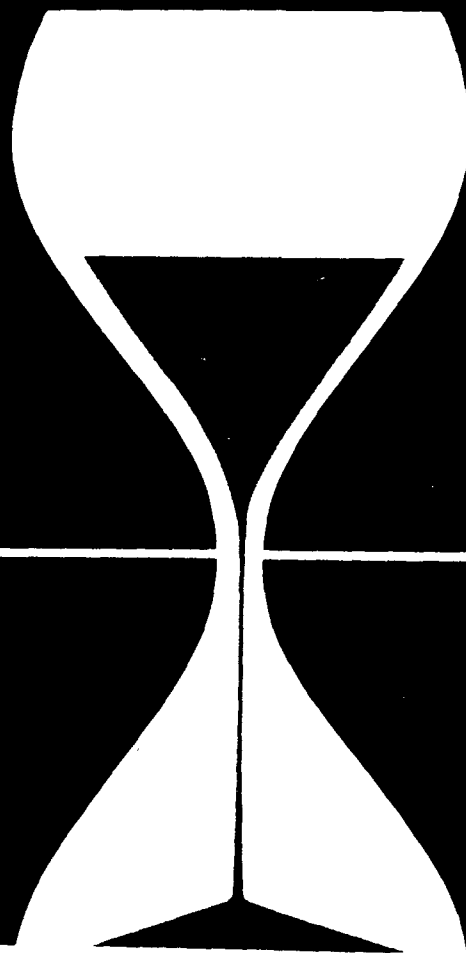


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Aging Aircraft

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EDITORIAL NOTE

The majority of the papers presented in this proceeding were transcribed from audio tapes recorded during the conference. An attempt has been made to retain the sense of a conversational tone. In this type of presentation there tends to be a duplication in text and illustrations. To correct for this feature, the editors deleted some illustrations that were better discussed in the text. Conversely, certain textual changes were made in these instances where the use of the illustration itself was more appropriate.

Artwork used in this proceeding is the best available. In several instances, the original photographs or slides were not available or were of such a quality that they could not be used. In these cases the text was edited to compensate.

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Introductory Remarks



THOMAS E. MCSWEENY, Conference Chairman

Deputy Director, Aircraft Certification Service, FAA

I want to welcome you all to the 2nd Annual International Conference on Aging Airplanes. Many of you I'm sure were at last year's conference. It was intended to be a general information meeting where all in attendance could share their experiences and give their views on the aging airplane issue and also what they thought were some of the solutions at the time.

We had many views, some consensus on the part of those present, and we summarized all the material in the proceedings which we've made available through the National Technical Information Service in Springfield, Virginia, if anybody wants to obtain a copy.

Last year at this time the FAA and industry were trying to scope the problem, identify some short- and long-term solutions, and get

on with the business of ensuring a safe transportation system as the fleet ages.

Much has been done since the last conference. In this conference we'll summarize the work accomplished or the work underway. Over the last year the FAA and industry have seen many examples of aging airplanes, airplanes that were not properly maintained, and improper repairs that have compromised the structural integrity of the airplane's structure.

We all need to look at the operations within our countries and within our airlines to ensure we do not have any problems in our fleets like those shown.

With that short introduction, I would like to now introduce Mr. Del Balzo. He is the FAA's Executive Director for System Development.

Welcome to Attendees



JOSEPH M. DEL BALZO

Executive Director for System Development, FAA

I will start by telling you that Administrator Busey is unable to be with us this morning. He has another commitment. He's asked me to extend his greetings to all of you, as well as his regrets that he could not be here to attend this very important conference.

I will also tell you that he believes that the subject of aging aircraft is extremely important. What I have heard him talk about so many times is how important it is for us to plan for the long term. The development and application of new technologies is one way. Getting more mileage out of the existing fleet is another way to achieve that goal. Improved maintenance technology, better quality control and highly trained inspectors are more keys to keeping older aircraft aloft.

I couldn't help but be struck by the pictures that Tom showed in the beginning. Not too long ago we would not have had the courage to come together to talk about an aging aircraft problem. We certainly wouldn't have had the courage to do it out in the open.

Certainly the world has changed. We came together last year for our first conference, and as Tom McSweeney said, it was more to ex-

change views, exchange information and to form a program to solve a problem. We didn't do it to point fingers, and we continue that approach today. The world has really changed.

I don't know your views, but most of you, I suspect, were at last year's conference. I think it was a success. I think a lot of good things happened as a result of that conference. An industry task force was initiated in August of 1988. An FAA program review research initiation was conducted in October, 1988 and the Aviation Safety Research Act was passed in November. An Industry Research and Development Task Force unit was formed in March of 1989 and an FAA Aging Aircraft Research Program Plan was completed in May of this year. In a lot of areas, research has already begun.

We come to this second annual conference with a different agenda. We come with several objectives. The first is to review the agency's role in maintaining the high level of aviation safety, especially in regard to aging transport aircraft, those aircraft operating beyond the original economic design life approved by the FAA.

Joseph M. Del Balzo

A second objective is to discuss the progress that we in the industry have made in resolving the problems associated with these older aircraft that were first discussed at last year's conference.

Finally, we are here to listen to what the international aviation community thinks, and has done, about older aircraft since last year's conference, and to hear its opinions about FAA's national aging aircraft program. What are we doing right? What have we done wrong? What should we be doing more of? What changes should we make?

I think it goes without saying — and I speak for FAA Administrator Busey, and Secretary of Transportation Skinner as well — that we are here this week to listen. What we did last year was good and we'll do it again this year. We not only welcome all the inputs we will receive this week; we consider them the most important benefit that we will get from this conference, a series that will and must continue.

I am reminded of what the manager, in the baseball movie "Bull Durham," said after he lost the game. "Sometimes you win, sometimes you lose, sometimes you get rained out." If I were to add another comment, it would be, "But in no case do you ever give up the quest." That's why we are here. We will not give up the quest to solve the problem of aging aircraft, until it is truly solved.

The history of air transportation in the United States during the last decade is a good news/bad news story. The good news is that the demand and traffic has grown at an unparalleled rate; and to meet the demands, the airlines have used their transport fleets beyond the aircraft's original economic design life.

The bad news is that we are seeing problems not encountered before. These are the problems of aging: stress, corrosion, high-cycle failure, low-cycle fatigue, and their effects individually and together on the safe operations of transport aircraft.

Another major contributor to the good news/bad news story is technology itself. Over the past decade, technology has provided the aviation industry with a host of advanced materials, manufacturing methods, and designs that save weight, reduce fuel consumption, increase

capacity, raise speed, and reduce crew workload. That's the good news.

The bad news is that the advances have brought with them a large number of question marks, and a large number of challenges that we must face together as an industry. There's no question that technology has provided the aviation industry with the benefits that have enabled air transportation to become strong and viable and, yes, a safe industry worldwide.

But it is also the FAA's job to mandate that we use the many benefits offered by our fast moving technology to ensure that the safety and viability of the aviation industry continue.

To meet these challenges, the FAA has established a very aggressive national aging aircraft research program. We developed and published a multiyear program plan that includes R&D projects and operational tasks. In developing the plan, we listened to you, the aviation industry. We listened to you especially carefully at last year's aging aircraft conference, and we liked a lot of what we heard. Those suggestions that still sounded good after scrutiny by experts we freely incorporated into the plan.

It was a good plan when we issued it. I think it's a good plan now. But the world changes and the plan will change, based on the discussions that take place this week.

The short-term objectives of our national aircraft aging program focus on the identification, definition, and resolution of immediate problems. These are near-term issues associated with in-service aircraft. Meanwhile, the research side of the agency has started formulating the multiyear R&D program.

The longer term objectives of the plan concentrate on those issues and potential problems that apply to new and future aircraft. We expect your inputs at this year's conference, as at last year's, to lead to changes in both the short- and long-term objectives of our plan.

The question now is, how are we doing? And that's what we hope to hear this week. I believe that we have made significant progress during the past 12 months. You will hear in more detail about our progress on both the operational and research fronts during the conference.

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Following Tony Broderick's overview, Leroy Keith, Manager of the Aircraft Certification Division of FAA's Northwest Mountain Region, will present us with a status report on transport certification.

Barry Clements, who is the Manager of the Small Airplane Directorate from the Central Region, will give you a status report on commuter aircraft certification.

Ray Ramakis, who is Manager in the Aircraft Maintenance Division at FAA Headquarters, will update us on the progress made in the maintenance area.

Dick Johnson, who is the Aging Aircraft Program Manager at the FAA Technical Center, will follow with a report on the agency's R&D efforts, focused on older transport aircraft.

Your challenge for this week, for all of you, for all of us, is to focus on what we should be doing together to improve the safety of aging airplanes. We look forward to the closeout discussions on Thursday afternoon.

As I close, it is with great pleasure that I introduce the Congressman from the Eighth

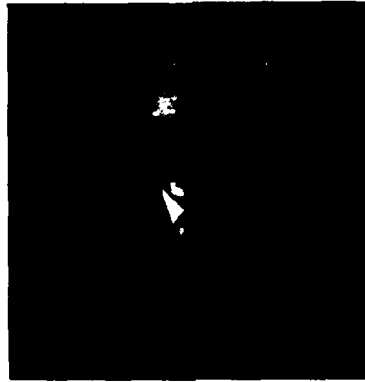
District of Minnesota, the Honorable James L. Oberstar. Jim Oberstar is somewhat of an enigma. All my life I've wanted to call a Congressman an enigma, and this morning I get that chance.

He is the son of a miner and he believes that public works projects have great potential as job creators, but yet he's not the typical House Public Works Committee member who believes in shoveling dirt first and thinking about policy implications later. In fact, in Congressman Oberstar's case, our observations say it is just the opposite.

He has the instincts of a scholar and reformer, and he's legendary on Capitol Hill for his insightful and in-depth questioning of witnesses who appear before him.

As the taxpayer and traveler's interest in aviation has grown, Congressman Oberstar's chairmanship of the House Subcommittee on Aviation has taken on greater importance and significance. He is a distinguished leader in the field of aviation. We are fortunate to have him with us today. Please welcome Congressman Oberstar.

Keynote Address



THE HONORABLE JAMES L. OBERSTAR

Chairman, House Subcommittee on Aviation
U. S. House of Representatives

Many years ago, Lyndon Johnson, long before he was President, was glowingly introduced. As he got to the microphone, he said, "I wish my parents had been here to hear that introduction. My father would have loved it, and my mother would have believed it."

Good morning. It was this past mid-August, and, as I do almost every year, I was at the Almerlund Threshing Festival in the Swedish part of my district, farm country, dairy country. I was down there for the annual display of farm equipment; pieces of machinery, some of which have been running for well over 100 years, meticulously cared for by farmers and shown off to their friends and neighbors. I had boned up for what I knew was going to be a day of grilling about dairy price supports, the coming 50-cent cut in the price support for dairy farmers, regional marketing orders, the price support for corn and prices on soybeans, the drought and the new legislation that several of us from dairy country had authored to help dairy farmers.

So I was all prepared when I walked down to the grounds and this big, burly, overalled,

bespectacled, farmer approached me. And he said, "Say, Jimmy, you know, you better keep on those guys about those old aircraft. By God, you better make them fix them because I don't know if it's safe to fly anymore."

Also there was a visiting group of farmers from Sweden on an exchange program. My friends asked me to come into the bus and talk to the farmers. And you know, the first question from those Swedes was, "Is it safe to fly?"

And so it went for over an hour. I didn't get a question about dairy price supports. Four years earlier I went not to Almerlund, but to Karl Lasterdase, which is in the same region with all those Swedes, and I remember this young fellow by the name of Ernie Lund coming up. After we had a long discussion about dairy price supports, he said, "Boy, I sure am glad to hear you talking about dairy because all we've been seeing you on television is about flying and airplanes. We thought you'd forgot about us dairy farmers, wondering why you spending so much time on aviation."

Well, today they know why. Today they care and today they're worried. You and all of

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us are gathered here in the earnest purpose of putting Ernie Lund's mind at rest, his fears to rest, and keeping aviation the safest mode of travel for all humankind.

Over a year ago, when I addressed the first aging aircraft conference, I expressed hope it wouldn't be the last. And I congratulate Secretary Skinner and Administrator Busey, at the helm of FAA, for strong support of this process, but I particularly want to congratulate Tony Broderick who has made it a cause; Tom McSweeney who has carried the heavy lifting on this whole process; and for all the dedicated professionals at FAA and those in the industry who have really bent every effort, every idea, every energy to the multifaceted issues surrounding aging aircraft, continuing what was so brilliantly begun a year ago, courageously I must say, by Alan McArtor, who did so in the purpose that this effort would persist. It has, it will and, as Joe Del Balzo just said, it must. And it must bring about change, change that is dramatic, ever renewing and ever self-critiquing. The graying of America's civil aviation fleet has changed forever not just the way aircraft maintenance is conducted, but more importantly, it has radically changed our thinking about maintenance, our philosophy if you will, about the conduct of maintenance.

As the nation's air traffic continues to grow, aircraft that were expected to be retired at the end of their so-called economic design lives are being kept in service, and will continue to be kept in service, long beyond that point in order to meet the increasing passenger demand.

We had 461 million boardings last year. We expect that number to double in the next decade. Last year, 2,400 aircraft were more than 20 years old. By the year 2000, projections are that that number will rise to 5,700. The aging aircraft phenomenon is at our doorstep for keeps.

The dramatic Aloha Airlines tragedy of April 28, 1988, not only shocked FAA and the industry, but galvanized both groups into some steps that are fairly radical for what historically has been a rather slow-moving sector. My most vivid memories of that first aging aircraft conference are the electricity that was in the air, the sense of anticipation, the unswerving determination to do something good and lasting under

the haunting reality that something terrible had gone wrong in all of our thought processes and our calculations about the way in which aircraft are built, flown, and maintained.

And there was a determination to make a real difference, and you have done so.

What concerned me then at the outset of that conference was not that there wasn't a tracking system for aging aircraft; there was. It's not that the system wasn't used; it was. What concerned me was that all the right steps were taken, but for Flight Attendant Clarabell Lansing and for the injured and frightened passengers aboard Aloha Flight 243, the system failed. For Clarabell Lansing, the failure was fatal.

We must keep that in mind because that conference was a demarcation point, a landmark in aviation history. A fundamental shift in maintenance philosophy emerged as a product of that conference, and we saw a shift from the old approach of inspect and repair to a new philosophy of terminate and replace at specific intervals. And in this mode, airline maintenance for high-time aircraft will no longer wait for small cracks to develop into large problems. No longer will corrosion, fatigue, and multisite damage have to be discovered by an airline inspector often working late at night and always subject to the limitations of the naked eye, fatigue and other human factors.

The purpose of this conference, then, is to assess how far collectively, civil aviation — the manufacturers, the airlines, the FAA and its counterparts in other countries — has come with this new philosophy. How far have we come in correcting the deficiencies and to vastly improve the performance of high-cycled aircraft, and most of all to reassure the traveling public?

On balance, I can say after extensive hearings on this subject and very close involvement with the process that I am pleased and I am impressed with the actions that industry and government have taken and the decisive and purposeful way in which all have acted in response to this phenomenon.

I congratulate the Boeing and Douglas working groups on the thorough review they have undertaken of thousands of service bulletins.

James L. Oberstar

Additionally, there have been other short-term objectives. Many of them are underway and they include the development of more effective corrosion prevention and control programs, a review of existing maintenance plans and an assessment of supplemental structural inspection programs. All of those actions are necessary to ensure fleet airworthiness.

But I believe we need to go further. Last week, aviation industry representatives told my subcommittee on aging aircraft that with proper inspection and maintenance, aircraft can be operated virtually indefinitely. Maybe they're right; but what if they are wrong?

As we proceed through the process, let's keep one sobering statistic in mind. The National Transportation Safety Board data show that from 1970 through 1985, metal fatigue or corrosion, in some cases both, were involved in 77 out of 579 aviation incidents. Our goal should be to reduce that figure to a number approaching zero.

To reach that goal, all the recommendations of the Boeing and Douglas groups must be rigorously implemented by the carriers, domestic and foreign alike. That implementation must be vigorously inspected and enforced by the FAA and its foreign civil aviation counterparts. There must be more hands-on inspection of aircraft by the FAA and foreign authorities. We cannot afford, as in the past, a rather substantial reliance upon paperwork review of maintenance operations.

Government and industry — I think this is very important — must do a much better job of collecting and analyzing trend data on aircraft maintenance so we can know how to anticipate emerging problems and how most effectively to allocate our resources.

Industry and government both need a completely redesigned mindset about the longevity of aircraft. The manufacturer's assumptions and projections about economic design life need to be reexamined, especially in light of how certain carriers accumulate flight cycles. For example, Aloha accumulated flight cycles at twice the rate for which Boeing designed the 737.

D check intervals need to be shortened as aircraft accumulate higher numbers of cycles

between major maintenance undertakings. And as aircraft increasingly are operated in a wider range of climate conditions and are increasingly operated at the upper end of their economic design life, we have to change our mindset, and admit that we are operating at the threshold of knowledge and experience about the aging aircraft phenomenon, that we are in uncharted territory.

I have come to the conclusion that we need to raise a red flag, or at least a caution flag, at the high cycle point in an aircraft's life span. And I propose the establishment by the FAA of a comprehensive, high-cycle, airworthiness audit and review procedure for aging aircraft. I propose that the audit require aircraft operators to justify the continued operation of the aircraft as it approaches the high end of its design life.

A higher burden of proof of airworthiness would be exacted of the operator at this stage than for other previous maintenance actions. Both the carrier and the FAA will have to meet to review maintenance of the aircraft throughout its history, with emphasis on the aging process: terminating actions; corrosion prevention and control procedures; metal fatigue; the aircraft's total operating environment, where it customarily and ordinarily operates; and damage tolerance. All the other stresses to which aircraft are subjected would, in this process, be rigorously and critically evaluated.

This review would be supplemented by a hands-on inspection by the airworthiness authority. And if at the end of that process the airworthiness audit authority concludes that the aircraft is fit to continue safe operation, an appropriate notification can be issued and the aircraft returned to service.

