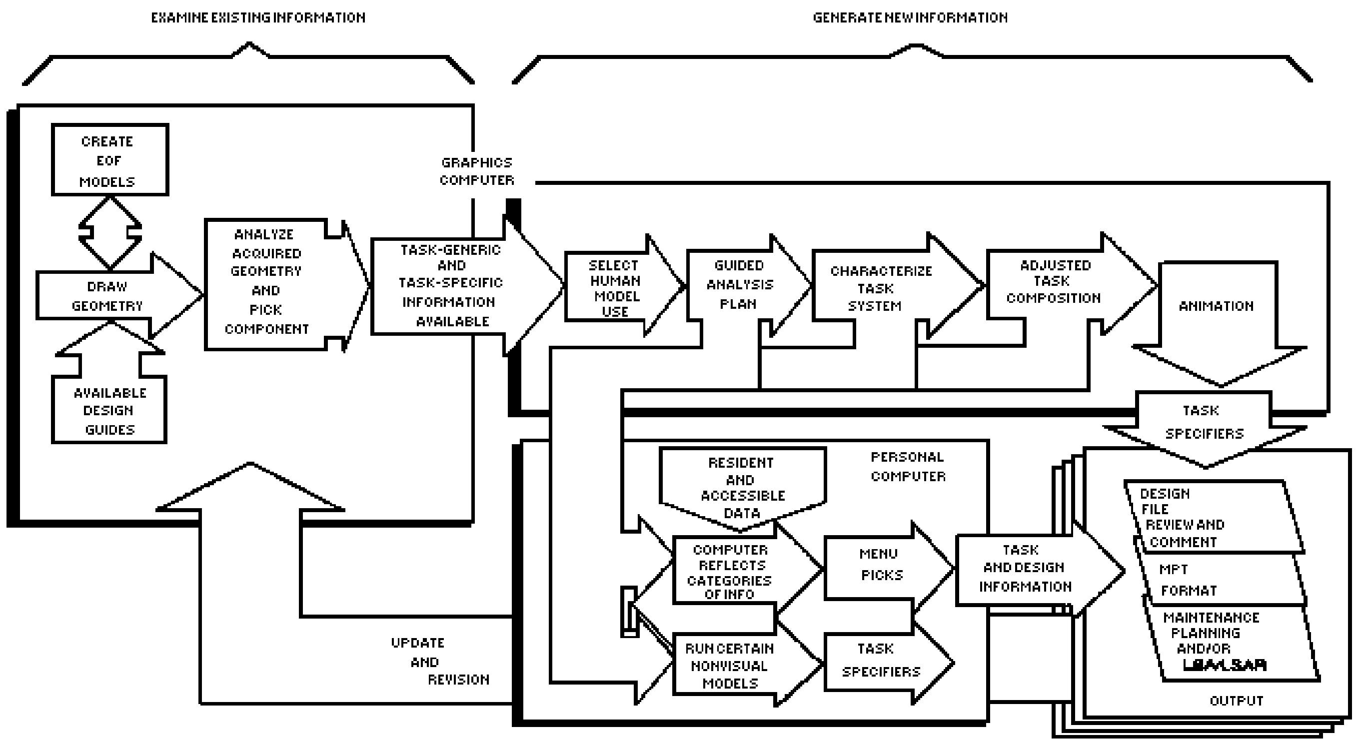


Figure 3

Characteristics of the workstation would include:

- Geometry manipulation;
- Design assistance;
- Component recognition;
- Maintenance task information;

- Evaluation of the design's human compatibility;
- Composition of maintenance task scenarios;
- Performance data bases and models; and,
- Logistics support information.

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

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

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

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

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

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

LOOKING TOWARD 2000: THE EVOLUTION OF HUMAN FACTORS IN MAINTENANCE

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

The Tools for Human Factors Application

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

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

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

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

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

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

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

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

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

Accident Investigations

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

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

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

The Regulatory Authorities

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

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

Airplane Design Considerations

We can also look at basic airplane design criteria to see the increasing emphasis put on human factors. A review of 727 and 777 design guidelines reveals significant improvement in the maintainability and human factors considerations from the 727 to the 777. The 727 design guide published in 1960 included only general considerations for ease of maintenance and accessibility for maintenance and inspection. For the 777, we have developed a dedicated maintenance design guide. It includes both general and specific design criteria gained from thirty years of experience since writing the 727 design guide. From both safety and economic perspectives, industry experience has promoted specific guidelines. For example, guidelines have been developed addressing the allocation of specific elapsed time to remove a line replaceable component. Other guidelines address the evaluation of maintenance access using anthropometric man models. And finally, there has been a move to build an engine magnetic chip detector that can perform for a sufficient amount of time with the O-ring missing.

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

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

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

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

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

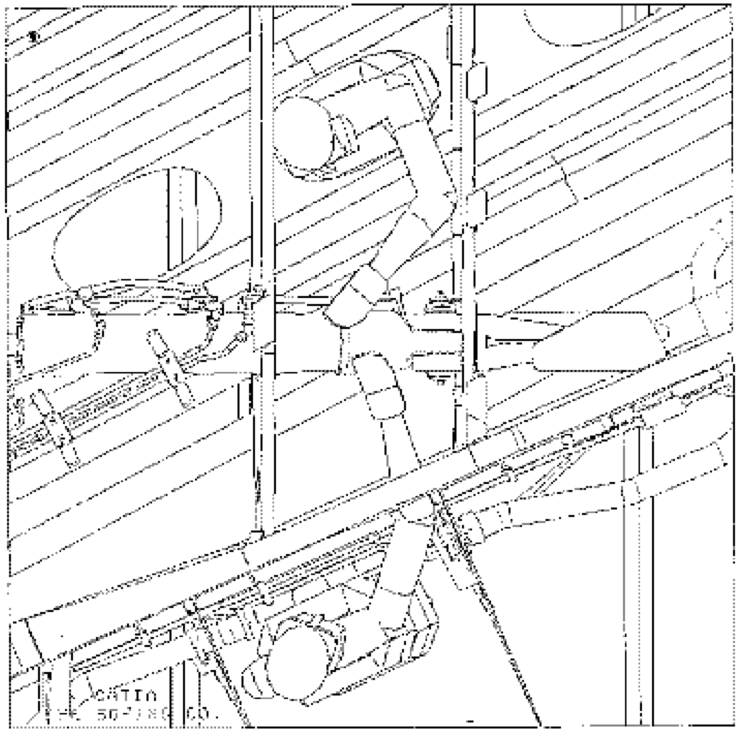


Figure 1 Use of Human Models to Evaluate Access to the 777 Wing Fold Actuator

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

Airline Operations

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

Looking Toward the Year 2000

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

Research. The use of lessons learned in basic human factors principles such as Murphy's Law are prevalent in the application of human factors to maintenance. However, the maintenance environment has not seen a significant research effort. This is necessary to understand those factors in maintenance most influenced by human performance. Circumstances are significantly changing, however. Research efforts have been identified and initiated through the National Plan for Human Factors Research and through the aging airplane initiatives. Accordingly, we will be better able to understand which factors in maintenance are most influenced by human error. We will learn what to do to reduce the recurrence or impact of human error.

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

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

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

HUMAN FACTORS CONSIDERATIONS OF THE 777 ON BOARD MAINTENANCE SYSTEM DESIGN

Jack Hessburg
777 Chief Mechanic, Customer Services
Boeing Commercial Airplane Group

Introduction

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

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

Airplane Description

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

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

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

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

The 777 On Board Maintenance System

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

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

The Problem with BITE (Built In Test Equipment)

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

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

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

Early BITE

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

The Digital World of Computers

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

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

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

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

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

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

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

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

Central BITE and the Message Explosion

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

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

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

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

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

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

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

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

Mechanics continue to distrust BITE. Their feelings are reinforced by this latest experience. BITE has struck a third time.

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

The 777 OMS Design Approach

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

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

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

We have defined a principal user and his requirements;

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

We have established a common user interface.

The OMS User and His Requirements

A lesson from the past is that as BITE capability grew many disciplines saw benefit. Consequently designers tried to satisfy everyone's needs; their own design needs, engineering at the airline and the manufacturer, hanger maintenance, bench mechanics and line mechanics, maintenance planners and statisticians. Now no device can be truly successful if it tries to be all things to all people.

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

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

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

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

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

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

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

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

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

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

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

> Optimize the mechanic's performance. Liberate the mechanic as much as possible from the burden of operating the computer;
>
> Design from the mechanic's perspective;
>
> Remember that these mechanics are not necessarily dedicated to working on the 777. They work several models of airplanes. Consequently, operation of the OMS should be intuitive;
>
> Understand that the OMS will be used by many nationalities. There are cultural and linguistic differences that may affect how a mechanic will use the device; and,
>
> Be consistent in the design. It should have a common look and feel.

Automation of the maintenance function shall be mechanic-centered. That is, the mechanic must be in control of the airplane and its systems, as well as the OMS. In a word, permit the mechanic to look at or do what he wants when he wants **--** not the way a computer programmer thinks it ought to be.

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

> Messages should not be generated or displayed unless they add value to the maintenance process;
>
> They should not be generated for systems that are inherently monitored.
>
> Don't use the computer to tell the mechanic that the airplane has a flat tire or that a light bulb in the galley is burned out;
>
> Tell the mechanic what he needs to know to restore airworthiness;

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

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

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

Represent the Mechanic in the Design

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

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

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

Common User Interface Document

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

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

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

Conclusion

In conclusion, we are using experience gained from the industry, as well as our own from past programs. We have better fault monitoring and fault consolidation to build a device that meets the specific needs of the mechanic. Our device will be a simple-to-use, simple-to-understand diagnostic tool that tells the truth without superfluous information.

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

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

TOMORROW'S PROBLEMS AS SEEN BY MAINTENANCE MANAGERS

Robert Lutzinger
United Airlines

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Training Requirements. We are conducting training on the visual side of inspection and on hands-on maintenance. We are experiencing increasing training costs to bring people up to speed to use the technical and complicated equipment now part of our daily activities.

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

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

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

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

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

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

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

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

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

PANEL DISCUSSION

Members
ATA Inspection Panel

ATA Inspection Panel members were introduced, including:

John Spiciarich, TWA;

Frank Sitterly, American Airlines;

Ray Chelberg, Northwest Airlines;

Steve Krause, Delta Air Lines; and,

Robert Lutzinger, United Airlines.

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

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

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

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

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

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

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

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

Some of you saw the recent California earthquake coverage on television. Simultaneous to the earthquake striking San Francisco, we had about 200 people signed on to report within two or three weeks. We lost about 60 percent of them by phone call following the earthquake.

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

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

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

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

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

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

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

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

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

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

Comment from the Floor (Question No. 6): I don't think there is anybody here who would argue that it's not appropriate to do some drug testing. We have gone through the testing now; as an industry we tested 0.4 percent positive. Well, that leaves 99.6 percent that were drug-free. That's pretty good. I'm proud of that from the industry's standpoint.

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

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

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

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

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

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

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

MAINTENANCE ADVANCES IN THE F-15 AIRCRAFT PROGRAM

Thomas Nondorf
McDonnell Aircraft Corporation

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

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

As we consider the F-15 and its maintenance, we should first review the U. S. Air Force maintenance structure. The Air Force has three levels of maintenance. The first level, Organizational Level (O-Level), would be analogous to your line maintenance. Once items are removed, if they can be repaired locally, they go to an Intermediate Level (I-Level), usually located on the base. In some cases, it is a consolidated facility that takes care of three or four Air Force bases (AFB). For items that require extensive repair above and beyond what the base can offer, repairs are made at the Depot Level. The Depots are Air Logistic Centers (ALC) through the United States. The prime Depot for the F-15 is Warner Robbins AFB in Georgia. San Antonio AFB does the engines and the secondary power systems. Hill AFB in Utah does the radar. Accordingly, the airplane gets dispersed throughout the continental United States to get fixed.

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

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

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

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

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

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

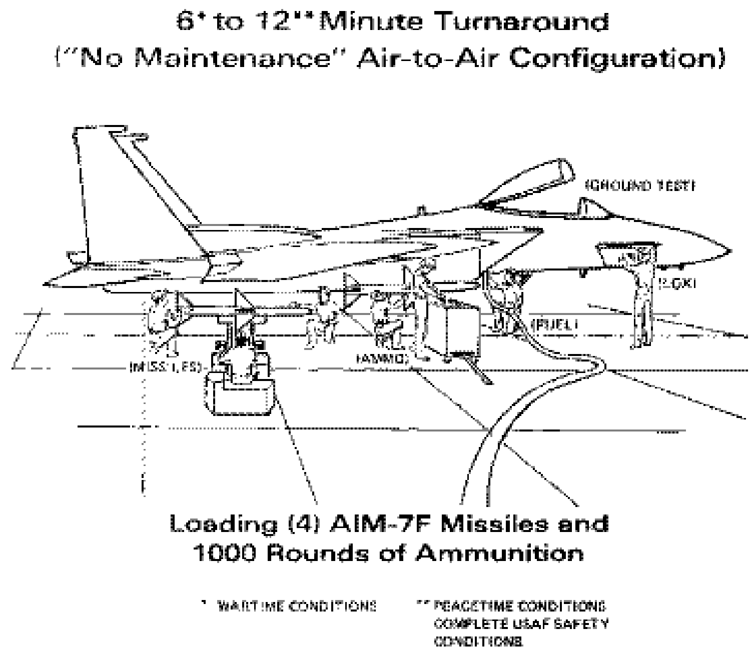


Figure 1

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

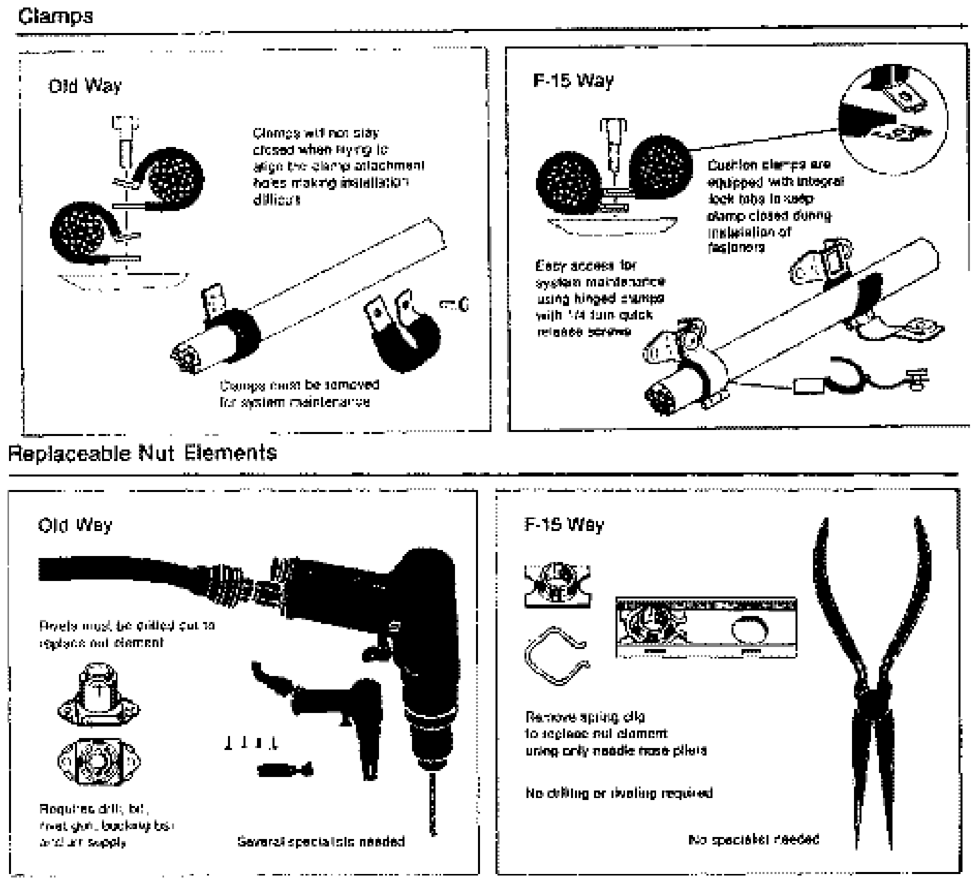


Figure 2

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

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

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

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

Built-in Test

- Avionics
- Flight Control Servos
- Fuel System Check Out Panel

- Anti-Skid
- Fuel Quantity Gaging System
- Environmental Control
- Fire Warning System