What I envision and propose is a holistic, not a segmented, piecemeal process applied to the continuing airworthiness and fitness operation. I am advocating an approach in which the aging aircraft is scrutinized as a system, not as pieces of a whole, and not as a collection of replaceable parts.

Only then can we genuinely assure the flying public that the nation's air transport system is operating not at the margin, not at only the safety we can afford, but at the highest possible level of safety.

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Civil aviation's biggest safety problem is what has become known as the human factor. Making decisions about a series of mechanical fixes and modifications to aircraft is much less difficult than fully understanding why human beings do not do what they are supposed to do or why they fail to perform as we expect them to perform.

There are a number of human performance questions that we need to address and I hope will be addressed in the course of this or other conferences. What can be done about the fact that rivet inspection is boring, tedious, mind-bending work, susceptible to human error? How do we ensure that the means established to communicate with each other are in fact effective, and that the right information is finding its way to the right people at the right time?

How do we know whether training of inspectors and mechanics is all that it needs to be? And how do we ensure that it will be?

All of these and other human factors are tough ones, difficult to attack because we are dealing with human beings who don't perform according to mathematical models. But the FAA and the industry have to attack them with the same vigor that the task forces have addressed to the other technological problems of aging aircraft.

Here there is no universe of documents to review on performance history. We're dealing with people. We can't throw up our hands and say they can't be dealt with; they can be, and they've got to be. We have to find answers to the human dimension or we will not have done our job completely or well enough.

The thinking here has to be just as bold and radical as it has been in other areas. Just because we fixed the aircraft does not mean that we have fixed the problem of aging aircraft, and we won't have done so until we have dealt with the human factors.

We have to remember that the aircraft, the flight crew and the passengers who ride those aircraft all operate in an inherently hostile and

unforgiving environment. We cannot relax our vigilance.

As we proceed in this process and work together, I want to assure you that my colleagues in the congress are concerned about this issue and ready to do whatever is necessary and devote whatever resources are required to address it effectively. I assure you also that the traveling public, while not yet white-knuckled, is serious and concerned and has a lot at stake riding on what you do, what you decide, and what actions you take as a consequence of these conferences.

In conclusion, I am reminded so often, as I deal with this issue of aviation, of Thornton Wilder's quest for truth and for answers to the age-old problem of death. He wrote of the bridge at San Luis Rey, and a tragic accident in which five people fell into a chasm when the bridge collapsed over a century-and-a-half ago.

Brother Juniper, who happened upon a community where an annual remembrance was taking place, undertook to find the cause of why those particular five people died at that particular time. And he said, either we live by accident and die by accident, or we live by plan and die by plan.

Brother Juniper resolved to inquire into the secret lives of those five persons to surmise the reason of their dying. At the conclusion of that marvelous inquiry into human nature, he said, "Some say that we shall never know, and that to the gods we are like flies that boys kill on a summer day. Some say, on the contrary, that sparrows do not lose a feather that has not been brushed away by the finger of God."

Let us not wait for philosophical interpretations, or prayer, or insight into lives lost, to unlock the secrets of aging aircraft and what best to do to prevent mysterious loss of life.

You are engaged in a great enterprise. I congratulate you. I wish you well in this endeavor and will follow very closely the proceedings of this conference.

Thank you for the privilege of being with you this morning.

Conference Overview



ANTHONY J. BRODERICK

Acting Executive Director for Regulatory Standards and Compliance, FAA

Good morning, Mr. Chairman, ladies and gentlemen. This morning I would like to touch on some of the lessons we have learned so far from our cooperative aging airplane efforts over the last year. I would also like to discuss actions that should be taken by airworthiness authorities, manufacturers, and airlines around the world.

Like most aviation issues, this is not one we face or can deal with alone. The FAA has initiated a program, as an integral part of our overall aging airplane program, for its inspectors and engineers to visit operators while aging airplanes are undergoing major maintenance.

This renewed emphasis on hands-on work has enabled the FAA to gain better firsthand knowledge of the condition of the aging fleet in the United States and the adequacy of operators' maintenance efforts.

At the same time, the manufacturers have intensified their programs of looking at aging aircraft under repair at airlines throughout the world. We have learned a number of lessons. Let me cite a few that strike us as significant.

There appears to be more awareness of the

need for better maintenance as airplanes age. Those in attendance at this aging aircraft conference a year ago heard many of the operators state that the majority of in-service failures are a result of corrosion, prevention of which is basically a maintenance function.

Since that conference, there have been many efforts on the part of the airlines to improve maintenance as a whole, and corrosion control and prevention specifically.

Multisite damage does occur in service. It is hard to find, and it does reduce the ability of the fuselage to tolerate in-service damage. We've seen several instances of multisite damage on transport airplanes. While it had not progressed to the point of becoming an imminent safety hazard some of that damage has been extensive and has obviously reduced the ability of the airplane structure to accommodate the level of service damage which the original design could withstand. Laboratory testing has also confirmed the possibility of the occurrence of multisite damage in typical airplane structures.

Corrosion is more widespread than thought. Programs must be adopted early in the life of an airplane to ensure continued safety, since as

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noted earlier, corrosion is the leading cause of in-service failures.

As the FAA visits aging airplanes under inspection, we are vigilant for corrosion and we see it on a regular basis and in many areas not previously thought to be prone to corrosion. The more cost-effective solution to the corrosion problem is to adopt early programs to control it, rather than replace or repair the material after it corrodes.

A good corrosion prevention and control program must be one of the basic elements of any maintenance program. It is essential that corrosion control not just be a secondary function performed when the opportunity presents itself. Corrosion control should be a program of its own, staged to coincide with other maintenance visits.

In areas of the airplane where structural strength is important, where there is a high probability of occurrence of cracking, and inspection is difficult, it is essential that modifications or material replacement be accomplished as airplanes age. This is an essential element of the aging aircraft program. We can no longer rely on extensive, routine, boring and monotonous inspections in areas that are critical to flight safety. A structure known to be prone to the aging phenomenon must be replaced before it ages.

The aging airplane problem is international in scope and requires the cooperation of all airworthiness authorities and airlines in following defined aging airplane programs including mandatory airworthiness directives.

In countries that have adopted mandatory aging airplane requirements, we expect that more validation of service history and adequate maintenance will be required before bringing airplanes onto the register of that country or into service on its airlines.

It is essential then, that airplanes moving from country to country on leasing agreements, be maintained in accordance with recognized and accepted standards; that maintenance records and records of major modifications or alterations be complete.

Future leasing agreements are likely to be much more specific as to maintenance and inspection requirements as lessors attempt to

protect their investments. Those requirements will parallel very closely the programs recommended by the manufacturers and, of course, mandatory aging airplane requirements that are issued by the cognizant airworthiness authority.

Data have been obtained that show some operators around the world are taking less than adequate care of aging airplanes. The presentation by Tom McSweeney graphically described some examples. But don't think that it can't happen here. It could if we don't do our job; but it shall not, because not one of us in this room can permit it to happen.

In looking at aging airplanes, we discovered numerous cases of improper repairs that reduced the structural integrity and damage tolerance capabilities of the basic airplane design. In visits to U.S. carriers to evaluate aging airplane maintenance, several cases were discovered where the basic structural strength and crack-stopping features of the design were compromised by a repair.

More information needs to be provided by the manufacturers regarding proper repair techniques, and that guidance should be followed by all airlines.

It appears clear that the international cooperation already evident in some of the aging airplane programs must be continued. Each of us needs to draw on the lessons learned by others. There must be a commitment, by those in authority, to do several things:

- We must ensure that at the design stage, all new airplanes adequately take into account the aging airplane phenomenon.
- We must ensure that manufacturers of transport airplanes prepare and revise supplemental structural inspection documents, taking into account the lessons learned, and to be learned, from present and future aging airplane programs.
- We must ensure that all manufacturers of transport airplanes prepare a corrosion control program for use by the operators. Mandatory action requiring adherence to this program should be considered by the cognizant airworthiness authority.
- We must work together to review and rewrite

Anthony J. Broderick

the operators' maintenance and inspection programs so they are more in tune with the aging airplane needs. We intend to require all operators to have an approved corrosion control program modeled after the one recommended by the manufacturer. We urge all other airworthiness authorities to consider doing the same thing.

- We must continue the work initiated in this past year to ensure that a process exists where service problems, structural failures and other significant events are reported to the airplane and engine manufacturer and made available for others to benefit from. The current service difficulty report system just does not fill that bill.
- Finally, we must continue to follow and cooperate on worldwide aging airplane issues in order to implement timely actions and maintain the confidence of the traveling public.

The FAA has committed its resources to these challenges. We stand ready to share aging airplane experiences with anyone. The manufacturers in the United States, and I would

assume other countries as well, stand ready to share their wealth of knowledge with airworthiness authorities and operators around the world.

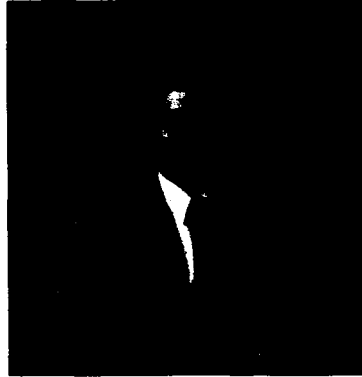
In the past year, the airlines have done much to improve the programs they are using to address these important safety issues. Their efforts have been truly extraordinary.

This work of industry and governments, in a cooperative and nonadversarial environment, has been a hallmark. We at FAA are proud of our part in the accomplishments of this joint effort. We pledge a continued dedication to that spirit of cooperation.

I am delighted to see a continuation of international interest in these important issues, as evidenced by the strong attendance here at this meeting. I am particularly pleased to see that we have sustained momentum on a broad front and that the conference will cover in some detail the areas of structure, loads, corrosion and human factors.

All of us have an exciting opportunity to make a difference by applying our individual expertise to a variety of challenging technical problems.

Transport Aircraft Certification



LEROY A. KEITH

Manager, Transport Airplane Directorate
FAA Northwest Mountain Region

Good morning, ladies and gentlemen. It's certainly my pleasure and honor to address such a distinguished group and to share with you the status of all of the efforts that we have had underway in the Transport Directorate in the last 16 or 18 months, and to talk about some of the plans that we have underway.

Before getting into the program, I would like to just put in a little plug for our organization, the Transport Airplane Directorate. Located in Seattle, I have a staff that handles all of the rulemaking activity concerning design rules for transport airplanes.

There is also an office in Seattle that deals primarily with Boeing airplanes. I have an office in Long Beach that deals with Douglas and Lockheed airplanes, among a lot of other things. That's where the transport activities are located.

The staff in Seattle also deals with all of the imported transport airplanes that operate with FAA type certificates. We're responsible for the

continued operational safety of all transport airplanes that have an FAA type certificate. We are responsible for the rulemaking for Part 25, and for the certification of new or modified aircraft.

As Congressman Oberstar and Tony Broderick said, the tragic Aloha accident certainly did refocus our attention on the aging airplane issue. What I want to cover today are basically three things: what we did in the Transport Directorate immediately following Aloha; second, the accomplishments achieved in the last 18 months; and then finally, our plans for the future.

Within hours after the Aloha accident, we issued a precautionary telegraphic airworthiness directive that limited the cabin pressure differential on those airplanes to a lower level, while everybody went to work trying to understand the mechanics of that accident.

Within a few days, we had issued another immediately-adopted airworthiness directive

that did in fact require some inspections of specific lap splices on the 737. In the meantime, in the Transport Directorate, we sent people to Hawaii to support the NTSB investigation efforts.

Those who stayed behind started asking some fundamental questions about aging aircraft and what assumptions we had made, and what philosophies we had used in certifying airplanes in the past. We started to rethink our philosophy and assumptions concerning the design, the inspection, and the maintenance of airplanes in general, and especially as they start to approach their economic design goal and beyond.

We had been asking those kinds of questions for at least 20 years. I know that the industry has long grappled with the aging aircraft question, but the degree of damage to that Aloha airplane certainly caused us to rethink the issue. It was shocking to see that much damage, and it was totally unexpected.

One of the first questions we asked ourselves in Seattle was "Should we pick a time when we start parking these airplanes?" We also started looking at specific things on other transport airplanes besides the 737, to see if there were service bulletins that we needed to make mandatory.

All of these efforts were within weeks after the Aloha accident, and they were pretty much unilateral by the Transport Directorate.

Our most immediate concern, as was everybody else's, was the safety of the air carrier fleet.

We certainly weren't alone in asking those kinds of questions, but those questions and concerns did prepare us for the aging aircraft conference that was held June 1-3 of 1988. I had 10 people from our Directorate attend that June 1988 conference. We were on various steering committees and panels, and in the audience, and I think there was a very good dialogue.

With that kind of a background, I'd like to talk about the ATA/AIA Airworthiness Assurance Task Force that was formed following the conference.

We did have a lot of people involved in it, and I think that this task force was one of the single, most significant outcomes of that conference.

The task force is in fact reviewing five major areas: (See Figure 1) The service bulletin review, which is pretty well completed, but is expanding to review all of the fatigue service bulletins that have been issued for these airplanes, use a criteria that I'll discuss shortly.

Corrosion program development is the major effort that's underway right now. The supplemental structural inspection document program review is just beginning, and the repair review and maintenance review are things that will happen in the future.

Other actions that we have postured ourselves for, are listed in Figure 2. We decided that we needed to pay more attention and focus more on testing that was underway, or planned by the manufacturers, and look at some of the teardowns that were planned for airplanes that were out of service, and had been purchased back by manufacturers. We wanted to see what unexpected damage may have happened to those airplanes in their lifetime or during continued fatigue testing. We've had a lot of involvement with the manufacturers on those.

We certainly support, as Joe Del Balzo mentioned earlier, the R&D efforts that are underway. In addition to R&D in inspection, there is some R&D effort in human factors.

We also support the flight standards aging fleet inspections. We have engineers involved assisting and counseling flight standards inspectors in their review of the fleet.

We support and responded to Dr. Mar (MIT) and the technical oversight group for aging aircraft. They have been very active in critiquing our efforts. They have given us various recommendations and we have implemented or responded to those recommendations.

- ATA/AIA/FAA Task Force
 - Service Bulletin Review
 - Corrosion Program Development
 - SSID Program Review
 - Repair Review
 - Maintenance Review

Figure 1 — Approach

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- Seattle & Long Beach ACO's
 - Fatigue Test/Teardown Reviews
 - Support R & D and Human Factors
 - Support Flight Standards Aging Fleet Inspections
 - Support & Response to TOGAA Recommendations
 - Participate in Training Program
- Standards Staff
 - Development of Rules

Figure 2 — Approach (Cont.)

Additionally, our engineers are involved with the flight standards training Ray Ramakis has with Douglas and Boeing.

The standards staff in Seattle has four or five very significant rulemaking or advisory circular projects underway. Again, I'll tell you about the details later.

We also support headquarters. I hope Tom McSweeney and Tony Broderick agree. It's related back to what Congressman Oberstar was saying about reassuring those white-knuckled fliers out there that there is reason for concern, but there are no immediate safety problems that we know of. So we do feed a lot of information back to the folks in headquarters to help allay some of those concerns.

One other thing that has happened in our approach is that I did create a dedicated position, one person on the staff, to deal with the aging aircraft issue. That job will be to pull everything together, not in a technical sense, but to include all of these various efforts that we have underway in the Directorate, in addition to providing some dedicated resources to following through on some of the actions.

Figure 3 is the FAA's role in the Aging Aircraft Task Force. The Airworthiness Assurance Task Force is its new name. There have been 113 meetings held. Those have been composed of steering committee meetings, working groups, and the special committee meetings where there are detailed looks at each specific type airplane and the history of that airplane in service.

- 113 Meetings Held
 - Steering Committee
 - Working Groups
 - Special Committees
- 22 Certification Engineers and Managers Involved
- Active Participation in All Meetings

Figure 3 — FAA Participation in the Aging Aircraft Task Force

There have been 22 engineers or managers from the Directorate who have been involved so far; one or more of whom participate in every one of those meetings.

Most of the 113 meetings have been reviewing the fatigue service bulletins, with little work on corrosion or the other activities we have had underway. The focus has been on a review of the fatigue service bulletins and to determine those that should be terminated.

Figure 4 states one of the major things that happened during the year. It has to do with the policy change we made last August and implemented in October, with a couple of significant airworthiness directives.

The figure says basically that you can't inspect an airplane forever. There is a criteria that was developed by the steering committee that said if a fatigue crack is difficult to inspect, and if the probability of detection is not high and if the consequences could be catastrophic, that

Continued inspection of an airplane for evidence of occurrence of a known problem for that model airplane, is an unacceptable procedure to assure safety. Modification or replacement of parts must be accomplished to preclude the occurrence of the problem.

Figure 4 — FAA Policy Change

Leroy A. Keith

service bulletin should be terminated by a modification or by replacement of the part.

For example, the Boeing working groups for all the Boeing fleet reviewed 703 service bulletins with this criteria in mind, and there are 157 that are being terminated by airworthiness directive. The Douglas working group reviewed 462 service bulletins, and there are 140 that will be terminated. The Lockheed working group reviewed 251, and they are recommending 39 for terminating action.

An issue that is not directly related to aging aircraft, but that we are also looking at as a group, has to do with service bulletins other than the fatigue type. Our review applies the same sort of a philosophy that you can't inspect forever.

We've also decided that we would go back and review all service bulletins where there are possibly operational procedures and a design change where a service bulletin or an FAA action would allow both to continue. We're going back and reviewing those and asking the question: "Does it make sense, if there is a design change available, to rely on an operational procedure such as placards or maintenance procedures or something along that line?"

Figure 5 is the first application of the new policy that you can't inspect forever. In October we issued an AD NPRM on the 737 lap splice that would affect the first 291 airplanes that were cold-bonded, and which basically required button-head rivets on the airplane to replace the cold-bonded lap splices.