Failure Cues/Indicators

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

Sight Gages

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

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

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

F-15 Fault Isolation

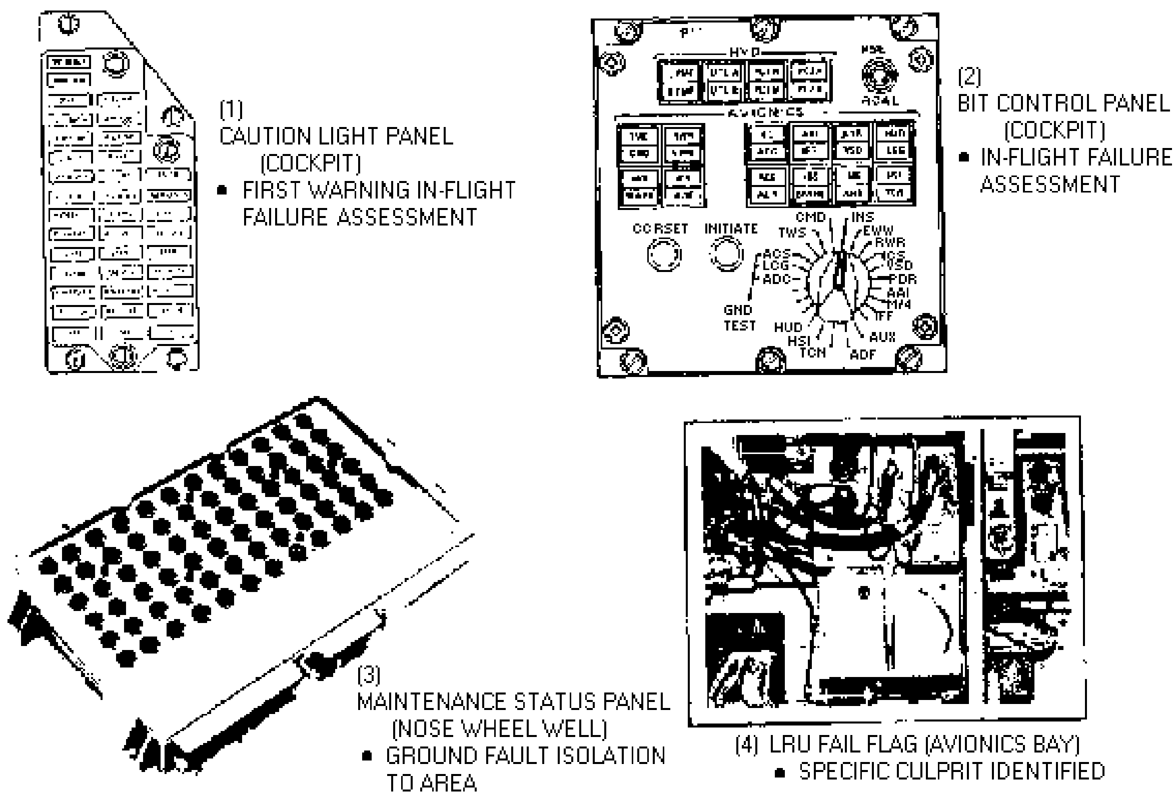


Figure 3

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

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

In terms of on-condition maintenance, we have:

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

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

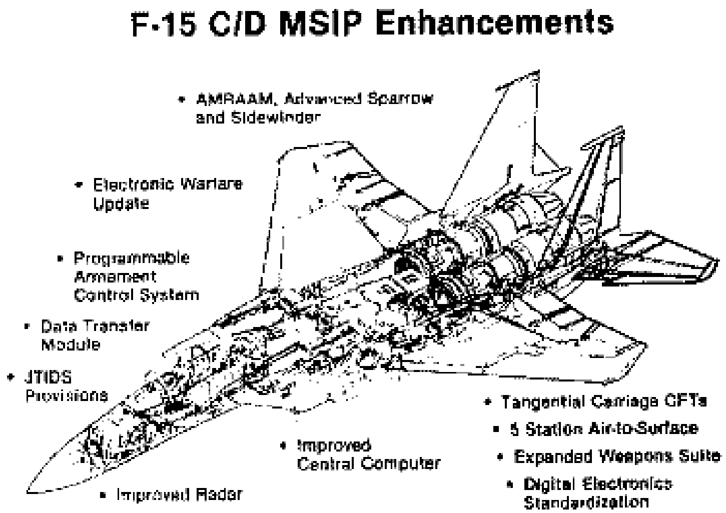


Figure 4

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

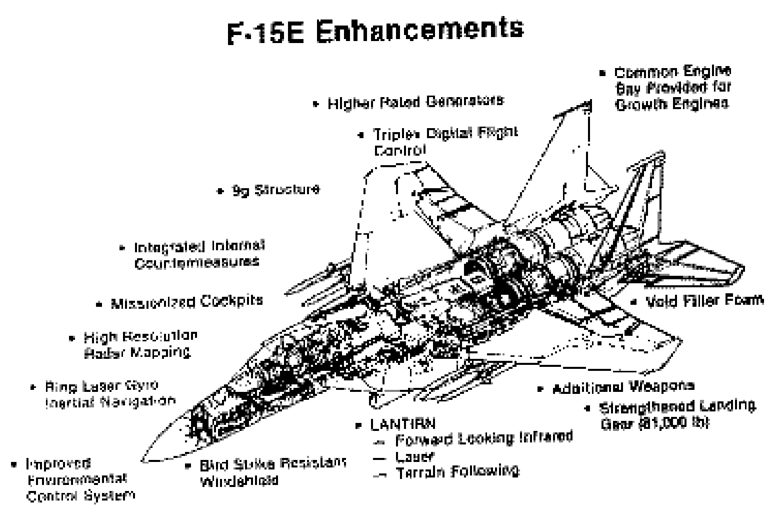


Figure 5

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

As part of this effort, summarized in Figure 6, we are reducing the Inertial Navigation Set in size and eliminating the depot maintenance repair requirements. We have improved the Mean Time Between Unscheduled Maintenance Actions (MTBUMA) from 140 to 500 hours.

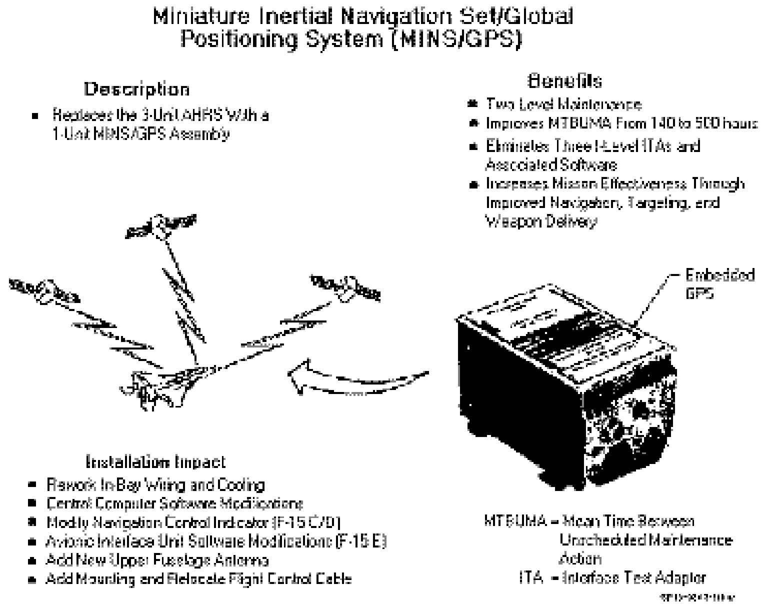


Figure 6

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

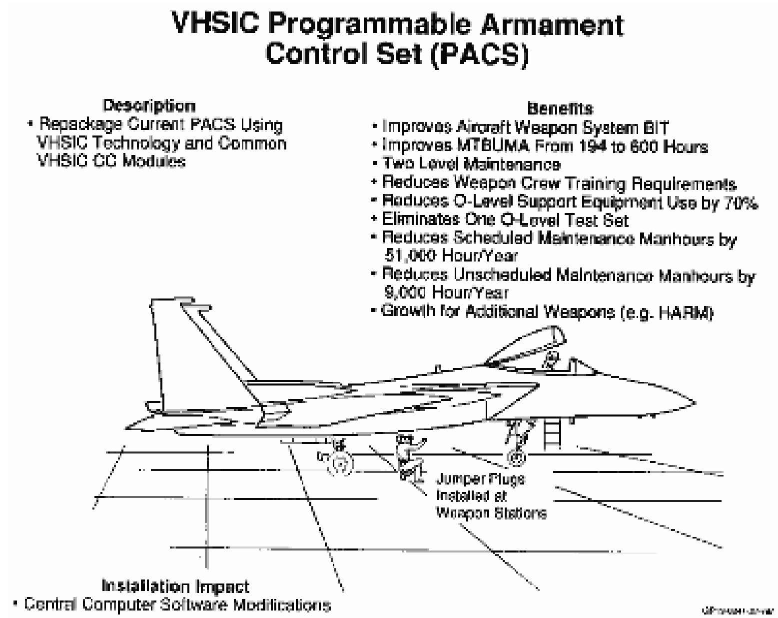


Figure 7

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

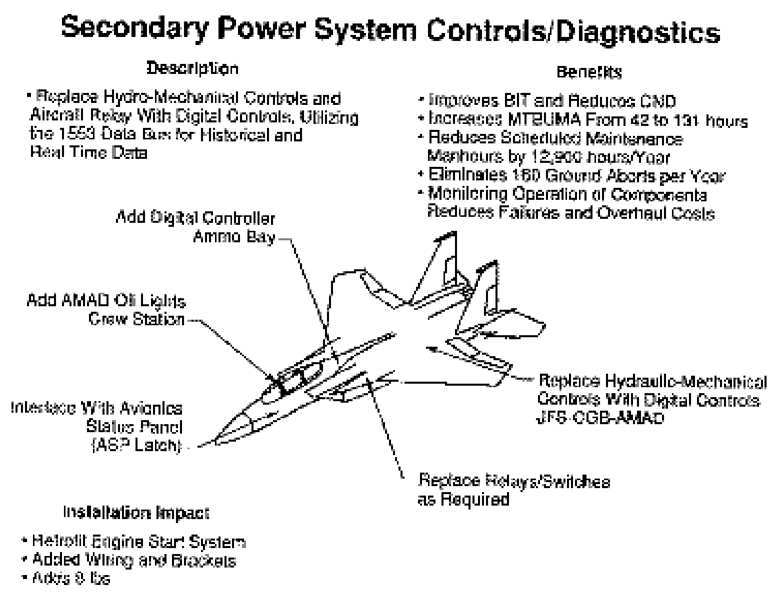


Figure 8

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

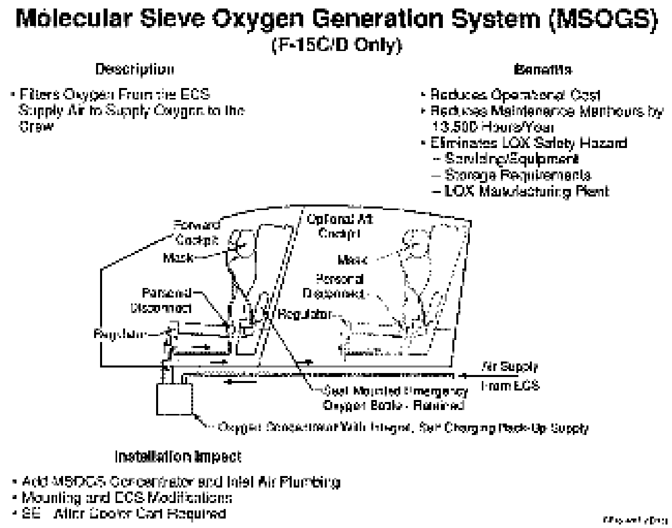


Figure 9

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

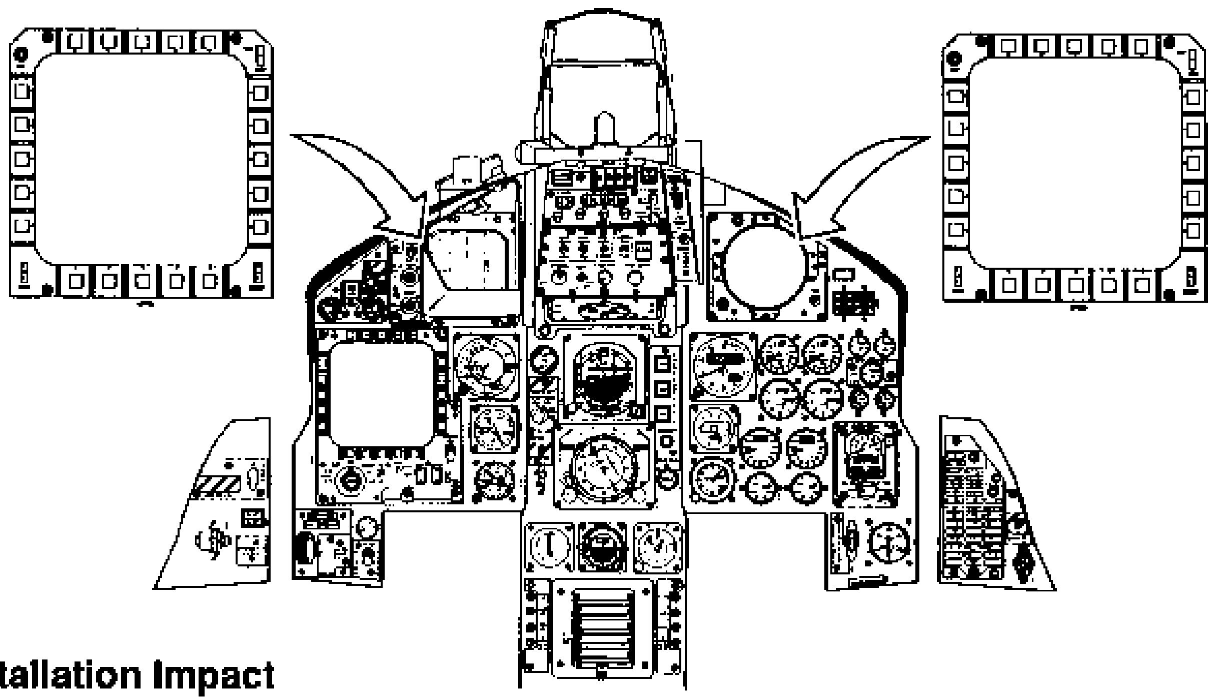
F-15C/D Cockpit Upgrade

Description

• Replace ANMI and TEWS Displays With F-15E MPDs

Benefits

• Common Components With F-15E
• Reduces Parts Obsolescence Problems
• Larger Displays for Increased Situation Awareness and Reduced Pilot Workload
• Reduces Maintenance Manhours by 3,800 Hours/Year



Installation Impact

• Replace Display Processor With Modified F-15E Processor
• Replace Main Instrument Panels
• Modify Central Computer Software
• Rework Wiring, Cooling and Mounting

• All Redesigns to Accommodate MPDs Require the Following F-15E Solutions to Avoid Over Nose Vision Loss and Ejection Envelope Encroachment
  – Replace Engine Instruments With EMD
  – Remove ADI and HSI. Add AIU for EADI and EHSI.

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Figure 10

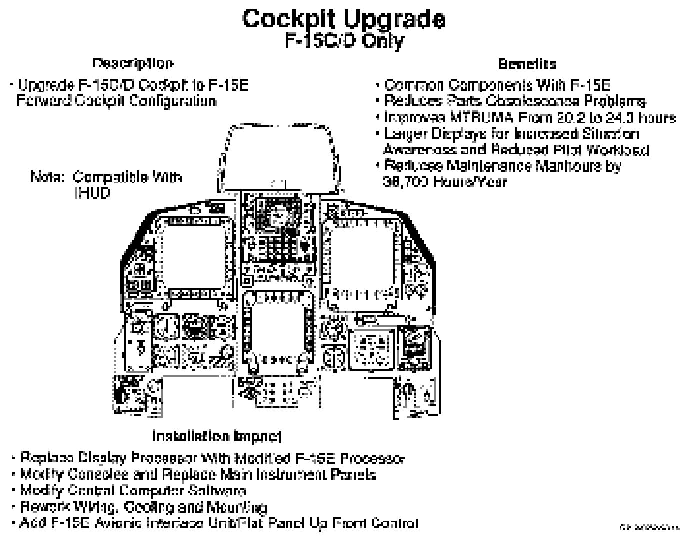

Figure 11

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

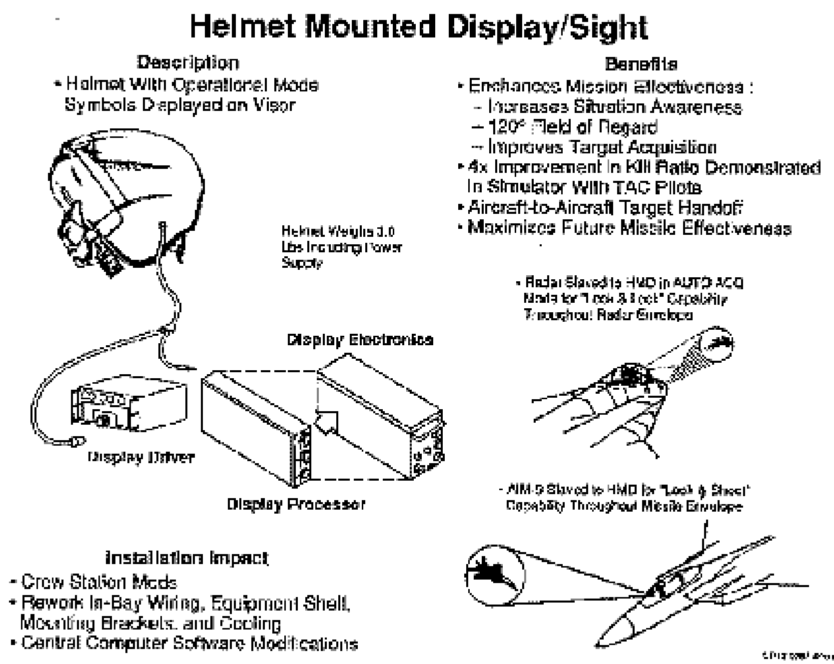

Figure 12

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

- Provides more two level maintenance;

- Reduces support equipment;
- Reduces maintenance manpower;
- Improves logistics;
- Improves deployability; and,
- Increases mission readiness.