- 737 Lap Splice Fastener Replacement
 - First 291 Airplanes
 - 100 U.S. Registered Airplanes
 - Total Cost/Airplane \$80,000
 - AD Effective May 8, 1989
- 727 Lap Splice Fastener Replacement
 - First 849 Airplanes
 - 623 U.S. Registered Airplanes
 - Total Cost/Airplane \$58,000
 - AD Effective August 21, 1989

Figure 5 — First Application of New Policy

The same thing applies to the 727, but it affects a significantly larger number of airplanes. Those modification programs are underway.

Figures 6 and 7 are the AD products that came out of the working groups from the ATA committee.

The working groups from Boeing gave us their recommendations in late February or March 1989. We had an AD NPRM out in May. We've gone through all of the comment and public notice period, review of the comments, and the final rule should be out as indicated.

The Douglas group forwarded their recommendations to the FAA in September 1989. We followed with an NPRM AD within a week or so. We expect those ADs will take about six months to go through the public comment process and would be final about March of 1990. The MD-80 and the DC-10 are also shown.

Figure 8 shows some other accomplishments that we've had. We have had 10 airline evaluations supported from the Transport Directorate, with engineers going out and looking at aircraft.

- 727
 - 74 Service Bulletins
 - 1,700 Airplanes World Fleet
 - \$1,000,000/Airplane
 - Est. Final Rule AD Effective January 1990
- 737
 - 58 Service Bulletins
 - 1,200 Airplanes World Fleet
 - \$900,000/Airplane
 - Est. Final Rule AD Effective January 1990
- 747
 - 31 Service Bulletins
 - 680 Airplanes World Fleet
 - \$2,300,000/Airplane
 - Est. Final Rule AD Effective January 1990

Figure 6 — Aging Aircraft ADs - Boeing

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- DC-8
 - 152 Service Bulletins
 - 346 Airplanes World Fleet
 - \$18,620/Airplane
 - NPRM Issued September 14, 1989
- DC-9
 - 52 Service Bulletins
 - 920 Airplanes World Fleet
 - \$76,100/Airplane
 - NPRM Issued September 14, 1989
- MD-80
 - 22 Service Bulletins
 - 568 Airplanes World Fleet
 - \$3,752/Airplane
 - NPRM Issued September 14, 1989
- DC-10
 - 33 Service Bulletins
 - 426 Airplanes World Fleet
 - \$179,480/Airplane
 - NPRM Issued September 14, 1989

Figure 7 — Aging Aircraft ADs - Douglas

- Participation by Certification Engineers in Aging Fleet Evaluations
 - 10 Airline Evaluations Completed; 60 Planned
 - Plan to Evaluate Each Manufacturer's Transport Category Type Aircraft

Figure 8 — Aging Aircraft Inspections

We will be going out and looking at every transport category aircraft and all of the operators.

Figure 9 shows working group activity that is still underway. Very close to completion is the fatigue review of the L-1011. We expect to have an NPRM out before this year is up.

- L-1011
 - 39 Service Bulletins - Termination
 - 7 Service Bulletins - Inspection
 - 243 Airplanes World Fleet
 - Issue NPRM Est. December 1989

Figure 9 — Future Aging Aircraft AD's - Lockheed

Figure 10 shows the rest of the working groups. These efforts are still underway, and a little further downstream. Again, this is a fatigue service bulletin review only.

We are expecting the model groups and task groups to give their recommendations on what to do with the supplemental structural inspection programs, what to do about repairs as they affect the damage tolerance evaluations and what to do about maintenance and the quality of maintenance.

Figure 11 is about corrosion, probably one of the big hitters. In my opinion, this is an extremely big hitter that is going to have an impact on the way we do business in the Transport Airplane Directorate.

The second major policy change the FAA has made in the last year deals with corrosion control. Last February we decided that we would mandate corrosion control programs for these type airplanes by airworthiness direc-

- Recommendations from Other Model Task Group Service Bulletin Reviews
 - Airbus A-300
Issue NPRM Est. March 1990
 - Fokker F-28
Issue NPRM Est. April 1990
 - Convair 580
Issue NPRM Est. March 1990
 - British Aerospace BAC 1-11
Issue NPRM Est. March 1990

Figure 10 — Future Aging Aircraft AD's

Leroy A. Keith

- Recommendation from Model Task Group Review of Corrosion Program
 - Boeing 707/727/737/747
Issue NPRM Est. November 1989
 - Douglas DC-8/9/10
Issue NPRM Est. February 1990
 - Lockheed L-1011
Issue NPRM Est. March 1990
 - Airbus A-300
Issue NPRM Est. March 1990
 - Fokker F-28
Issue NPRM Est. April 1990
 - Convair 580
Issue NPRM Est. March 1990
 - British Aerospace BAC 1-11
Issue NPRM Est. March 1990

Figure 11 — Future Aging Aircraft ADs

tive. We just received the Boeing working group's recommendations and we plan on having an AD NPRM soon. There will be more coming on corrosion control but we fundamentally will plan on a mandatory corrosion control program for all transport aircraft operated in U.S. air carrier service.

From the regulatory standpoint, we have some significant activities underway as shown in Figure 12. A lot are internal in the Transport Directorate. These are internal evaluations right now and they're subject to change.

A couple of items I'd like to call your attention to on that figure are the second and fourth bullet concerning two lifetimes of fatigue testing. The 25.571 rule would affect future design. We're also planning on proposing a special Federal Aviation Regulation that would require fatigue testing of the existing fleet to two lifetimes. It would be a retroactive rule.

I want to stress that we do not believe that fatigue testing is the ultimate solution to the aging aircraft program. But it can help you better design SID documents or inspection programs or you can find unexpected, possibly multiple site damage that you hadn't predicted or found. AC 25.1529, which will be published next month, is continued airworthiness as it

- Require SID Programs for All Airplanes Certified to CAR 4b or FAR Part 25 — to FAA HQ March 1990
- Amend FAR Part 25.571 to Require 2 Life Times Fatigue Test — to FAA HQ January 1990
- Issue Revision to AC 25.571 — to FAA HQ January 1990
- Propose SFAR to Require Fatigue Testing of Existing Airplanes to 2 Lifetimes. (Retroactive Rule) — To FAA HQ January 1990
- Issue New AC 25.1529 — To F.R. Publication November 1989, for Comments
- Issue New AC on Aging Aircraft Policy — FAA Coordination November 1989

Figure 12 — Future Regulatory Action

relates to damage tolerance and repairs. We've been working on that one for a number of months.

The new aging aircraft policy that we have in coordination right now and plan to issue next month, talks about some of the policy changes made in the last year.

In summary I would like to say I feel that it was a magnificent effort on the part of the international aviation community to go to work the way we all did since June 1988, to make sure that there aren't going to be any more "Alohas."

There have been a lot of accomplishments. I have been very gratified with the work that I have seen and the cooperative efforts that have been made.

Still, there is certainly a lot more work that needs to be done with the aging aircraft. There are going to be some fundamental shifts, as I've said, in the way we do business, especially as to the way it relates to corrosion and especially concerning the Transport Directorate. I just made a quick calculation this morning. We have expended about 20 percent of the total Transport Directorate resources on aging aircraft today. Resources that we weren't spending last year. When we get into the corrosion

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control business, it's going to take even more. There's going to be a large involvement of Transport Directorate engineers in monitoring the health of the fleet.

One of the measures of success of the way we have approached the aging aircraft problem is reflected in what happened following the tragic accident of United Flight 242 in Sioux City last July. You recall the Administrator announced then the formation of another group to be under the R&D advisory committee umbrella that Joseph Del Balzo is in charge of. The group is the Transport Aircraft Safety Subgroup. That group is being chaired by ATA, I

believe, and in fact we are preparing a systems working group dealing with transport aircraft, and it's being structured almost exactly the way we handled the aging aircraft program.

I'm comfortable in saying the fleet is certainly safe today. If it weren't, the Transport Directorate would be taking steps to do more. We did ask that basic question early on: "Should we park the airplanes at a given time?" Right now we have no plans to have a mandatory retirement age, but it's safe to say that the costs are certainly going to be going up in maintaining these older airplanes.

Commuter Aircraft Certification



BARRY D. CLEMENTS

Manager, Small Airplane Directorate, FAA Central Region

Good morning. It is very much my pleasure to speak to you this morning. Assisting me is Bob Sexton, the Manager of our Aging Commuter Aircraft Program Plan.

Leroy Keith reviewed the transport aircraft program plan, some of their actions, some of their accomplishments, and you've heard about the need for action this morning from Congressman Oberstar, and from Tony Broderick. You certainly are aware of it yourselves. We're talking about actions not only by the FAA, but by the industry and the other airworthiness support agencies. A significant and growing percentage of our regional or commuter fleet, is made by non-U.S. manufacturers and we are going to have to enlist the support of the other-than-FAA airworthiness authorities to help us get a handle on the commuter aircraft program.

I'll review what's planned and what has been accomplished to date on the commuter class of airplanes. Frankly, we're not as far into the program as the Transport Directorate. They had a bit of a head start on us.

We do have some important parallel efforts to our engineering program and those are in maintenance and the research and development community.

The commuter class includes some transport category airplanes used in regional or commuter service. These are smaller airplanes that the Transport Directorate has agreed we should handle.

I'm sure our friends at Aloha are tired of seeing that mishap used as a catalyst, but in fact it did act as a catalyst to focus renewed attention on the issue of aging aircraft in the commuter fleet. We had to move very quickly from the talking about someday having a problem to developing an action plan to avoid a problem. (See Figure 1)

The second bullet is probably one of the most important ones we're able to share with you. There has been no dramatic failure of a commuter airplane due to aging and we intend to ensure that those airplanes used in regional passenger service do not have a structural failure due to age-related issues.

We have a pretty good workload. As shown in Figure 2, the 1988 Regional Airline Association figures show an air carrier passenger fleet of 1,800 airplanes, 59 different types, 17 different manufacturers, and about 165 different operators. It's a tremendous workload to try and get a handle on. That includes, as I said, some

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- The April 28, 1988 Aloha structural failure acted as a catalyst to focus renewed attention on the issue of aging aircraft.
- There has been no dramatic failure of a commuter airplane due to aging.
- The Aging Commuter Airplane Program is intended to assure that an airplane used in regional passenger service does not have a structural failure due to the issues related to aging.

Figure 1 — Background

The 1988 Regional Aircraft Passenger fleet

- 1800 airplanes
- 59 different types
- 17 different manufacturers
- 165 different operators

Includes

- Transport Category Airplanes
- Small Airplanes
- Latest Designs
- Designs over 40 years old

Figure 2 — Regional Fleet

transport category airplanes, certainly what we call small airplanes. It includes some of the latest designs and technology and some designs over 40 years old.

The commuter program is going to be very, very similar to the transport program, but with some differences due to the size, the design of the airplanes, the complexity of them, and the smaller resources in terms of manpower of the commuter or regional air carrier industry. And as with their program, ours has to be based on a mutual commitment from industry and the government, from the FAA, from the RAA and the operators, from GAMA and the manufacturers themselves.

Our approach has been to initiate this program within the available resources, and we have finite resources. We decided to address those aircraft with under 60 passenger seats, not covered by the ATA/AIA task force initiatives, in scheduled or air carrier commuter service, and initially those with a passenger capacity of 10 or more seats.

This results in 1,180 airplanes or 66 percent of those used in the scheduled regional air carrier fleet. Those are the airplanes most often used in their operation, so we are confident we are addressing a much greater percentage of the total passenger seat capacity of the commuter fleet. We will be working with 92 operators and 16 manufacturers.

The program content will initially be a service bulletin review for those service bulletins that relate to aging issues, and appropriate closing action; and a review of airworthiness directives we have on the books to see which ones should be changed, perhaps from recurrent inspections to closing actions.

We had to have input on the very important issue of maintenance considerations. We are looking for recommendations from the technical oversight group. And we are looking to SID and structural SID development and approval. At some point in the process we have to get into major repair reviews: was enough consideration given to fatigue and corrosion in those repairs?

We're developing supporting regulatory and policy actions and we have other actions, for example those being taken by the R&D community.

The airworthiness directive and service bulletin review will be similar to the AIA/ATA/Transport Directorate initiative. In this case, considering the limitations on manpower in the commuter regional air carrier industry, it's going to be an FAA action with industry support instead of the reverse.

We will review ADs for possible terminating action and we will be reviewing age-related service bulletins for possible closing or mandatory action.

The technical oversight group's recommendations are going to be very important to us in establishing and identifying whether we have

Barry D. Clements

a SID need; certainly in prioritizing the aging airplane reviews; the adequacy of continued airworthiness information that's available to the industry now; and the adequacy itself of some of our service bulletin and AD actions that are presently out there.

The SID program is going to be very similar to the transport effort. There is a GAMA format under development. We are very anxious to see the proposal that is forthcoming very shortly. We envision the manufacturers developing the SIDs, with FAA approval, in part if not all, and appropriate AD action to mandate those.

We're still trying to get a handle on major repair reviews and on how best to conduct them. We see a very great problem in terms of record access, record availability. But we do see a need for an industry review of existing airframe repairs. Were the considerations for fatigue adequate? Was corrosion control adequately addressed? Were repetitive inspections sufficient to ensure continued airworthiness? Those are issues that have to be reviewed.

We have several initiatives underway in the areas of supporting regulatory and policy actions. One, we are considering proposing either rules to mandate SIDs or place hard lifetimes on those aircraft using commuter service. Can they be maintained, or do they become paperweights?

We are developing, and we will be proposing, rulemaking addressing aircraft issues. For example, corrosion control in the initial certification process.

We have, in a joint effort with Flight Standards, a review of our service difficulty system. Are we getting the adequate information back to address both new certification and our aging aircraft program?

There is a joint industry/FAA evaluation of possible licensing of NDI inspectors and a level of effort in human factors consideration in NDI and NDE testing.

Charts 1 and 2 show some of the actions we have taken. Again, we are exploring, more or less, the total commuter program plan. We had an initial GAMA/FAA/RAA steering committee meeting in December 1988. We got together again in February 1989, to prioritize

their efforts and ours. GAMA hosted a corrosion conference in March in St. Louis. GAMA and RAA jointly hosted the Commuter International Aging Conference in Kansas City in April. We received the recommendations coming from that conference in June. We are continuing to develop our program plan.

We've had a number of meetings with the technical oversight group and we're anxious for them to complete their site visits and make their reports available to us.

We had a meeting in August with Canada's Department of Transport, and Boeing de Havilland, regarding an initiative needed on the de Havilland fleet. It was a very productive meeting. We are working very closely with them and I thank them publicly.

GAMA is developing the format for the SID development program, a joint industry/FAA approach. We'll be proposing that shortly. We are looking to industry to develop some damage tolerance, and to develop and conduct some damage tolerance studies to support what is going to be proposed in the SIDs.

The SID development, of course, will be a long-term process running through early to mid-1991. The SID approval and FAA/AD issuance to mandate those SIDs will follow in lock step.

We intend to develop an NPRM and put that out for an extensive comment period, to allow comments from the international industry. We expect to have a final rule by early 1991.

Figure 3 shows completed actions to date. I mentioned the GAMA-sponsored corrosion conference in St. Louis, a RAA and GAMA co-sponsored conference in Kansas City, the development of 23 recommendations, all of which we and other parts of the FAA are looking at. Many of which we acted on or are acting on, and some that we still have open IOUs on, unfortunately.

Industry and FAA have a firm commitment to jointly address the issues. We have developed a program plan for commuters similar to that of the transport plan. It does not address the entire Part 23 fleet, if you will, but our initial actions, considering our resources, will not permit that.