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

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

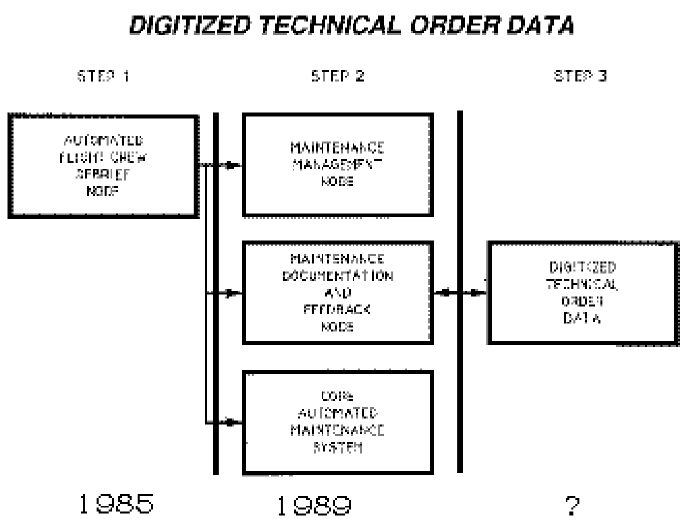

Figure 13

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

Consider:

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

Goal:

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

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

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

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

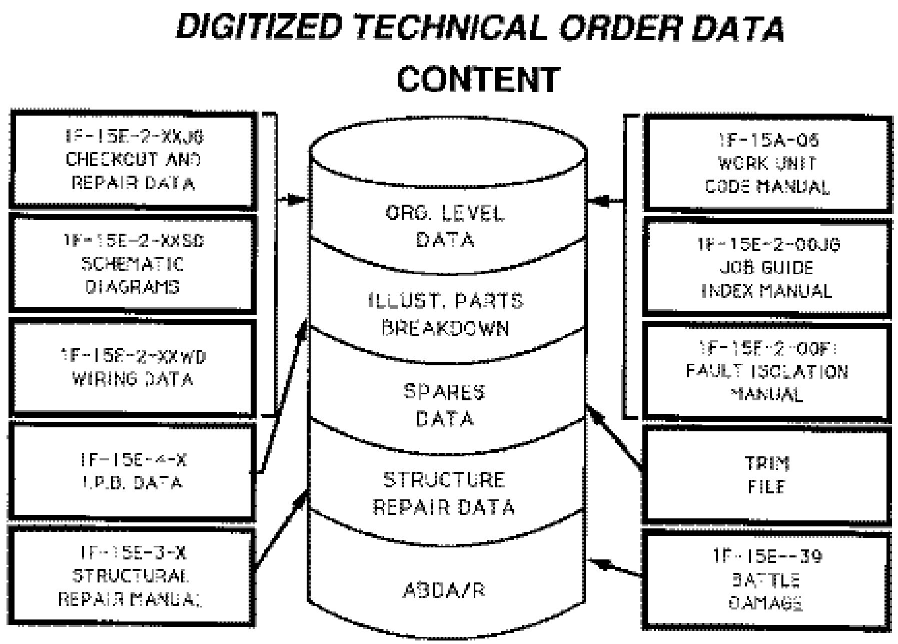

Figure 14

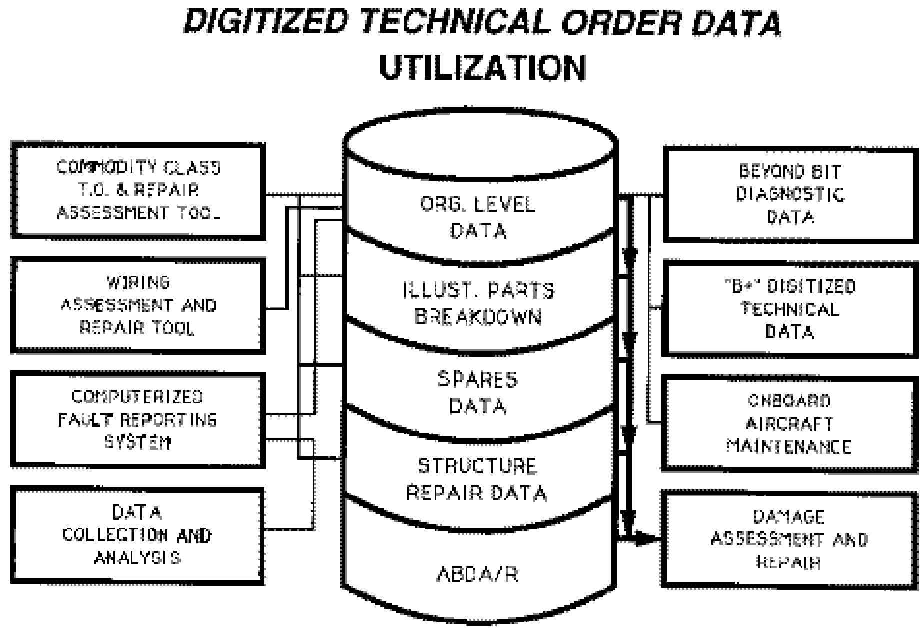

Figure 15

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

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

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

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

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

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

INFORMATION MANAGEMENT "LIKE NEVER BEFORE"

Paul Singleton
IdentiTech, Inc.

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

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

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

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

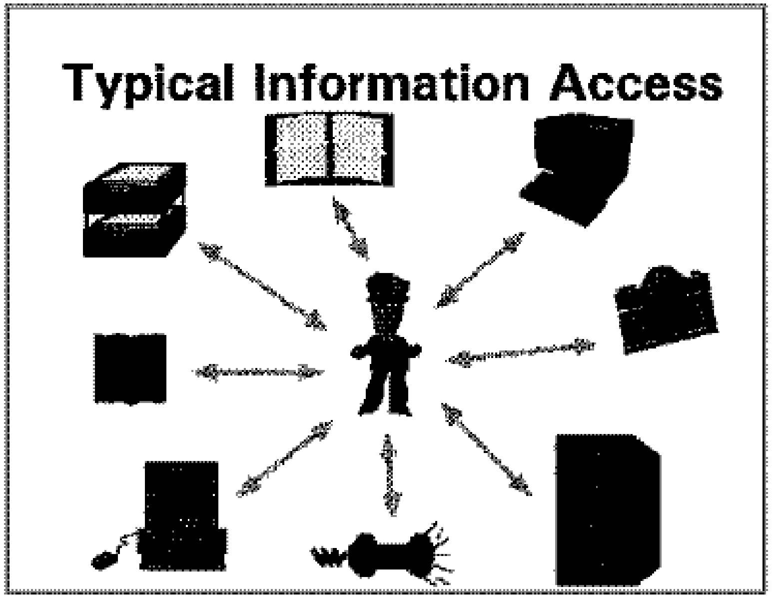

Figure 1

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

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

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

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

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

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

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

Any information you want will be accessible.

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

- Not designed by hardware vendor to help sell more hardware.

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

The first design element that everybody wanted was open architecture.

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

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

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

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

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

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

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

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

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

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

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

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

An example of an audit trail application of IdentiTech's package is at the Johnson Space Center in support of the automated briefing system for the Orbiter Project. All data entities are submitted as objects into the system and pulled together as a folder. Design engineers can go in and make multiple modifications at one specific object in that folder. When they are done, the System Administrator says when it is ready for release. He pulls all the latest versions and automatically moves them across the link from Downey, CA, to Houston, TX. NASA gets an E-mail message that tells them they have a briefing. The NASA Administrator pulls up the briefing and approves it. He then would send it to responsible design engineers and other people in the review and approval loops. Reviewers can make their red-lines using the original data elements, CAD drawings or whatever method appropriate. Upon receipt and approval of coordinated review comments and incorporation into a master update, the revised master can be distributed to all parties concerned.

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

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

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

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

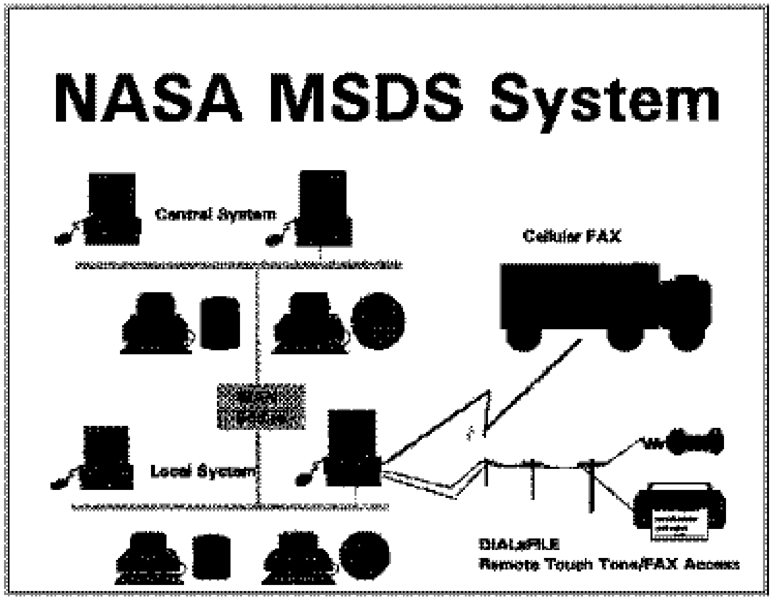

Figure 2

Our system has no limitation on the number of work stations that can attach to the servers. For example, the NASA Johnson Space Center (JSC) site will have at least 3000 nodes that can access information across a large WAN. Therefore, anyone on the network can access the information throughout the data base. They can retrieve any files they need.