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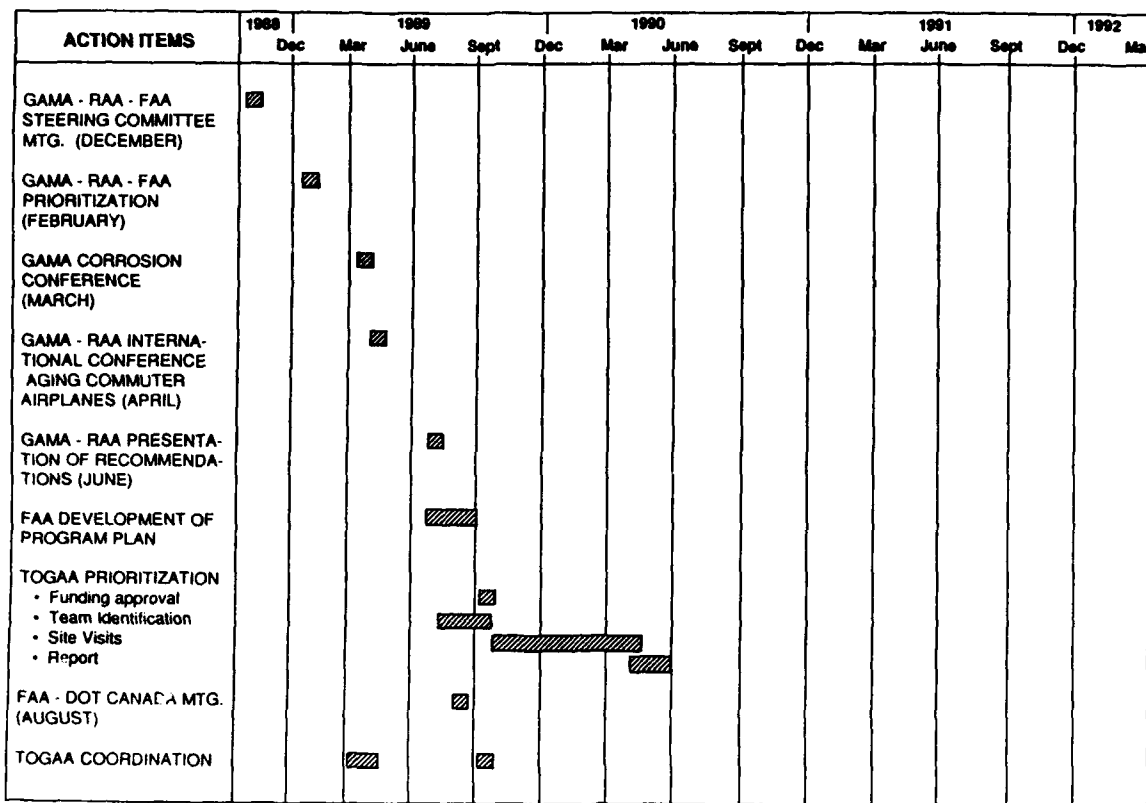


Chart 1 — Small Airplane Directorate, Aging Commuter Fleet Program

- GAMA Sponsored Corrosion Conference
- RAA/GAMA Co-sponsored International Conference on Aging Commuter Airplanes
— 23 recommended actions —
- Industry-FAA commitment to jointly address issues
- FAA Developed Program Plan for commuters similar to transport program
- Held first Mfgr/FAA/other Airworthiness Authority meeting (Canada, DOT/FAA/BDHC)
- Other Actions by Flight Standards

Figure 3 — Completed Actions

Barry D. Clements

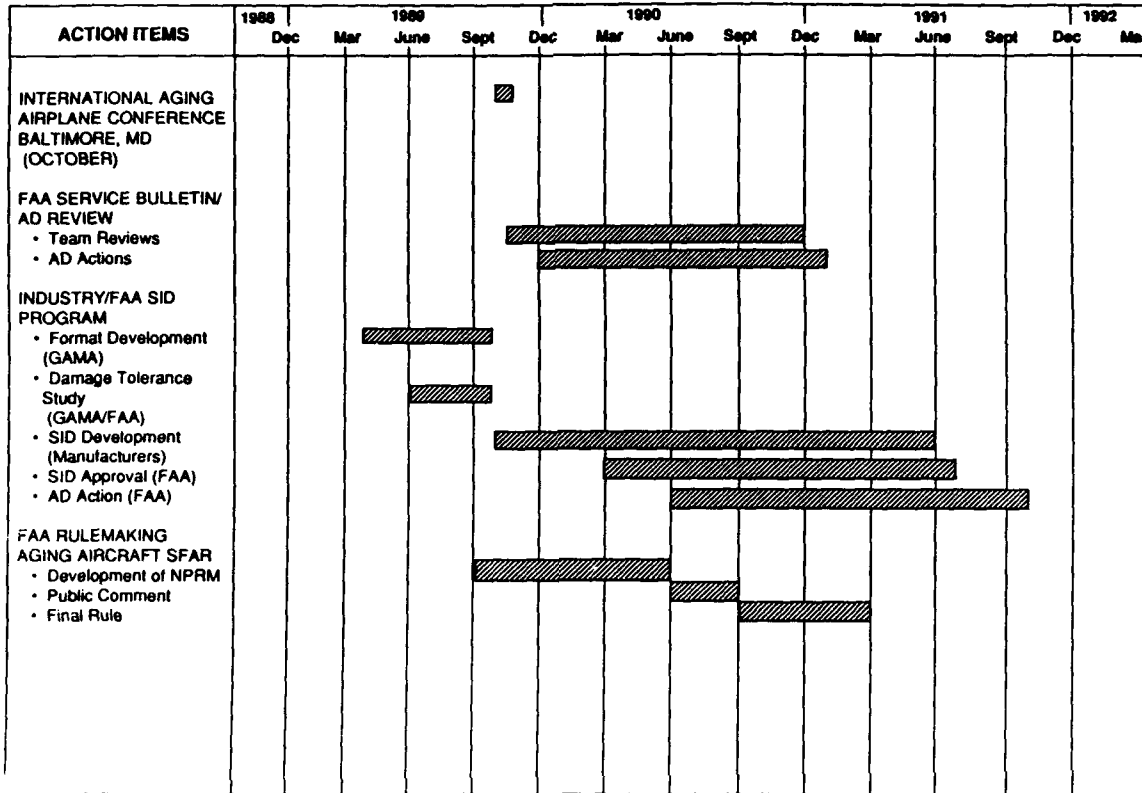
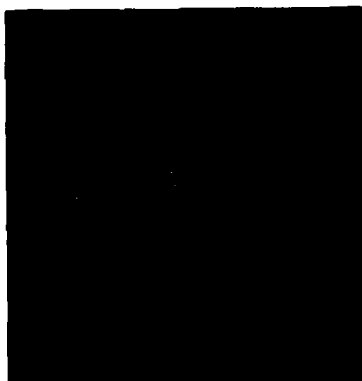


Chart 2 — Small Airplane Directorate, Aging Commuter Fleet Program

Maintenance



RAYMOND E. RAMAKIS

Assistant Director for Special Programs
Flight Standards Service, FAA Headquarters

Good morning, ladies and gentlemen. It is indeed my pleasure to be here. This morning I'd like to share with you the Flight Standards aging fleet program, which complements Leroy Keith's program in the Transport Certification Directorate, and Barry Clements' in the Small Airplane Directorate.

You've heard a lot about maintenance this morning. You heard about maintenance from Congressman Oberstar, Mr. Broderick, Tom McSweeney and the rest. Now you're going to hear a little bit more about it and some of the details. It's one of flight standards' highest priorities. In fact it is the highest priority program, and a program designed to evaluate the effectiveness of airline maintenance programs as they affect the U.S. air carrier aging fleet.

This program is fully underway and I'd like to describe it to you. We believe it will go a long way to eliminate the examples of aircraft you saw earlier today.

I want to give you some feedback on some of the things we found in the 11 inspections we

have accomplished already and share our plans with you for the future.

We're going to evaluate the effectiveness of the airline maintenance programs and we're going to identify discrepancies in the programs and make changes. This will come about through actual changes on site as they're found through advisory information, advisory circulars, FAA policy changes for our inspector workforce and through regulatory changes for the entire industry.

Our objectives are to look at the structural inspection program relative to the aircraft and the maintenance programs. We want to look at corrosion control and prevention, nondestructive inspection, major structural repairs, and, perhaps most important of all, human factors.

So let's take each objective and look at what we're going to do. (See Figure 1) In the structural inspection program, we start with a maintenance planning document. That's a document developed by the airframe manufacturer in conjunction with the FAA. It's part of the

- Maintenance Planning Document (MPD) versus Operator's Program
- MPD Structural Sampling versus Operators Program
- Is Operator Still Sampling
- Review SSID Program
- On Site Inspection of Aircraft

Figure 1 — Objective Structural Inspection Program

Maintenance Review Board (MRB) process. We take that document and match it up against the operator's program.

We also take the maintenance planning document and structural sampling program versus what the operator is doing right now. We ask if the operator is still sampling. We review his supplemental structural inspection document program and we do on-site inspection of the entire aircraft. We don't do it just on the day shift, we do it on the afternoon shift and we do it on the midnight shift. Our inspectors are issued coveralls and everything else they need to inspect an airplane.

Corrosion control and prevention is shown in Figure 2. We look at the maintenance planning document versus the operator's program. We look at how well he complied with corrosion control service bulletins. Is the manufacturer's recommended corrosion control manual being complied with? And we do on-site inspection of selected aircraft zones for corrosion.

- MPD versus Operator's Program
- Corrosion Service Bulletin Compliance
- Is the Manufacturer's Corrosion Manual Being Complied with
- Inspection of Aircraft Zones for Corrosion

Figure 2 — Objective Corrosion Control and Prevention

Nondestructive inspection (NDI), a critical factor in the review of problems on aging aircraft is detailed in Figure 3. We look at the training given to the mechanics at the airlines and what type of NDI equipment they use. Does the operator contract his work out or does he have his own people do it?

We look at the certification of individuals. There are some industry certifications, (not FAA's), and we actually observe nondestructive inspection being performed on the aircraft.

Major structural repairs and data are covered in Figure 4. We look at the major repair records of the airline and we examine them. We find out if the airline classified the repairs properly, either major or minor, and we use a structural engineer to evaluate the repairs on the aircraft.

Human factors is shown in Figures 5. It's one thing to talk about airline maintenance, it's another to work on an airplane at midnight, in a cold hangar, under poor lighting conditions, after you've had an argument with your wife.

So we look at the human factors aspect of the mechanic. We look at whether or not he has had a physical, including an eye test.

We look at his work space and design layout. We look at the types of stands, and

- Training
- Type of Equipment Being Used
- Does Operator Contract for Services
- Certification of Individuals
- Observe NDI Being Performed

Figure 3 — Objective Nondestructive Inspection

- Retrieval of Repair Records
- Classification of Repairs Major/Minor
- Evaluate Repairs on Aircraft

Figure 4 — Objective Major Structural Repairs/Data

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- Visual Acuity/Color Vision
- Workspace Design/Layout
- Types of Stands/Platforms
 - Aircraft Overhaul Docks
 - Construction Scaffolding
 - Cherry-pickers
- Lighting
 - Lighting Measurements
 - Primary Work Area Lighting
 - Supplementary Lighting
- Noise
 - Noise Measurements
 - Ear Protection
- Eye Protection

Figure 5 — Objective Human Factors

platforms, overhaul docks, and construction scaffolding that he has to use to inspect an airplane.

I said before that we completed 11 inspections. We're going to do up to nearly 90 inspections, and we're going to do a companion, complementary, same type iteration with the commuter category aircraft identified as aging.

What approach are we going to use? We're going to do on-site evaluation of the operator's maintenance programs and aircraft. We are using inspection protocols from the Boeing company, from Douglas, and we plan to use others. We have been given those documents freely by the airframe manufacturers. We've adopted them for the use of our inspectors. They have the whole airplane categorized into zones and they know exactly where to go and what to look for.

We used qualified, experienced and trained teams. We are gathering this inspection data and feeding it into a computer. At the end of all the inspections we'll have a final picture of the entire maintenance programs of the U.S. aging fleet. (See Figure 6)

We are going to observe, study, and correlate the actual against the manufacturer's rec-

1. Team Leader
2. Operator's Principal Maintenance Inspector
3. Experienced Airworthiness Inspectors
4. Structural Engineer
5. Human Factors Analyst from the Office of Aviation Medicine

Figure 6 — Team Composition

ommended maintenance and corrosion control programs. It's not enough to know what is on paper. We want to know exactly what is being done for the aircraft.

To do this we use a team. We start with the team leader — the operator's principal maintenance inspector. That's the person who has day-to-day contact with the air carrier. They are experienced airworthiness inspectors, and we use about four of those inspectors. Even though experienced, they go through a heavy formal OJT program before we allow them to inspect the airplanes. We get a structural engineer from the certification directorate; we plan to get structural engineers from the Small Airplane Directorate as part of the Aging Fleet Inspection Team. They participate in all team activities. And we get a human factors analyst from the Office of Aviation Medicine. We also take nondestructive inspection experts along.

Let me talk about some of the observations we made during the 11 inspections done in the area of structural inspection, corrosion control, NDI, major structural repairs and human factors.

Now, take these in context. There isn't any one of them that will cause anything catastrophic to happen to an airplane. But they are symptoms of things wrong in the system, things that need to be corrected and have been corrected.

We go in, they welcome us with open arms, they give us all the information we need, and the feedback from them is that we have performed a positive benefit for them. We have a

Raymond E. Ramakis

team right now that's at Aloha. I didn't plan it this way, it just so happened that's the way the schedule went.

The structural inspection program is covered in Figure 7. We found in some cases that operators' fleet sample sizes were wrong. The program was based on what the fleet size was years ago. We found operators not removing items from the sampling program when defects were found. They should have been. When a defect is found, then it should be converted to a 100 percent inspection. Sampling no longer applies. Operators have dropped sampling items from their program and they can do that if they do an analysis. In some cases they just fell through the cracks and were dropped out of the program. Items removed from the sampling program, which should be put on a 100 percent inspection, were found to be in the general visual zonal program rather than detailed inspection program.

Some operators have no corrosion control program at all. There is no real regulatory requirement to have one. You've heard Tony Broderick say he's going to mandate corrosion control by regulation, which is airworthiness directive.

In cases where there is a specific program, some of the work cards are too general with

- Operator's Fleet Sample Size Wrong. Program Based on Smaller Amount of Aircraft than in Current Inventory.
- Operators not Removing Items from Sampling Program when Defects Are Found. Should Convert to 100% Inspection on All Aircraft.
- Operators Have Dropped Sampling Items from their Program.
- Items Removed from the Sampling Program and Put on 100% Inspection Were Found to be in the General Visual Zonal Program Rather than a Detailed Inspection Program.

Figure 7 — Structural Inspection Program

regard to the type of compounds used or their application. It's one thing to have a program. It's another thing to break it down into work cards that the mechanic will understand. That's what is important. The program is important but you have to be able to implement that program to make it effective.

Nondestructive inspection is another concern. There are no *government* standards for industry to follow. There are a lot of *industry* standards. There are no qualifications required, no visual acuity test required. Everyone has a different program. There's no formal program identified with the maintenance program, and the calibration of the equipment is not current.

What we plan to do with this one is keep observing, making corrections, giving counsel, getting things straight. We have a regulatory review underway of FAR Part 65, (airmen other than crew members), where we plan to issue an NPRM that will propose a mechanic's rating for a nondestructive inspection. As you now have airframe and power plant ratings, we're going to propose one for nondestructive inspection. Nondestructive testing is very complicated and if you don't do it right, you might not catch multisite damage in the lap joints and you could have a problem.

So we think it's significant enough to create standards. Industry has a lot of standards, but they are not mandatory.

Major structural repairs are shown in Figure 8. Sometimes we find that there are no major repair records, and that comes from confusion in the regulations. There are limited records, lost records, and improper classification.

Human factors, (Figure 9), is a major concern. Noise levels are high, lighting levels are

- No Major Repair Records
- Limited Records
- Lost Records
- Improper Classification of Repairs
- No Reinspection Intervals for Repairs

Figure 8 — Major Structural Repairs

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- Noise Levels High
- Lighting Levels Low/Poor
- Supplemental Lighting Inadequate
- Work Stands/Platforms Inadequate
- Ground Support Equipment in General Poor/Lacking in Repair

Figure 9 — Human Factors

low or poor, supplemental lighting is inadequate, work stands and platforms inadequate.

In a few places we visited, ground support equipment was poor, lacking in repair, although most larger organizations have good support equipment for the mechanics.

Our schedule is shown in Figure 10. We plan to extend it out a little bit in order to do at least 90 airplanes, and I'll tell you how we're going to accomplish that later.

Structurally the program is handled out of Headquarters. AFS-1 means the Director of Flight Standards, and AFS-3 is one of his staff people. We have two Project Managers out in Seattle that handle this program. Eventually we plan to get up to six teams. We have about four people out there right now.

We are going to expand that number to 25. So we're really going to push and shove this aging fleet inspection program.

While the industry task force and groups of people are working towards solving some of the problems through the airworthiness directive process on fatigue and corrosion, this program of necessity needs to continue because you can have all the programs on paper you want, all the airworthiness directives you want, all the structural inspection programs you want but if you don't do the work, then that's the problem.

Our inspectors are trained. The Boeing company trained 300 of our inspectors and engineers on structural inspection document pro-

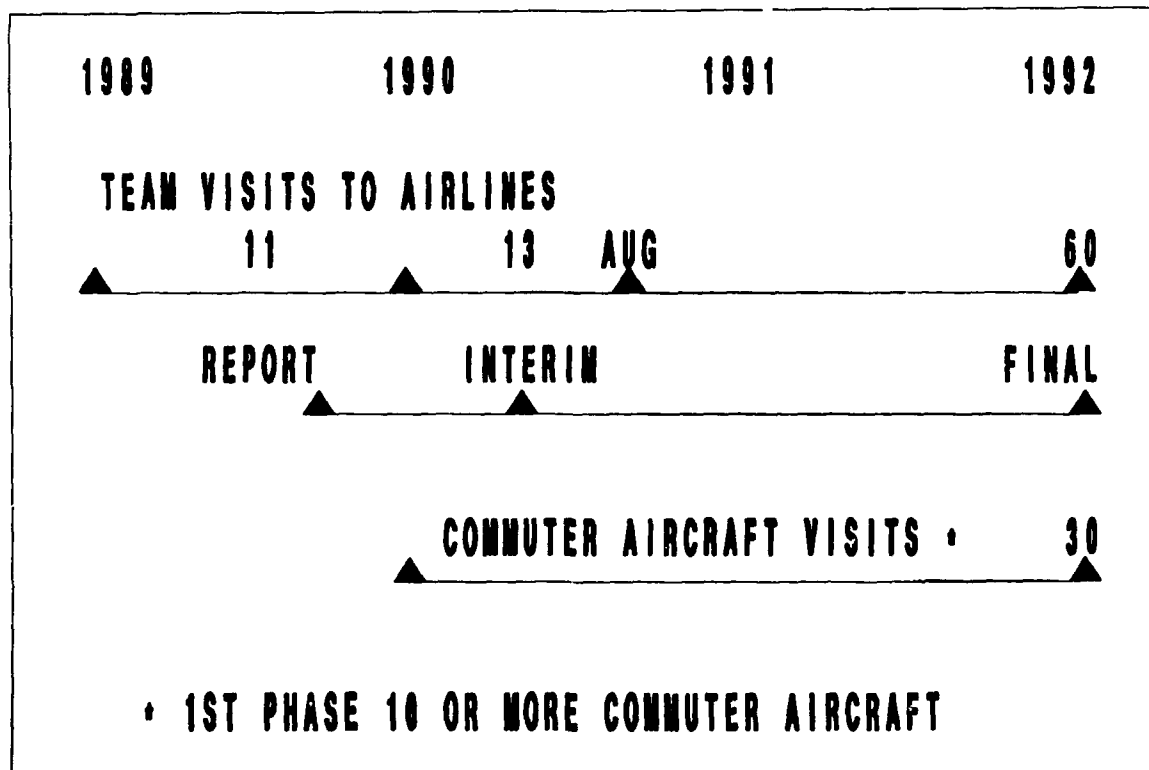


Figure 10 — Principal Activities and Milestones (Program Formation Began September 1988)

Raymond E. Ramakis

grams which included damage tolerance and corrosion. Douglas is going to do that also, and train up to 300 of our people. We have a formal OJT program for inspectors. We have a corrosion course underway in conjunction with the

Technical Center. We have an advisory circular on corrosion that's in coordination right now. We're reviewing the nondestructive inspection courses at Oklahoma City and we plan to make a major effort in the SDR program.