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

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

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

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

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

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

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

THE MANNEQUIN COMPUTER PROGRAM

David Rome
Humancad

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

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

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

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

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

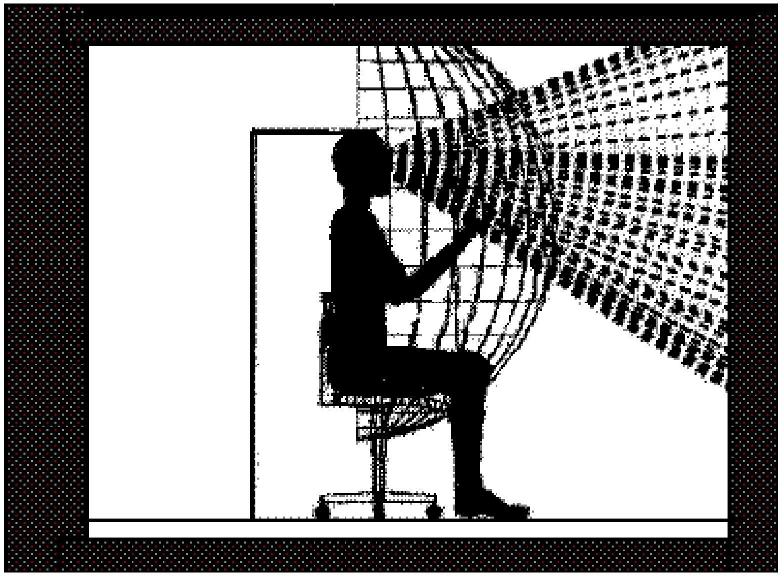

Figure 1

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

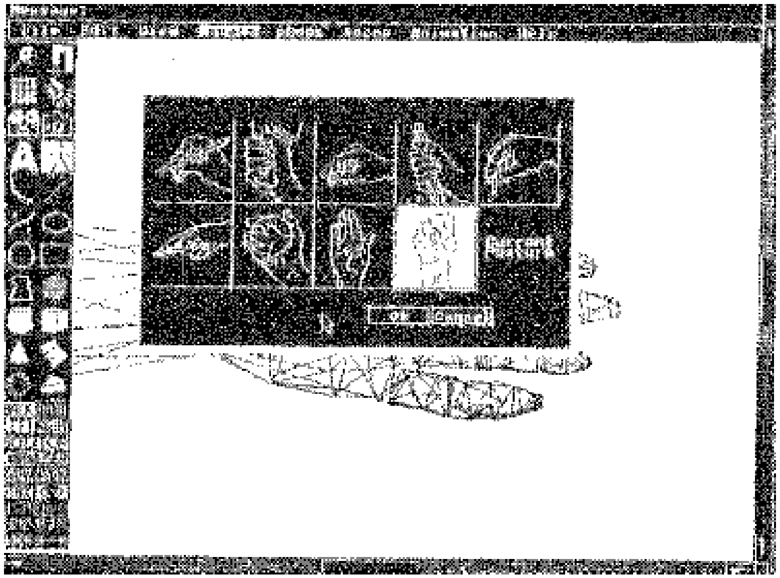

Figure 2

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

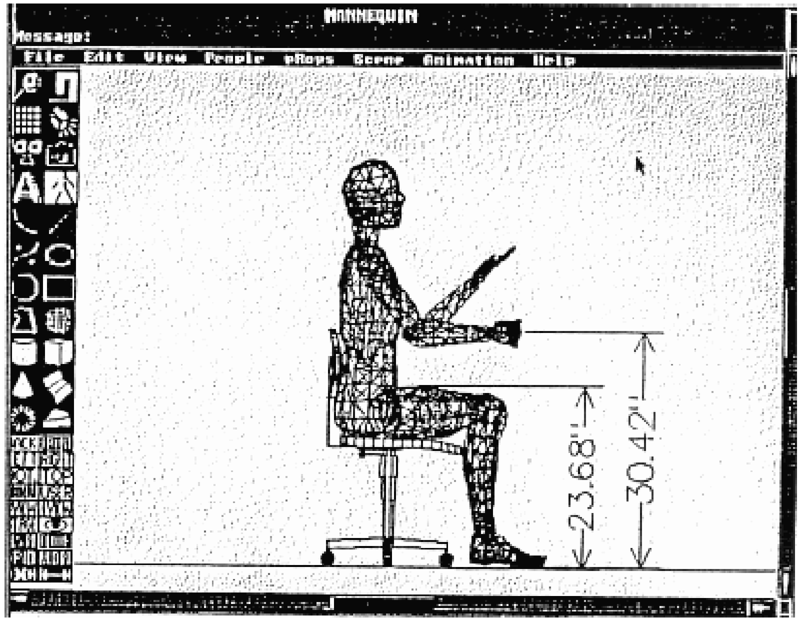

Figure 3

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

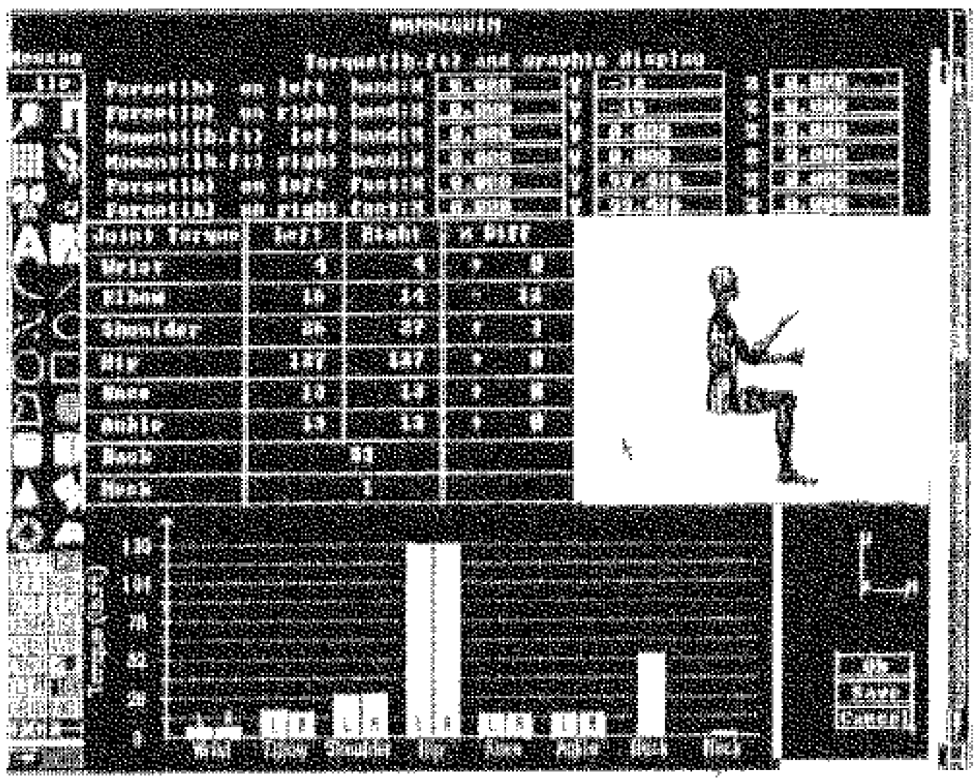

Figure 4

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

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

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

Grasp.

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

PC Paintbrush.