Research and Development



DICK JOHNSON

Aging Aircraft Research Program Manager, FAA Technical Center

It is my pleasure to be here this morning to provide an overview and brief summary of FAA's National Aging Aircraft Research Program. The program represents a major FAA commitment to develop and introduce new technologies into the current maintenance, design and manufacturing process. This effort will ensure the structural integrity, and continued safe operation and maintainability of in-service and future aircraft designs beyond their originally intended service lives. It should be noted that the program is being directed by the FAA Technical Center in Atlantic City, and is in total integration with and in support of actions being taken by the FAA Aircraft Certification, Manufacturing and Flight Standard's Maintenance Offices. Several of the regulatory issues that have been discussed previously (by Mr. Keith, Mr. Clements, and Mr. Ramakis) will be addressed further. The primary focus will be placed upon a review of emerging and advanced technologies that can be applied to the enhancement of current structural design, maintenance and inspection procedures. Taking into account the safety and economic needs of the aviation industry, the program will attempt to

define current technology gaps and develop a basis in which updated practices can be established.

Today, I am going to briefly touch upon the basic program elements, beginning with the program background, major issues, overall research objectives and approaches, and a description of the plan and status of the included short and long-term research studies.

Background

The dates and initiated actions shown in Figure 1 represent the basis for current research on both the aging commuter and large air carrier aircraft starting out with the June 1988 International Aging Airplane Conference which was initiated, in part, on the basic fatigue related occurrences (including the Aloha B-737 in-flight accident in April 1988). The primary recommendations for research at the conference were presented by industry's Air Transport Association/Aerospace Industry Association (ATA/AIA) and later reemphasized during the establishment of an air carrier industry task

• June 1988	International Aging Airplane Conference
• August 1988	Industry Task Force Initiation
• October 1988	FAA Program Review/Research Initiation
• November 1988	Aviation Safety Research Act
• March 1988	Industry R&D Task Unit Summary
• April 1988	International Aging Commuter Aircraft Conference
• May 1988	FAA Research Program Plan Publication

Figure 1 — Background

force and an FAA program review in the fall of 1988. These recommendation were included under the initiation of an FAA research program (in October 1988) and further reflected under the subsequent "Aviation Safety Research Act," which stated that the FAA undertake and direct research into the development of technology to predict the effects of wear and fatigue and to improve current maintenance practices including nondestructive inspection procedures. In early 1989, a research program plan was drafted to accommodate further recommendations on large air carrier aircraft (presented on behalf of the ATA/AIA research task unit group,) and on smaller commuter aircraft (presented by the Regional Airline Association and General Aviation Manufacturers Association (RAA/GAMA) at the April International Aging Commuter Aircraft Conference). In May 1989, a final FAA Aging Aircraft Research Program Plan was published and the program became fully operational.

Issues

Figure 2 shows the six major issues that are addressed under the plan, and again were highlighted as a result of industry recommendations involving primarily large, pressurized, aircraft structures. As affecting both large and small airplanes, I would like to add that at this time the program emphasis and included tasks have been placed primarily upon the larger pressurized transport airframe, and engine static structures, because of a significant number of reported fatigue-related occurrences and also, in part, because of the higher average age of the transport air carrier fleet (12.1 years) as compared to a younger commuter fleet (5 years or less).

Objective/Approach

As previously discussed, the program's primary objective will be the introduction of those technologies into the maintenance design and manufacturing process that will ensure the structural integrity of high-time, highly cycled airframe and engine structures. Specifically, we are interested in developing existing and new technologies that will provide us with the ability to predict, detect, prevent or control fatigue and corrosion in civil airframe and engine static structures. The approach consists of short- (2 years), intermediate, and long-term (3-5 years and beyond) research study tasks. The major emphasis at this time is the completion of those near-term tasks that will provide a benefit or improvement to current in-service airplanes, such as improved crack growth control disbond inspection procedures, or improved corrosion inspection and control techniques.

- Fatigue/Fracture
- Flight Loads
- Corrosion
- Nondestructive Inspection
- Repairs

Figure 2 — Issues

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Obviously, following our long-term tasks are those that concern newer inspection concepts, and design or material properties that have greater applicability to existing but primarily to future aircraft configurations.

Research Program Plan

Figure 3 describes the basic elements of FAA's Aging Aircraft Research Program Plan, which initially provides for the identification of issues and the selection of recommended research tasks that have a direct bearing on current maintenance, and structural design and manufacturing procedures. As shown, emerging and advanced technologies will, and are being, transferred from ongoing basic research activities at NASA, the Department of Defense, industry institutions and universities. We presently have agreements and contracts in place with these organizations. The results of this research effort are essentially a series of data bases that will provide for the establishment of

new and updated advisory, training and regulatory material. At present, the plan provides for a multiyear short- and long-term research effort. We envision the plan to also represent a living document that can be updated periodically. It presently includes 27 identified research tasks we anticipate completing during the 2-5 year period. In the short-term segment, we will attempt to introduce existing and emerging laboratory technology onto the manufacturers and airlines for the benefit of the current and in-service fleet. In the long-term, we will concentrate on the development of new and advanced concepts that will have a major effect on the performance and maintenance of new and future aircraft designs.

Research Activities

Some of the major short- and long-term research tasks that are now underway are reflected in Figure 4. During the research sessions beginning later this afternoon, many of these

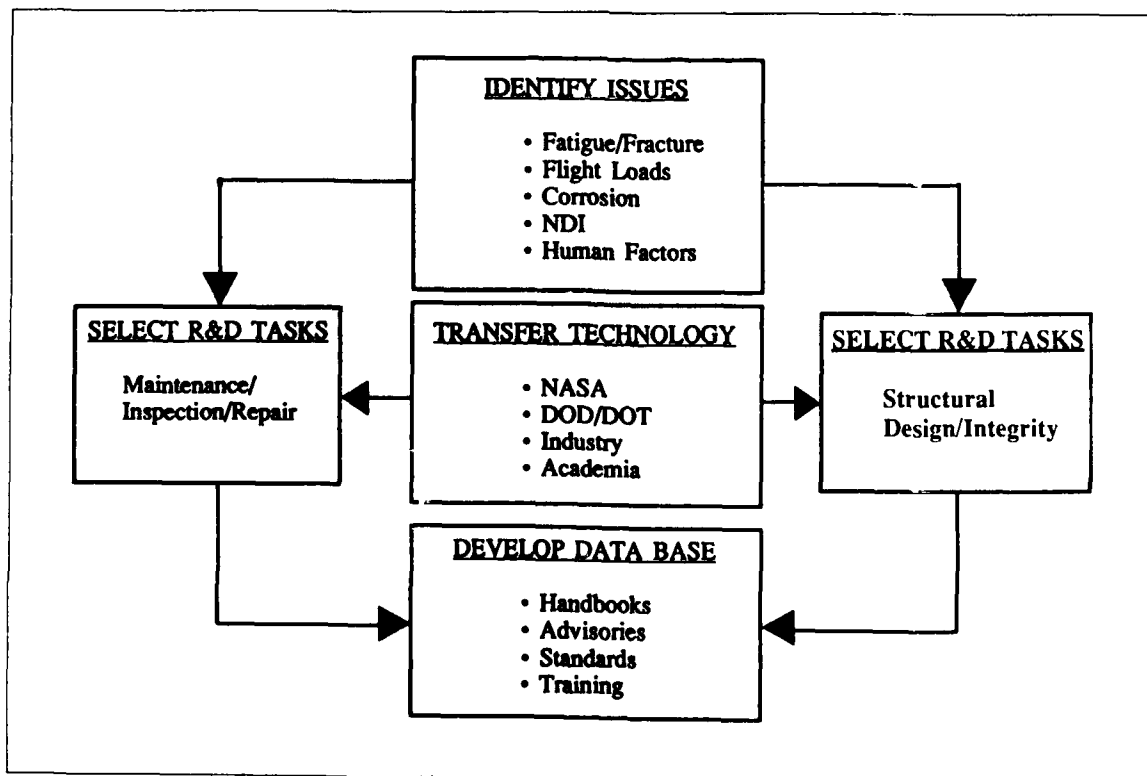


Figure 3 — Research Program Plan

ISSUES	SHORT TERM (FY 89-90)	LONG TERM (FY 91-Beyond)
Fatigue/Fracture	• Develop Damage Tolerance Handbook • Assess Proof Pressure Test Viability • Document DOD Tr. A/C Life Assessment • Evaluate Commuter Fleet Structures	• Review Analysis/Test Methodologies • Assess MSC/Damage Tolerance Handbook • Evaluate Engine Life Cycle Limits • Review Analysis/Test Methodologies
Flight Loads	• Publish V-G-H Data Reports • Design Prototype Smart Recorder	• Install Onboard Smart Recorders • Conduct Flight Load Data Collection
Corrosion	• Assess Corrosion Control AC 43-4 • Review Manufacturer's Corrosion Manuals • Develop Corrosion Protection Training Material	• Develop Corrosion Protection Handbook • Conduct Corrosion Crack Growth Control
Nondestructive Inspection	• Survey NDI Equipment/Techniques • Assess NDI AC 43-3/43-7 • Evaluate Emerging NDI Systems	• Develop NDI System Handbook • Update NDI Training Manual • Evaluate Advanced NDI Systems • Assess Engine NDI/Microsensor Usage
Human Factors	• Perform Task Analysis • Study Equipment Design/Environment • Assess Simulation Oriented CBI	• Study Job Performance Aids • Assess Job Selection/Placement Procedure • Develop Human Factors Handbook
Repair/MSIP	• Survey Engine Repair Practices	• Review Airframe Repair Practices • Document Engine Component Condition • Establish Maintenance/Structural Design Integrity Plan

Figure 4 — Research

tasks will be discussed in more detail. As shown in the Figures, we are defining the short-term activities as those that will be completed within the first two years of the program, while long-term efforts will be completed during a next 3-5 year intermediate period and beyond.

Fatigue/Fracture

Under the identified fatigue/fracture area which is being supported, in part, by NASA, DOD, and DOT Transportation System Center, we have focused attention upon bringing up the level of awareness of our own technical personnel with the development of a fracture mechanics handbook or damage tolerance design practices that will later, during the long-term activity, be updated to include added details on multisite cracking and a further review of existing test and analysis methodologies. One of the major efforts being taken presently is an assessment on the viability of proof pressure testing as a means to ensure integrity of a given fuselage structure. Other actions include a review of DOD transport life assessment procedures and evaluation of smaller commuter aircraft structure for the establishment of appropriate supplemental inspection procedures.

Flight Loads

In the flight load area, a major effort is being directed at the updating of an existing flight load data base. To this extent, we are working jointly with NASA-Langley in the development and implementation of an on board flight load data collection program. During the 1970s, NASA collected a significant amount of V-G-H data on current widebody airplanes. A joint program with NASA is now under way to publish this information and to further develop a *new smart* data recorder system for the purpose of obtaining additional in-flight gust and maneuvering load data on current generation airplanes. The results of this effort should assist both the airplane designer and user in the establishment of safe and precise operating usage envelopes.

Corrosion

Current research in the corrosion protection area consists of tasks being directed primarily at corrosion control, in which case results can be readily obtained for application to the existing in-service fleet. Again, we are assisting our flight standards people in the updating of Advisory Circular 43-4. Hopefully, this update will identify new and more effective coatings and inhibitors that have been previously researched by the military. This leads us to a review of current manufacturer proposed manuals and into the development of new corrosion protection training material, all of which will be completed this fiscal year. Long-term efforts include the development of a comprehensive corrosion control handbook for both engineers and maintenance personnel. Also, as another long-term effort relating primarily to the structural fatigue area, we and the CAA will be jointly involved in a study to determine the effects of corrosion on crack growth.

Nondestructive Inspection

The approach taken to ensure the development and introduction of new technologies into the nondestructive inspection area was to survey what equipment and techniques are presently being used, review their overall effectiveness, and then, simultaneously, provide for a near-term evaluation of new emerging systems. This effort will be followed by a long-term assessment of new advanced concepts such as large scan holographic or neutron radiography systems, or concepts which reduce or eliminate personnel workloads through use of robotics or automotive scanning systems. At this time we are in process of reviewing a draft survey report which addresses current and existing NDI equipment used in airline service; assisting our Flight Standards maintenance organization in the assessment of current NDI advisory material (43-3/43-7); and initiating evaluation of other emerging NDI systems, using the FAA Technical Center's B-727-100 [N-40]. These systems include new acoustic

Dick Johnson

emissions and large area scan thermal systems using new image enhancement methods to reduce inspector workload. Long-term goals for FY-91 and beyond will include the development of a long overdue FAA NDI handbook and training material for FAA engineering and maintenance personnel. In addition, we intend to look into new concepts of on-ramp engine inspection including use of microsensors and newly advanced automatic systems for airframe inspection.

Human Factors

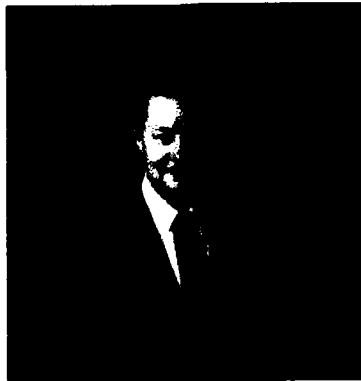
Short- and long-term research studies covering the effects of human performance, on the overall engineering, manufacturing and maintenance process, first will involve a review and assessment of personnel work tasks and environmental effects, followed by the identification of areas that could be improved — such as improvements in equipment, equipment usage and training. The goal under the human factor study program will be the establishment of a human factors handbook that will include equipment needs, job training, personnel performance aids and updated job selection and placement procedures. At this time the major emphasis of the program is aimed at the inspection area. Civil Aviation Medical Institute personnel are actually participants in the Flight Standard airline fleet evaluation program. With respect to current funding involving this effort, our flight standards people indicate that there is a wide variance of equipment and maintenance manual instruction, including on-the-

job training procedures; therefore the need exists to establish minimum guidelines.

Repair/MSIP

In view of recent industry and FAA fleet surveys of older aircraft maintenance inspection and repair practices, there has been concern about the adequacy of some structural repairs and their effect on the life of surrounding structures and supporting damage tolerance design analysis. In many cases, repairs, such as structural patches and replacement of frame sections, may appear to be minor and satisfactorily meet local static loading requirements. However, the same repairs, without engineering or manufacturer review, could easily result in increased crack growth and failure of the surrounding structure. Other concerns involving both airframe and engine repair practices are variances that may exist between airlines and contractor repair facilities, and the effect these variances may have on fleet safety. At present, one of the near- and long-term actions includes a review of these practices and other repairs and maintenance factors affecting engine and airframe life. One of the major tasks that we see developing from this effort is the establishment of an overall maintenance and structural design integrity plan (MSIP). The plan will provide for the identification and close integration of critical design issues and maintenance action affecting the life of a given airplane. Specifically, it will provide the FAA with the maintenance of documentation to include minimum retention of permanent records involving maintenance and repair.

ATA/AIA Airworthiness Assurance Task Force



CLYDE R. KIZER

Vice President, Engineering & Maintenance, Air Transport Association

Several of the previous speakers have mentioned the activities of the Airworthiness Assurance Task Force, led by Robert Doll, Vice President of Technical Services at United Airlines.

I think that the effectiveness of that group is unique in the history of the industry. It's unique from several aspects: one, because of the activity that they have undertaken over this last year-and-a-half, but also more importantly, it's unique because over 200 people have participated in this activity and have been able to break down barriers that existed in the past to open honest communications.

And I think that we truly have a forum for open and honest discourse. That to me is the key. If you don't have that honesty and that openness, there's no way that you can understand and address the issues.

The activities, of course, have been very productive. The activity has been intensive, as related by Leroy Keith and some of the other task force members. It has also been very creative. Often, if you assign insoluble problems to

people who don't know that the problems are insoluble or unsolvable, they get resolved.

I'm going to borrow a comment made by Jim Marr of the Massachusetts Institute of Technology. He was visiting Taiwan and met with a gentleman who is a scientist and an artist of that country. Jim marveled at the artistry of this gentleman.

Jim asked the man if he thought that Jim, at his age, could undertake this type of art activity, and the gentleman said to him, "Old men ask a lot of questions but don't make much progress. Young men don't ask any questions and frequently make a lot of progress."

And that's truly been the case in many of the things that we've done. We've turned really difficult problems over to young engineers, and have been amazed at the creativity that they bring to the problems. So it's been an intensive, creative and productive undertaking.

Many in this audience are participants in what we have done over the last year-and-a-half, and I sometimes feel that we're on a closed

loop system where we gather together, we work, we solve some problems, and then we gather together to tell everybody what we've done. And it's almost like preaching to the choir because everybody out there has been involved in one way, shape or form with this whole activity.

One of the things that I'd like to stress is the international scope of the activity. Several of the previous speakers indicated that aging aircraft is truly an international problem and it is being attacked on an international plane.

Considerable publicity has been accorded for the Boeing working group and the Douglas working group, and those working groups of course not only represent the manufacturer but are manned and staffed by all of the operators, plus the regulatory agencies. We have over 94 separate and independent agencies involved in this activity, again involving over 200 people.

To get 94 separate agencies to agree to a course of action is not easy, and it is not easy to communicate with 94 separate agencies and organizations. But because of the quality of the people who have participated, we have been able to do so, and do so effectively.

In the past, the press, and perhaps ourselves, have overlooked the fact that the international working groups are working as effectively as the Boeing and Douglas working groups and in many cases are further ahead in their efforts. They haven't produced their results for publication yet because of differences in the way we are going to have to promulgate that information and ensure consistency between the task units.