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

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

ADVANCES IN ARTIFICIAL INTELLIGENCE FOR AIRCRAFT MAINTENANCE

Mark Husni
Naval Air Warfare Center

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

Artificial Intelligence

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

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

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

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

Expert Systems

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

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

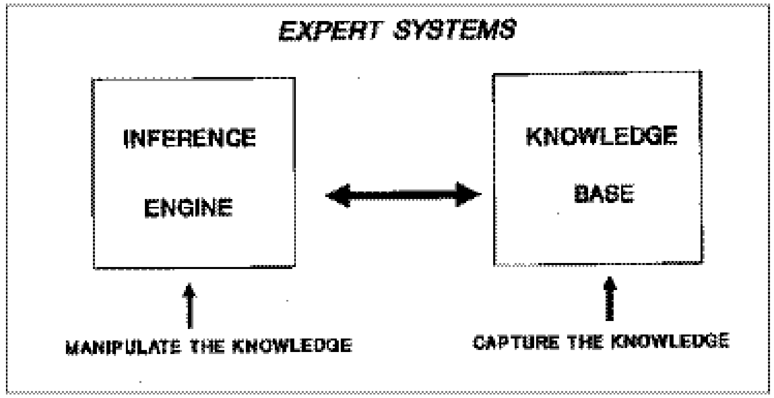

Figure 1

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

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

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

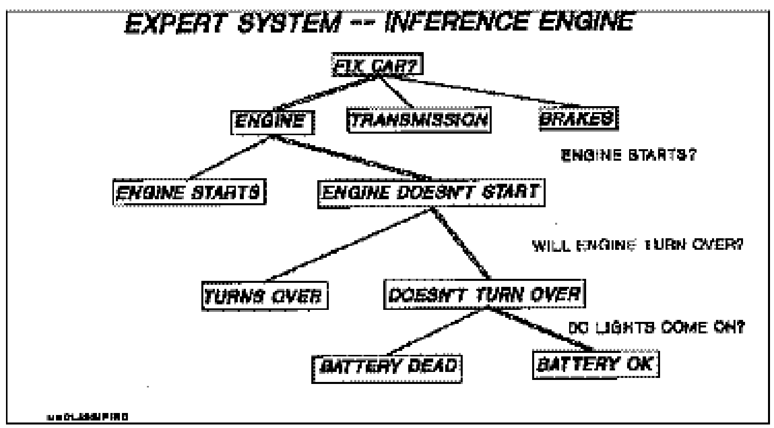

Figure 2

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

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

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

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

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

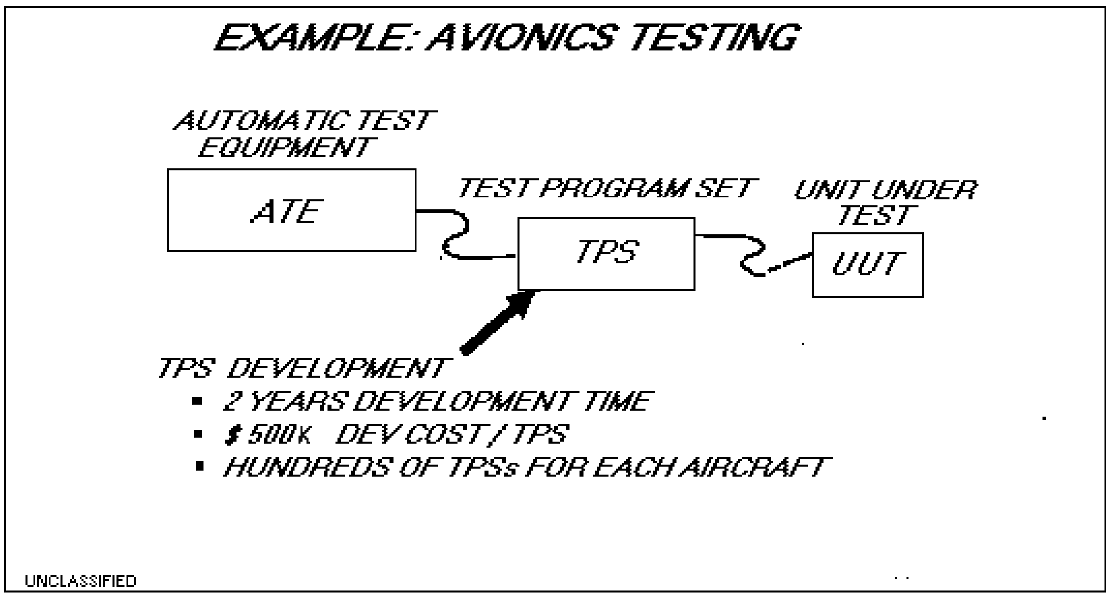

Figure 3

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

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

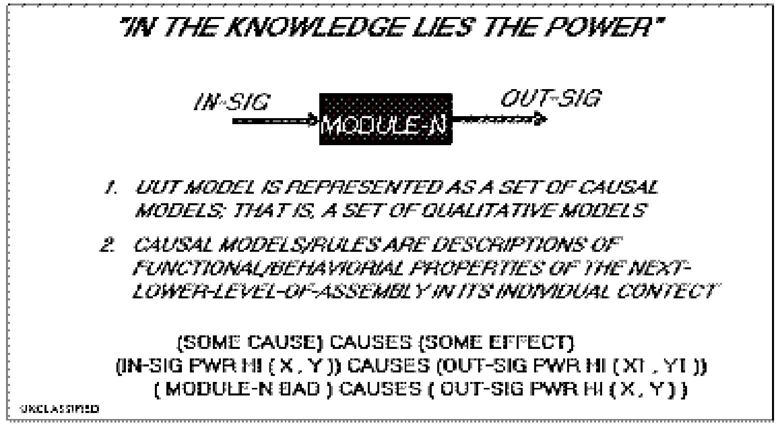

Figure 4

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

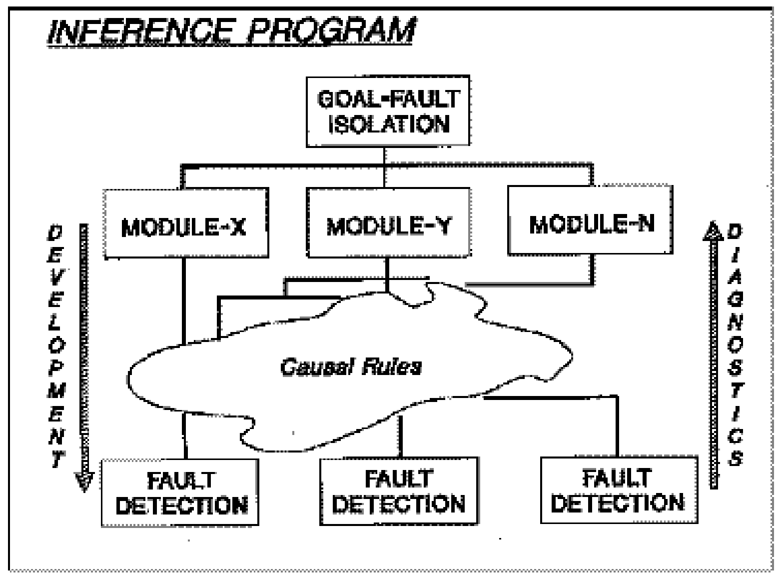

Figure 5

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

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

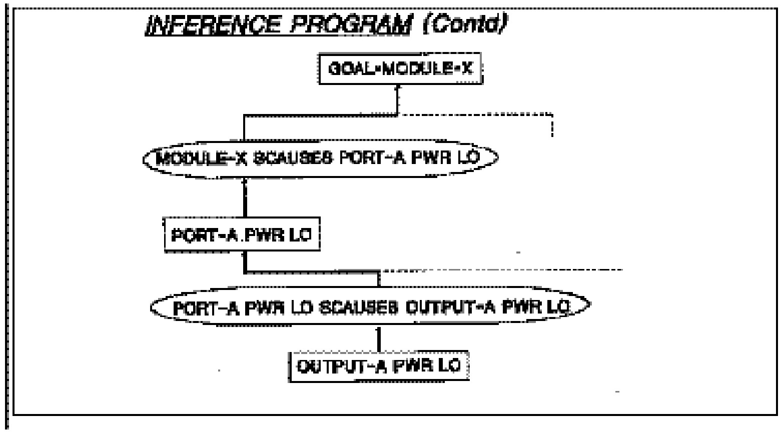

Figure 6

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

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

Back in the late 70's and early 80's, teams of psychologists and computer scientists attempted to develop a new paradigm. This model would be based on the neuron structure of the brain. By creating an artificial neuron and layering it, they found that they were able to adjust the weights. Figure 7 and Figure 8 provide a very crude model of a neural network and the basic theory behind it, respectively.