We can't overlook the activities of Lockheed, Airbus, British Aerospace and Fokker in this undertaking, because certainly it has been as intense for the manufacturers and the operators of those task units as it has for the Boeing and Douglas working groups.

I received some information recently that the Aeronautical and Astronautical Association of France (AAF), which is equivalent to our American Institute of Aeronautics and Astronautics (AIAA), is going to conduct a conference on aging aircraft in Bordeaux, France on March 28th and 29th, 1990. The members of the

Aging Aircraft Task Force have been asked to participate in that meeting. So that again reflects the true international recognition of the problem of continuing airworthiness and the intensity with which people are trying to attack the problem and resolve it.

Numerous summaries of our activities have been presented in various forums. What I would like to do today is present a summary of what we recently gave to the ICAO Assembly. This was an effort on the part of the FAA to inform that international body about our activities. ICAO represents 170 different nations. What I'd like to do today is run through that summary with you. This represents the latest summary update, as given to ICAO.

This presentation is meant to convey the historical background concerning the continuing airworthiness of the air transport fleet. It includes the extraordinary activities intended to address the aircraft structural issues arising from the fact that many aircraft in the world's commercial fleet are being operated beyond their original economic design goals.

We shall start with a discussion of the background, which has led us to our current fleet status, followed by a brief summary of that status and a discussion of the events leading to the establishment of the ATA/AIA Airworthiness Assurance Task Force, including its objectives and progress to date.

Safety is the paramount issue relating to an effective air transport system, and of primary importance to the issue of safety is the airworthiness of the fleet of aircraft serving that system. From the time an aircraft is conceived on the drawing board until it is retired from use in the commercial system, its airworthiness is based on mutually dependent principles and responsibilities.

Airworthiness begins when the aircraft manufacturer incorporates damage tolerant design criteria according to regulatory requirements. That airworthiness is assured by the airlines who must operate the aircraft in accordance with a progressive program of preventative maintenance.

The regulatory agency must provide a system of surveillance to ensure that the design

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criteria are correct, that the manufacturer and airlines operate in accordance with their defined procedures and that any threat to airworthiness is detected, reported, analyzed and acted upon in a timely and effective manner.

The airlines, manufacturers and regulatory agencies represent a triad of check and balance responsibilities meant to ensure the viability of the basic and crucial element of safety in airworthiness. The system has proven its effectiveness throughout the dynamic and successful years of development of our world air transport system. It has been so successful, that over the years, aircraft have been retired from major commercial use almost exclusively for economic reasons when they could no longer compete effectively in the marketplace.

In many instances, those aircraft did not actually retire, but were shifted to another operation in which they could still perform a productive function for society.

With few exceptions, the ability to maintain airworthiness has not entered the decision concerning retirement for our commercial fleet. In fact, the industry has long believed that there are no structural considerations which define life limits for aircraft fleets.

Aircraft are designed to meet many performance, tactical and economic goals. The economic goals are generally meant to convey, to prospective buyers, planning considerations for strategic and marketing issues. They do not reflect the manufacturer's assessment of structural limitations. Economic design goals are defined in terms of years of service, numbers of flight cycles and flight hours.

The fast-paced aircraft industry has developed at a phenomenal rate. The leading edge of technology moved us from wooden airplanes powered by newly-developed internal combustion engines of sufficient performance and weight to allow the briefest of flights, to our current inventory of metallic ships of the air whose speed, range and comfort have allowed major portions of the world's population to benefit from the advantages of air travel.

That technology was a driving force to the economic obsolescence of our aircraft fleets. Bigger, faster, higher were always the precursors to competitive success.

With the advent of pressurization, the jet engine, the swept wing, and the jumbo jet, we have reached a point where major technological breakthroughs will be required to relegate an aircraft to a position of noncompetitiveness. Until and unless noise constraints or fuel costs become prohibitive, the first and second generation jet aircraft can continue to be productive in competition with their glass cockpit counterparts of the current generation.

These conditions have resulted in our current environment where a significant number of aircraft in our commercial fleet are operating beyond their original economic design goals. We are facing a new era in our need to assure the continuing airworthiness of our transport fleet.

New challenges often mean that new philosophies must be developed to meet those challenges. We have faced similar challenges, to our collective responsibilities for airworthiness in the past, and are required to do so again.

When the first pressurized aircraft came into use, we found that we had to pool our resources so as to study this new technical development and determine appropriate revisions to design, test and maintenance procedures in order to accommodate it.

In 1968, an industry panel of manufacturers, airlines and the FAA was established to address those issues. The success of that endeavor has led to a similar organizational approach to widespread industry issues, including the development of a new damage tolerance criteria in 1978.

The industry was able to initiate revolutionary action in 1981 when it developed the Supplemental Structural Inspection Program (SSIP). This process allowed a proactive approach to maintenance problems through early detection stemming from lead aircraft inspections. The industry was thus capable of planning to accommodate expected maintenance difficulties, rather than having to react to them as they occurred.

The manufacturer was able to predict production requirements. The airlines were able to plan for appropriate resources, and the FAA had better guidance as to where problems were

Clyde R. Kizer

likely to occur so that they could initiate appropriate regulatory requirements to ensure airworthiness.

The process worked smoothly and effectively until several aircraft structural failures required that we reassess our process and our philosophy. The seriousness and significance of those failures required that the industry review the effectiveness of the well-established principle of check and balance with respect to our shared responsibilities.

These incidents demanded that we thoroughly question our concepts concerning the means to continuing airworthiness.

Let us review the status of the fleet (see Figure 1) that contributed to our need for reassessment. The average age of the U.S. commercial fleet is almost 13 years. The figure indicates

that better than 46 percent of that fleet is older than 15 years of age.

Figure 2 shows that eight common transport category aircraft have exceeded their economic design goals. Many of these aircraft are in common use throughout the world. Despite these age-related concerns and despite the structural failures, which required that we question our current practices, the exceptional safety record compiled by the air transport system and the continued safe and productive use of those aircraft after they have left the major airlines proves beyond question that airplanes are capable of operating safely beyond their economic design goals.

Aircraft are like people; some show signs of

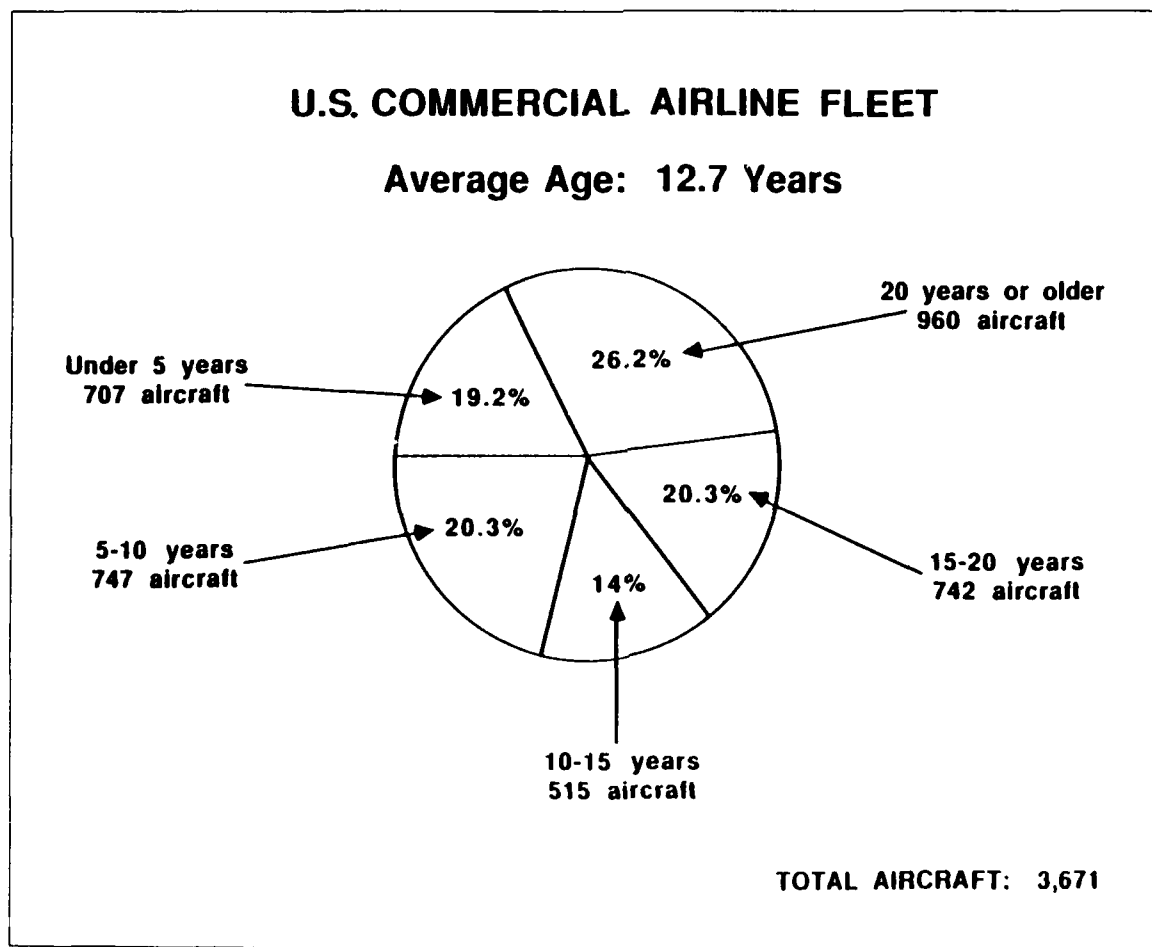


Figure 1

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- Airplanes from eight different models (B-707, 720, 727, 737, 747, DC-8, DC-9, BAC 1-11) have exceeded the economic design goal
- Airplanes are capable of operating safely beyond their economic design goal

Figure 2 — Service History

age earlier than others and for reasons not attendant to chronology.

The major effects of aircraft age are brought about by flight cycles due to the skin-stretching process involved in pressurization. Other effects result from hours of operation, years of operation and operating conditions.

The major factor concerning continuing airworthiness for the operating fleet is diligent application of an effective maintenance program. Despite recent events, structural failures account for a very small percentage of aircraft accidents.

Figures 3, 4, 5, and 6 reflect the economic design goals and current status of the major aircraft models produced in the United States. Most aircraft have a 20-year economical goal, while the flight hour and cycle goals reflect the intended use of the aircraft in terms of stage length and flight frequency.

The Boeing aircraft fleet status figure is typical of the expected growth in our aging fleet resulting from the combined effects of high consumer demand, limited existing capacity and extended lead time requirements for fleet replacement.

The two major threats to the continuing airworthiness for aircraft are fatigue and corrosion. The mechanics for fatigue are generally well-understood and our continuing maintenance programs are based on these concepts.

Corrosion is not confined to age, for it can begin the moment two dissimilar metals are brought in contact on the assembly line. As aircraft age, the incidence of fatigue increases and corrosion can become more widespread.

The major concern rests with the interaction of these two processes, for our understanding of fatigue principles is invalidated by the presence of corrosion.

Airworthiness is not strictly a mechanical process responding to known principles of structures and materials. Human involvement is crucial to the process of continued airworthiness. Because this will always be true, we must develop, understand and apply knowledge of human interaction with the maintenance process. This must include concepts regarding training and qualification as well as the development of an effective man/machine interface in the inspection process.

The FAA brought focus to all of these concerns when they sponsored the Conference on Aging Aircraft in June of 1988. That conference brought together over 400 world representatives to review the impact of aging on aircraft and engines and the need for improved inspection techniques and technologies to detect and counter the aging effects.

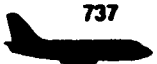
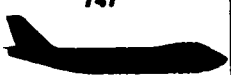
It was obvious to most of us who were present at that conference that the technical topics raised, airframes, engines, nondestructive testing and human factors, could not be resolved in the three days allotted for the conference. Consequently, representatives of the Air Transport Association and the Aerospace Industry Association submitted a list of eight recommendations for consideration by those attending the conference. The final point shown in Figure 7, recommended the establishment of an industry task force to resolve the technical issues raised at the conference.

The formula that had proven successful in the past was recommended once again, this time with a scope and scale that is unprecedented in the world of aviation. Once again, the triad of manufacturer, regulator and operator were called upon to contribute their expertise and experience in response to a common threat.

Since the issues were not confined to independent state borders, the resolution of those issues had to be international in scope. Thus, the parallel participation of an international triad was organized and enacted.

Figure 8 depicts the pyramid organizational approach adopted to include a steering

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AIRPLANE MODEL	INITIAL SERVICE DATE	ACTIVE (TOTAL) COMMERCIAL FLEET		ECONOMIC DESIGN LIFE OBJECTIVE	NUMBER OF AIRPLANES EXCEEDING GIVEN PERCENT OF DESIGN OBJECTIVE	
		NUMBER OF OPERATORS	NUMBER OF AIRPLANES		75%	100%
707 	SEPTEMBER 1958	80	213 (729)	20,000 FLIGHTS 60,000 HOURS 20 YEARS	170 152 192	59 47 123
720 	JULY 1960	7	14 (153)	30,000 FLIGHTS 30,000 HOURS 20 YEARS	14 14 14	7 6 14
727 	FEBRUARY 1964	128	1849 (1821)	60,000 FLIGHTS 50,000 HOURS 20 YEARS	170 785 784	2 358 435
737 	FEBRUARY 1968	132	1438 (1490)	75,000 FLIGHTS 51,000 HOURS 20 YEARS	52 226 297	3 38 9
747 	JANUARY 1970	67	614 (648)	20,000 FLIGHTS 60,000 HOURS 20 YEARS	84 222 180	5 68 0

- ▶ AIRPLANES REPORTED TO HAVE FLOWN DURING 1988.
- ▶ SPECIAL DESIGN LIFE OBJECTIVES HAVE BEEN ESTABLISHED FOR -SP AND -SR DERIVATIVES.
- ▶ AT THIS POINT IN THE AIRPLANE LIFETIME, SOME INITIAL FATIGUE CRACKING MIGHT OCCUR.

Figure 3 — Service History (March 1988)

AVL MODEL	NO. ACFT BUILT	ACFT CURRENTLY IN FLEET	DESIGN OBJECTIVE FLT CYCLE	NO. ACFT EXCEEDING	DESIGN OBJECTIVE FLT HRS	NO. ACFT EXCEEDING	DESIGN OBJECTIVE YEARS	NO. ACFT EXCEEDING
DC 8 	858	350	25,000	49	50,000	203	20	350
DC 9/MD 80 	DC 9/MD 80	924	40,000	504	30,000	635	20	184
	MD-80/543	496	50,000	0	50,000	0	20	0
DC 10 	440	425	42,000	0	60,000	0	20	0

Figure 4 — DAC Commercial Jet Aircraft Fleet Status

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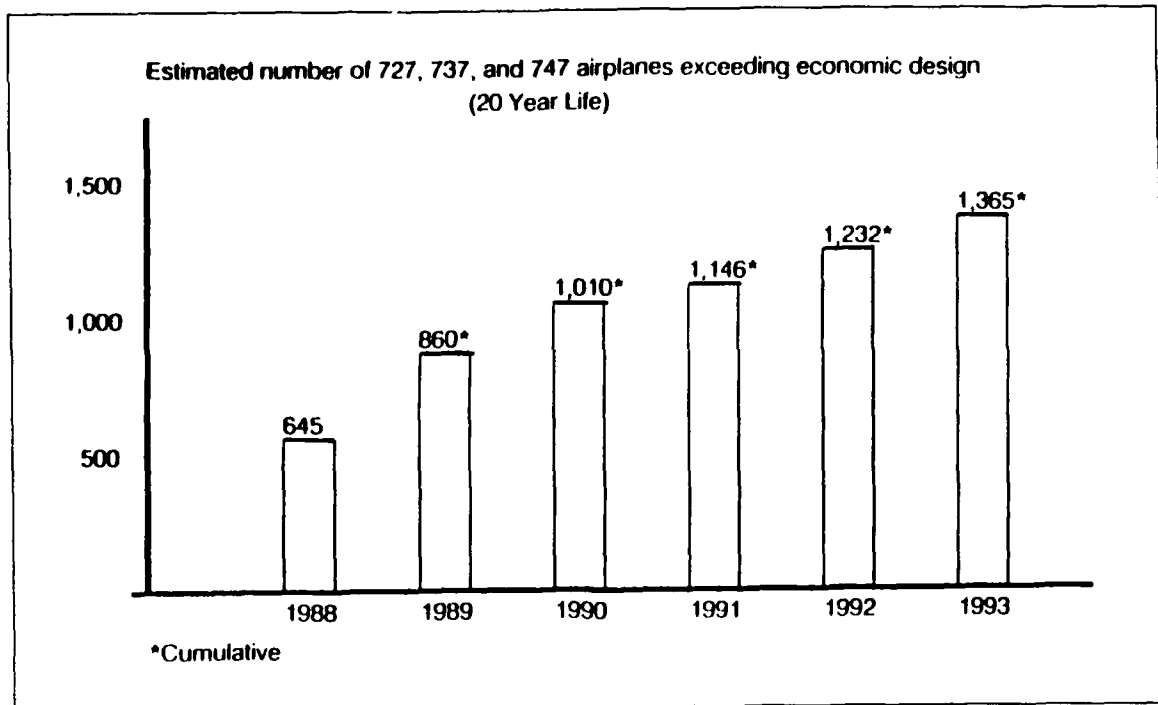


Figure 5 — Fleet Status

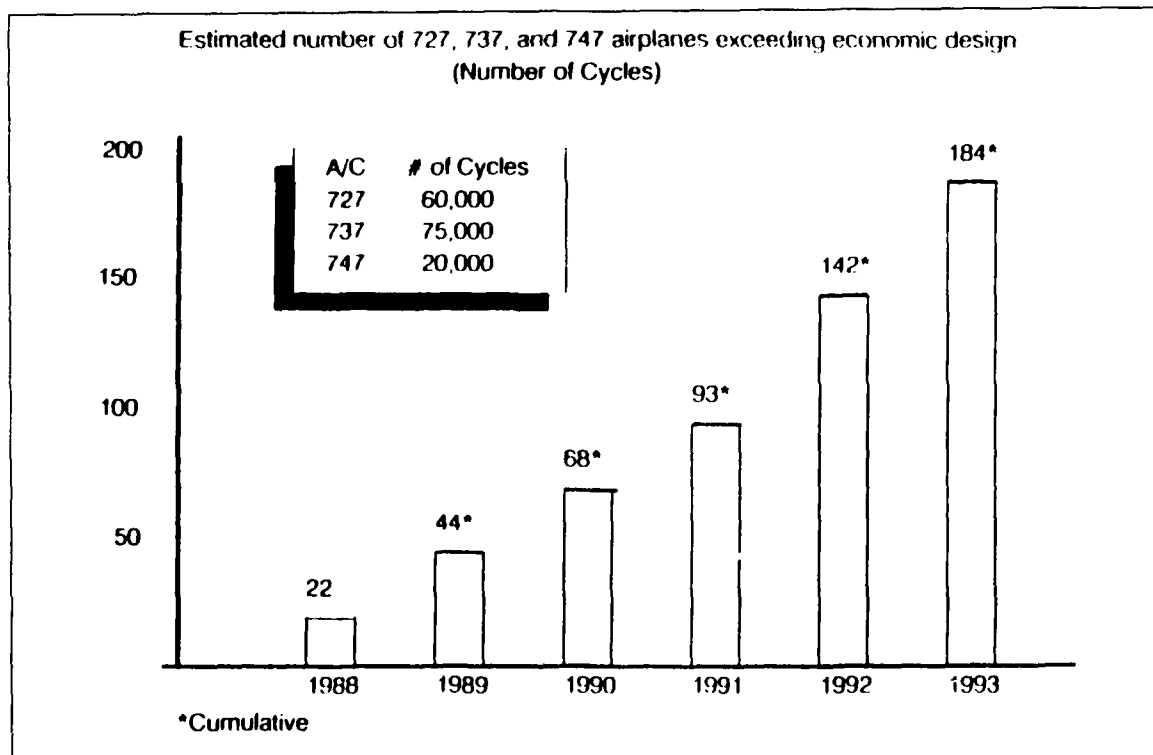


Figure 6 — Fleet Status

- Continue to use present system of maintenance and inspection with diligence and thoroughness. Find out why a single airplane suffered major structural failure and adjust systems as necessary.
- Initiate research to find better ways to assess structural condition and detect structural problems.
- Continue to pursue concept of tear-down of oldest airline aircraft to determine structural condition and conduct fatigue tests on older airplanes.
- Pursue transfer of available body of knowledge of NDT and its application to airplane inspection.
- Put research and development money into improving NDT techniques and methods.
- Examine all aspects of human factors involved including training and qualification of airline inspectors.
- Ensure that the communications systems among airlines, the manufacturers and the regulatory authorities are adequate.
- Establish task forces from the airlines, manufacturing industry, FAA and NASA to continue the work begun at this conference.

Figure 7 — Aging Aircraft Conference in Washington, D.C., June 1-3, 1988
Airline/Manufacturer Recommendations

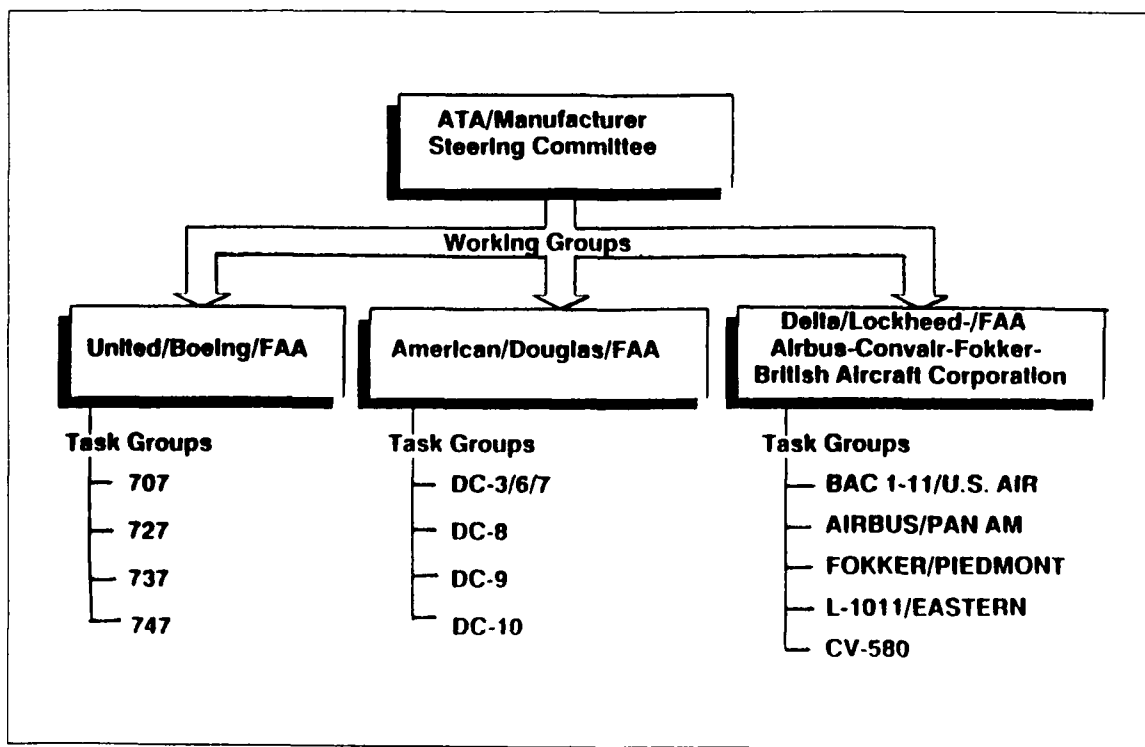


Figure 8 — ATA/AIA Airworthiness Assurance Task Force

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committee representing all agency and organizational factions of the task force and three working groups which encompass all aircraft models employed by most major world air carriers.

Figure 9 lists the 32 U.S. carriers and two military participants and the 42 international carriers who have contributed so effectively to the success of the task force. In addition to the operators, seven airframe manufacturers and five regulatory agencies are a part of the effort.

Finally, NASA and the Professional Aviation Maintenance Association (PAMA), are represented on the steering committee.

The problem was large, with significant ramifications and the size and scope of the task force reflects the sense of urgency needed to address the concern. The goal was to bring together the most comprehensive body of technical experience and expertise possible so as to accurately define the problems and provide the best collective judgment to the resolution of those problems.

We identified the world users of the aircraft fleets from the aircraft manufacturers' listings and invited operators of those fleets to participate on the basis of their fleet size.

Generally, 60 to 70 percent of the population of the world's fleet for the aircraft models of concern is covered. Working groups are

organized along manufacturer product lines for Boeing and Douglas aircraft. The remaining manufacturers are represented in the International working group, comprised of Airbus, Lockheed, British Aerospace, Fokker, and Convair.

These working groups are composed of the front line engineering and technical personnel who have the daily responsibility for the airworthiness of their respective fleets. There are over 200 individuals involved in this task force. All activities are conducted during monthly meetings, many of which require two to three weeks of preparation in order to adequately address the issues at hand. Leroy Keith indicated earlier that there have been 113 such meetings since this task force was formed.

The working group objectives are depicted in Figure 10 and have been reviewed by previous speakers. They are short-term in nature and reflect the priorities of establishing improved safety margins for structural integrity, and developing an effective corrosion prevention and control program to assure the viability of the maintenance process.

The first objective required a review of all structural problems that have affected the fleet since the specific aircraft model was introduced. This was accomplished during a review of existing service bulletins, which are manufac-

Airlines — USA		Airlines — International		
United	Evergreen	Air France	Scandinavian	Dan Air
American	Hawaiian	SWISSAIR	Air Canada	Ansett
Delta	Midwest Express	British Air	German Cargo Service	TAT
Federal Express	Orion Air	Alitalia	Iceland Air	Lingflug
Aloha	Emery	KLM	Nationair	Minerve
Piedmont	United Parcel Service	Lufthansa	Trinidad	Aero Lloyd
Northwest	Braniff	Britannia	Saudia	Oman Royal
USAir	Batch Air	Canadian	UTA	Transfrick
Trans World	Dalfort	Japan Airlines	Va.ig	World Ways Canada
Eastern	Emerald Air	Qantas	Gulf Air	Austral
Pan Am	International Air	Korean	Thai Airways	BWIA
Continental	Polaris Aircraft	Alisarda	Air Inter	Finnair
American West	Trans Continental	Avensa	Aer Lingus	Garuda
Alaska	Sunworld			
Southwest	Midway			
Flying Tigers	USN			
Airborne Express	USAF			

Figure 9 — Airworthiness Assurance Task Force Working Group Participants

- Service bulletin review
- Corrosion directed inspection program
- Review maintenance program for guidelines/recommendations
- Review SSIP/SSID for effectiveness/recommendations
- Develop guidelines for structural repairs in relations to long term operations

Figure 10 — Working Group Objectives/Activities

turer-initiated action documents to address reported fleet problems.

The collective experience of the working group elements was then brought to bear on the issue to determine if mandatory action should be initiated for some of those service bulletins based on their possible safety implications and their difficulty in detection. Several thousand such service bulletins have been reviewed and two of the working groups have made recommendations concerning mandatory action.

The Boeing working group recommended that 161 service bulletins become mandatory, while the Douglas working group recommended that 159 service bulletins become mandatory. The FAA, as indicated earlier, is taking the necessary action to promulgate these recommendations in the form of rulemaking. Other regulatory agencies will act as determined by their review of the proposals and the actions taken.

All of the working groups have essentially completed their efforts regarding the development of recommendations for an effective corrosion prevention and control program for their specific aircraft models. Once compiled, this program will be submitted to the FAA and other regulatory agencies for consideration and action in the form of regulatory requirements.

I might mention that since this text was prepared, we have presented the Boeing working group program, which has been reviewed and added to by other working groups, in a sub-committee action. This will form the basis of a

generic corrosion prevention and control program.

Other working group objectives include a review of existing maintenance programs to determine if recommendations should be made concerning limitations of such programs, a review of the SSIP to determine if that program has been effective with respect to its original intent, and a review of existing structural repairs to determine the need for additional action.

The composition of the steering committee headed by Bob Doll (refer to Figure 8) reflects the parallel international scope of that body. The function of the steering committee is to define the objectives of the task force, provide guidelines for the consistent accomplishment of those objectives, ensure that time lines are kept, and to provide coordination and resources for longer range objectives.

These objectives are delineated in Figure 11 and include coordination with the FAA human factors efforts led by Dr. Shepherd of FAA Headquarters, establishment of a committee to develop improved methods for technical data collection, analysis and distribution on an international basis, development of research and development efforts with respect to non-destructive testing technology and fatigue testing and development of recommendations for standardized training and qualification requirements for inspectors and mechanics. All of these projects are well underway.

The Airworthiness Assurance Task Force was originally intended to complete all of the objectives under its charge by the end of 1989

- Human factors
 - Maintenance communications
 - Non-destructive testing technology
 - Fatigue testing
 - Inspector/mechanic training and qualifications
- Industry commitment to fix the technical problems before political solutions are forced upon us

Figure 11 — Long Term Objectives

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and then its activities were to be dissolved. The unparalleled success of the individuals participating in the task force in achieving open, honest and effective communications and action plans indicates that this effort and its effects are too valuable to allow complete dissolution.

The intent at this time is to continue the activities of the steering committee and working groups, perhaps on a quarterly schedule

for the steering committee, and an annual basis for the working groups, so as not to lose the valuable synergism that this group has developed.

The task force was formed to address technical issues in a responsible and responsive manner. I believe we have done that and I think the testimony and the activities to date indicate the success of the organization is unparalleled in the history of the air transport system.

NASA Aging Aircraft Efforts



DANIEL R. MULVILLE

Deputy Director, Materials and Structures Division, NASA Headquarters

It's a pleasure to be here and have an opportunity to discuss the activities that NASA is undertaking in support of the aging aircraft issue. We see the FAA as the lead agency within the government to undertake these activities, and our role is to work with the FAA and to develop technology that would support their actions.

What I will do today is provide a background in terms of our past activity and the specific issues that we are focusing on at the present time and what we see as the opportunities for the future.

NASA has historically been involved in developing materials and structures technology to support aircraft applications. Most of you are quite familiar with the work that we've done at the NASA Langley and Lewis Research Centers. Although we did not have an Aging Aircraft Program a year ago, we did have a number of research and technology programs that focused on materials and structures activities of nondestructive inspection, fatigue and fracture, structural life prediction methodologies, and a host of other activities related to aircraft structures.

Within the past year, NASA has developed a focused program in coordination with the FAA to address specific issues that are related directly to the issue of aging aircraft. We have signed a memorandum of agreement with the FAA, which is focused in the areas identified in Figure 1; nondestructive inspection and nondestructive evaluation, fracture fatigue technology, and structural integrity prediction methods.

The NASA program has been coordinated with Dick Johnson and Nelson Miller at the FAA's Technical Center and we intend to have further discussions in terms of opportunities for us to cooperate and support their efforts.

We also had a number of discussions with industry to find opportunities for us to transfer NASA technology to industry and to find ways for us to work together with industry so that the technology we develop might be used in an effective manner in addressing aging aircraft.

As Clyde Kizer mentioned earlier, the ATA conducted an assessment of aging aircraft in which NASA participated. Mr. Sam Venneri from NASA's Office of Aeronautics and Space Technology is the chairman of the materials

- NASA research programs have historically focused on airframe materials and structures technology
- NASA initiated a focused airframe structural integrity program to support FAA as lead agency for aging aircraft research
- NASA/FAA memorandum of agreement on aging aircraft initiated with focus on:
 - Nondestructive inspection/non-destructive evaluation (NDI/NDE)
 - Fracture and fatigue technology
 - Structural integrity prediction methods
- NASA participation in ATA aging aircraft technology assessment

Figure 1 — Airframe Structural Integrity Program — Background

and structures activities that addressed research and technology needs.

Let me get into the discussion of the goals of our program, which are to develop and verify technology in the areas of nondestructive inspection and fracture mechanics, and to develop structural life prediction methodology that ensures the safety of airplane structures.

The specific objectives in that program are shown in Figure 2. In the NASA program, we will develop analytical methods that enable us to predict crack initiation and growth from multisite damage in fuselage structures as well as other elements of the airframe; we will develop analytical models that permit global and local analysis of airframe structure to incorporate the fracture and fatigue prediction methodology; we will also develop NDE devices and procedures within the laboratory and demonstrate those on aircraft elements; and then we will provide techniques whereby they could be economically applied to aging aircraft. That requires a cooperative effort be-

- Verify stress intensity factor solutions and fatigue crack growth methodology applicable to multiple-site damage at riveted joints.
- Verify nonlinear global/local structural analysis methodology for predicting crack growth in pressurized stiffened shell structures.
- Develop and demonstrate NDE devices to characterize the development of damage in materials undergoing laboratory simulated life testing.
- Demonstrate NDE technologies to economically and quantitatively evaluate aging aircraft.

Figure 2 — Airframe Structural Integrity Program — Objectives

tween ourselves, the airframe industry and the aircraft users in order to transition this technology to the users.

Figure 3 is a schematic that shows the various elements in our program. QNDE is Quantitative Nondestructive Evaluation technology. The NASA program includes the elements of fracture analysis, as I mentioned, analytical modeling and nondestructive inspection that focuses on a verified predicted methodology to enable us to enhance the life of airframe structures.