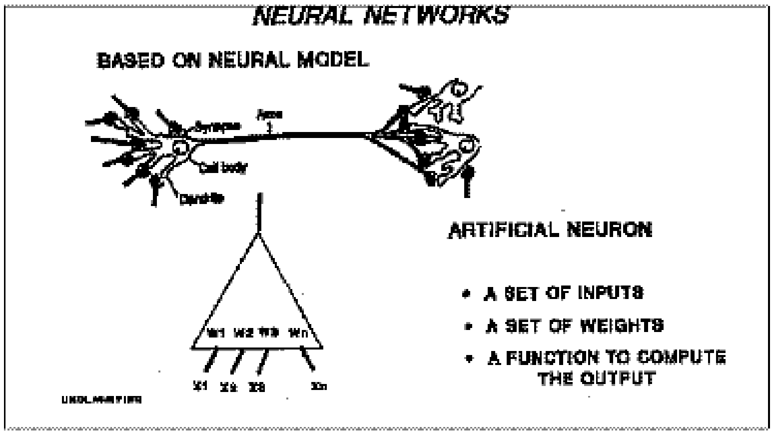

Figure 7

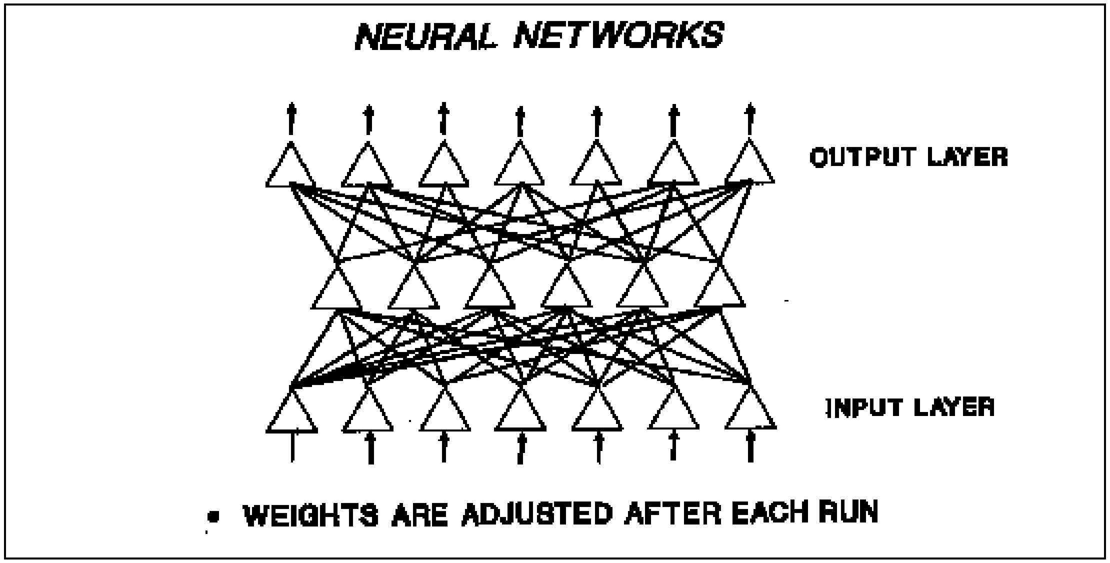

Figure 8

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

D

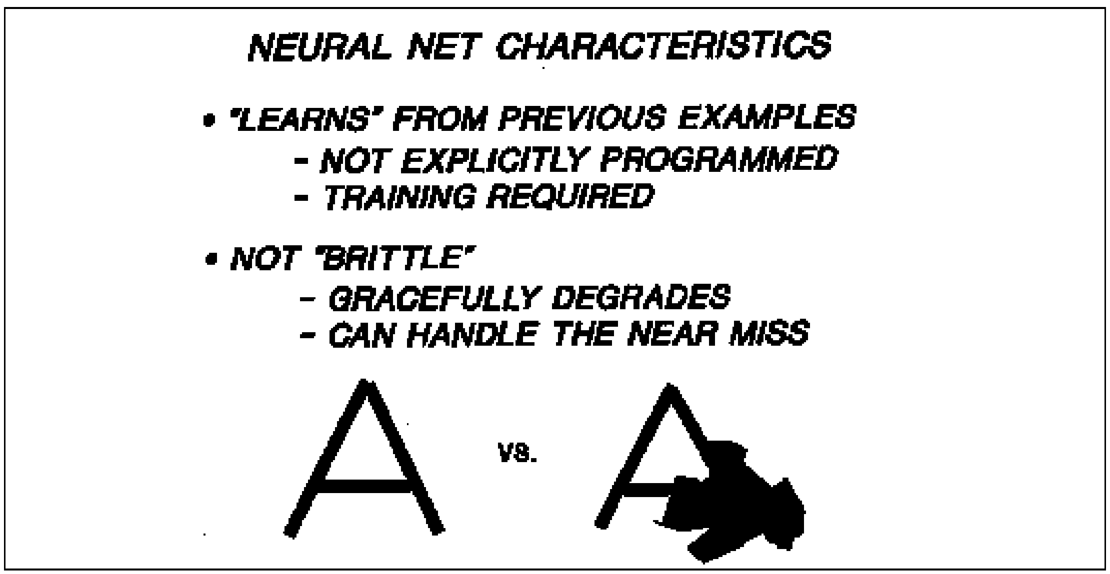

Figure 9

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

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

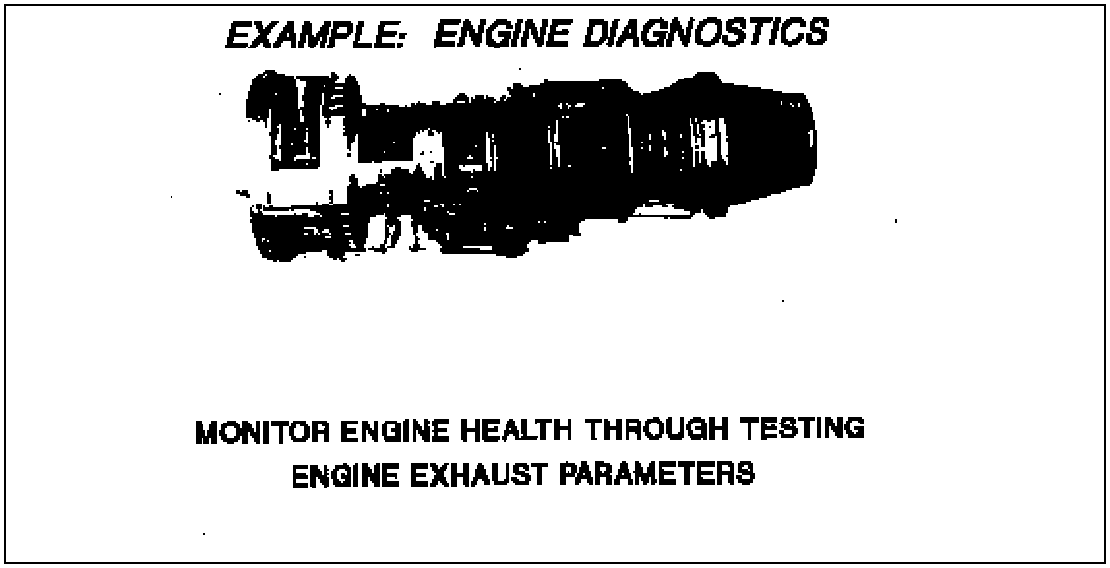

Figure 10

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

The key to this neural net application is the sensors:

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

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

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

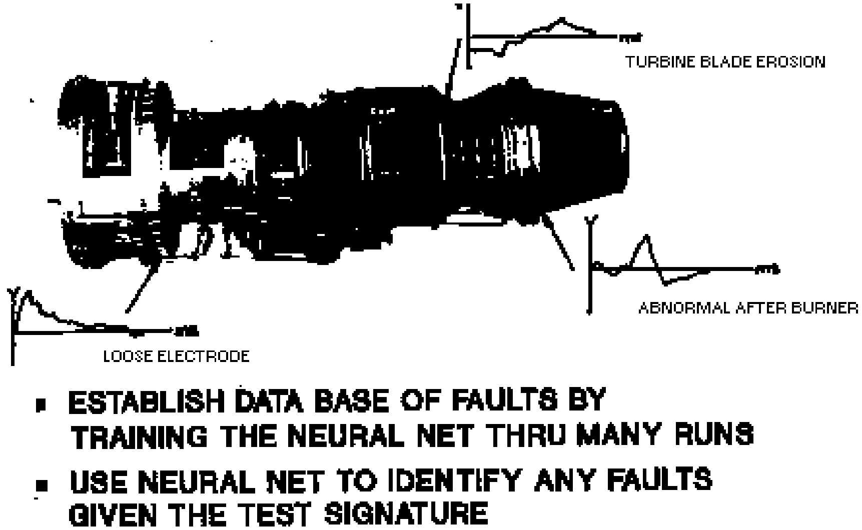

Figure 11

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

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

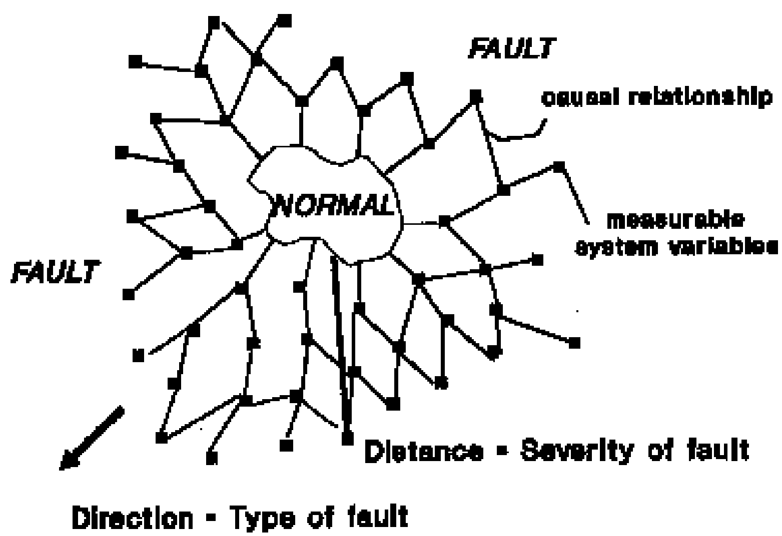

Figure 12

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

- Forecast future states
- Estimate failure-free operating time

- Given "symptoms," get a diagnosis
- Given a diagnosis, get "symptoms"
- Produce cost savings

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