Before I describe the elements of those programs in detail, I will review the organizational structure within NASA so you will have an idea of who the participants are in the NASA Aging Aircraft program. (See Figure 4)

At NASA Headquarters, Mr. Sam Venneri is the director of the Materials and Structures Division, which is the focal point for aging aircraft research and technology in the agency. At the Langley Research Center, which has the primary responsibility for airframe structures, Dr. Jim Starnes is responsible for the structural

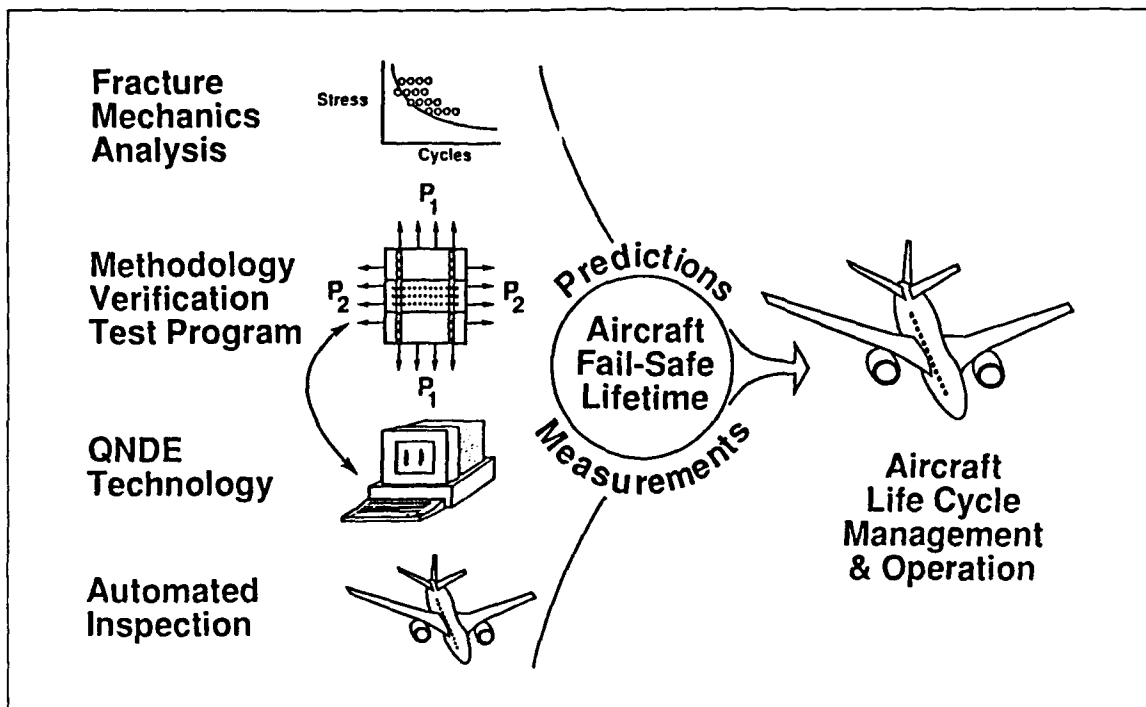


Figure 3 — Airframe Structural Integrity Program

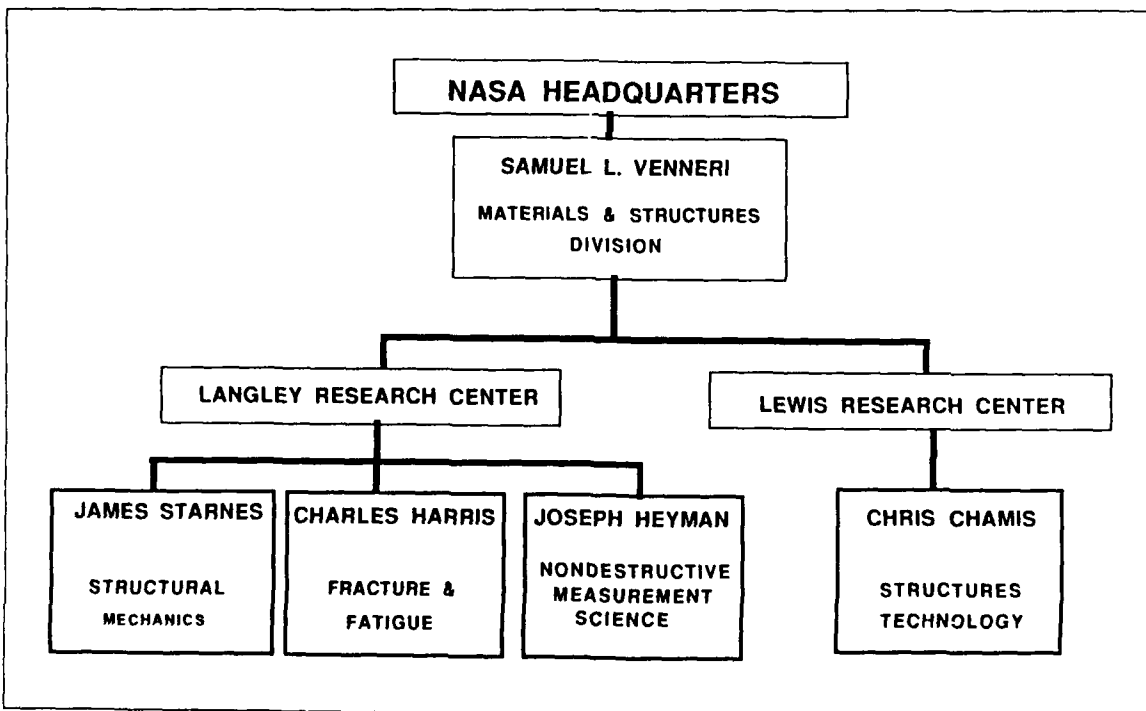


Figure 4 — Airframe Structural Integrity Program

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mechanics research and computational structural mechanics issues. Dr. Charlie Harris, is responsible for the fracture and fatigue methodology. Dr. Joe Heyman, who is developing nondestructive measurement science methods is responsible for NDE research. At the Lewis Research Center, Dr. Chris Chamis is responsible for developing the stochastic models for life prediction of airframe structures. I'll discuss these technology areas later.

The fatigue crack growth prediction methodology program is one of three program elements I'll be describing. The scope of this program is broken down into two specific tasks. The first is an evaluation of proof test concepts for fuselage structures. The second task focuses on a broader, long-term goal to develop fatigue and fracture methodologies necessary to address crack initiation and crack growth from multisite damage in fuselage structure. This includes not only the analysis models but also experimental studies to verify those models.

Figure 5 shows a composite of the various elements in the life prediction methodology. It illustrates the basis for the durability and damage tolerance concepts that have been successfully applied to airframe structural design. The NASA program focuses on crack initiation, fatigue crack growth models, to relate crack growth to the applied loads, and some of the nonlinear issues such as crack closure which causes a retardation of crack growth due to overloads in the spectrum, as well as the significance of small cracks and the influence of small crack growth versus large crack growth.

Those are some of the basic elements and issues that will be addressed in the fracture mechanics program. We will develop the stress intensity factor solutions which will allow the prediction of crack growth in metallic airframes for a variety of configurations, including multisite damage.

We will conduct elastic and elastic-plastic nonlinear analysis of some of the critical elements within the airframe, the splice joints as well as the loaded rivet holes. We will analyze short cracks emanating from rivet holes under spectrum loading, and then we will develop the analysis methodology to incorporate these fracture mechanics concepts into large-scale

global analysis. The formulation and verification of the fracture mechanics models is one of the developments that we see as a key to enable us to make predictions for these complex structures which involve multisite damage.

Another of the issues as I mentioned in the scope of our activity was an assessment of proof testing concepts. Figure 6 shows some of the benefits and concerns that we have concerning proof testing as it applies to large fuselage structures.

The potential benefits of proof testing is that it can be considered as a global non-destructive inspection method. Proof testing provides a rapid way of assessing the integrity of a structure, and it has been demonstrated very successfully in a number of specific applications, including the F-111 and B-2 wing structures. But it also has been used on a number of pressure vessels by the Department of Defense. For example, solid rocket motor cases are proof pressure tested as part of the acceptance procedure.

If the proof of a metallic structure is combined with a fracture mechanics methodology, then it can be shown that a specific level of proof test will assure a finite number of cycles at a specific load. A proof test approach for assessing structural integrity applies very well to materials that have low ductility, essentially those materials in which linear elastic fracture mechanics concepts are applicable.

One of the concerns that we are addressing in our assessment is that there is very limited experience on proof-testing of complex built-up fuselage structures. The issue of proof-testing structures made from a ductile alloy, a 2024 fuselage-type metallic system, raises some concerns about the application of the fracture mechanics approach in ductile materials, as well as whether some damage may occur during the proof test.

There is another concern about the complexity of corrosion and how corrosion influences any kind of a proof-tested structure, because crack growth in corrosive environments is not addressed very well in a fracture mechanics methodology.

As I mentioned, the issue of a very complex structure, which would have built-up elements,

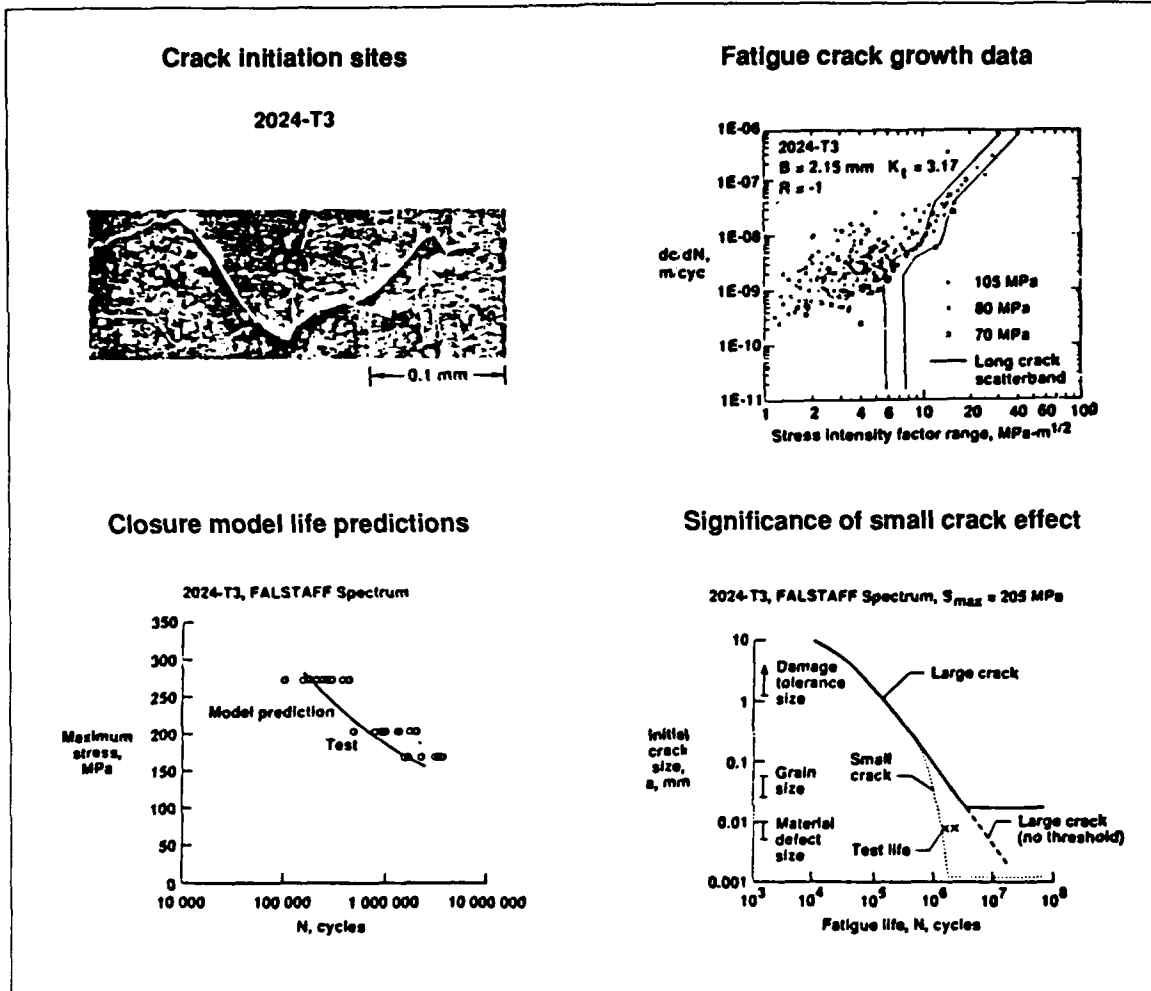


Figure 5 — Prediction Methodology for Total Fatigue Life

penetrations, bolted and bonded configurations is something that has really not been addressed completely in assessing the proof test methodology.

And, finally, if you can only assure a limited life after a proof test, then repeated proof tests will be required and these proof loads become part of the overall spectrum and must be considered as part of the design spectrum.

So we're not saying that these are show stoppers, but we are saying that before we commit ourselves to a proof test methodology to assure a specific life for a particular structure, these are the elements that should be addressed and resolved to ensure that we are

getting what we intend to get out of the proof test. And that would be a specific life extension for a fixed period of time.

I'll discuss briefly the elements that we are addressing in our evaluation of the proof test concept. We are essentially looking at it from a fracture mechanics viewpoint, considering the various crack growth and retardation aspects for 2024 aluminum alloys. We want to analytically establish the required proof test factors that could be used, using various parameters such as the crack size, the crack location, configuration and the operating stress levels, and we have a program to experimentally conduct some limited testing that would load panels to

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BENEFITS

- Can provide simple, rapid, effective demonstration of structural integrity
- Proven successful for military airframes
 - ~ F-111 wing box and B-52 wings
 - ~ Fracture mechanics methodology
 - ~ All metallic (low ductility) structures
 - ~ Coordinated with stress analysis and NDE

CONCERNS

- Often discussed and seldom applied — actual experience limited
- Proof testing of ductile alloys (2024 Al) raises ambiguities
 - ~ What is exact measure of fracture toughness?
 - ~ Can ductile subcritical crack extension be damaging?
- Effects of proof testing corrosion-damaged material unknown
- Response of complex riveted joints, cold-bonded joints, windows, doors, bulk-heads unknown — only proven for detecting cracks in metallic structures
- All structural details not equally critical — "safe life" varies with location
- Repetitive proof test loading can cause significant fatigue damage

Figure 6 — Proof Testing Issues

133 percent of design limit load, (subsequently fatigue design operating load) to determine the actual life of the elements.

Figure 7 shows some of the configurations we are testing and I must admit these are very simple when you consider the complexities of a fuselage structure: single cracked panels, panels with multiple penetrations and mechanically attached panels that are part of the test program. These test panels will be proof loaded to design limit load and then subsequently loaded to design operating load which would be three-fourths of the proof load. In other words, if you proof load to a level of 1.33, the subsequent fatigue loading would be to a level of 1.0.

This is part of the test program that we are pursuing at the present time to develop a data base by which an informed decision can be made concerning the benefits of proof testing. We are having continuing discussions with the various airframe industry participants, as well as the FAA participants, about the benefits of

that program and intend to coordinate our activities with those that are being pursued by the FAA.

The fatigue crack growth prediction methodology program schedule in Figure 8 shows a number of the issues that are being addressed and the time interval over which this activity will be pursued. The proof test issue is the topic we are addressing at the present time, but there are a number of other activities in the fracture mechanics analysis; experimental verification on panels and scaled-up elements, as well as the integration of the fracture mechanics methodology into a large-scale structural analysis program.

I will mention some additional aspects of the fracture and fatigue program later when I discuss the structural mechanics program and the computational structural issues, because these two program elements are integrated together, along with the NDE, in the total program.

The scope of the second element of the

Daniel R. Mulville

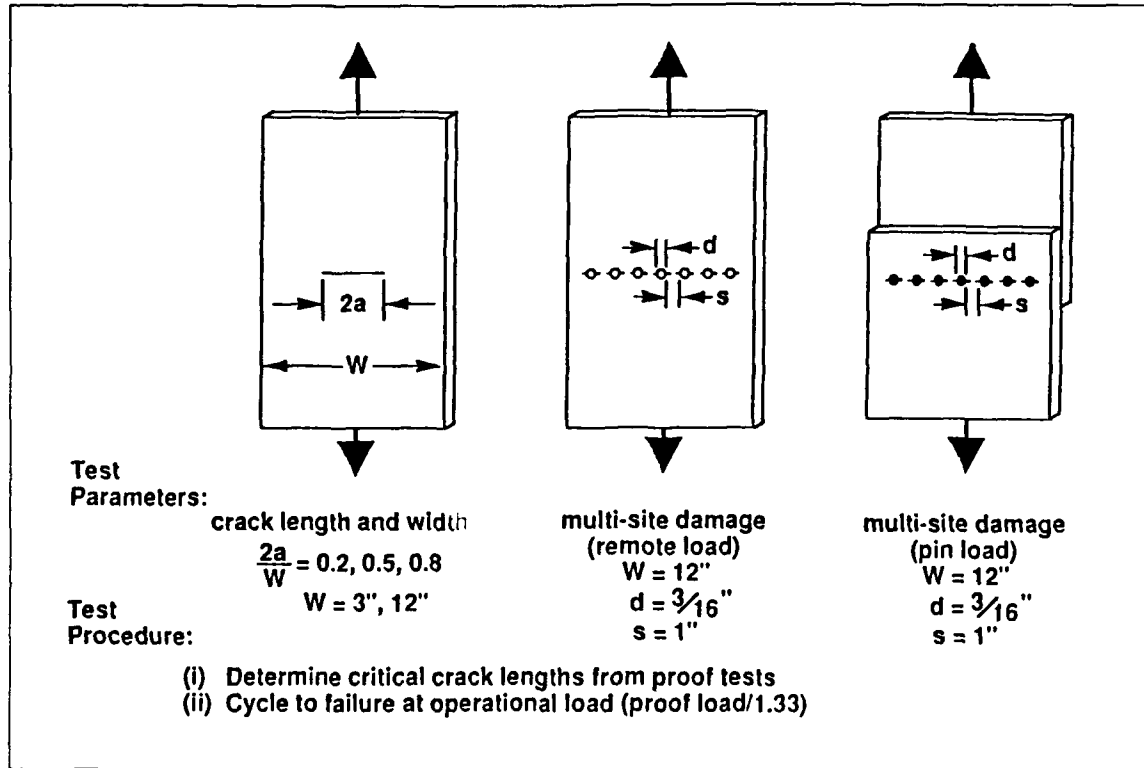


Figure 7 — Test Matrix to Evaluate Proof Test Concept

FY 89	FY 90	FY 91	FY 92	FY 93	FY 94	Anticipated Results
PROOF TEST						STRESS INTENSITY FACTOR SOLUTIONS FOR CRITICAL CRACK CONFIGURATIONS
	SHORT CRACK DATA BASE					
	FRACTURE MECHANICS ANALYSES					
	EXPERIMENTAL VERIFICATION OF FLAT PANEL CRACK GROWTH PREDICTION METHODOLOGY					VERIFIED FATIGUE CRACK GROWTH METHODOLOGY FOR BUILD-UP STRUCTURES
	STIFFENED SHELL CRACK GROWTH ANALYSIS METHODOLOGY					

Figure 8 — Fatigue Crack Growth Prediction Methodology Program

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Aging Aircraft Program, structural life prediction and analysis verification, focuses on development of the analytical models to predict the overall structural response of large pressurized airframes. As part of this effort, we intend to conduct some tests on prototype structural elements and subcomponents. We have also initiated discussions with industry whereby NASA would make predictions of structural performance of large-scale fuselage tests which would be conducted by industry to verify these analytical predictions. This activity provides NASA with an opportunity for us to work with industry in a cooperative manner whereby our technology in the fatigue and fracture and computational and structural mechanics would be verified through large-scale testing by the airframe industry.

One approach we use is the local-global analysis where you go from analysis of an entire aircraft down to panels with discontinuities, penetrations, elements and attachments in a logical manner that enables you to transition the loads from the large-scale structure down into the loads on the panel element.

The specific issue that we intend to address in our structural analysis methodology is to develop stiffened shell models which would be representative of airframe structures. These models would include the complexities of the frames, stringers, intersections and shear clips and attachments, and would include linear as well as nonlinear analysis, including geometrical material nonlinearity. Our research will also identify critical elements which will require three-dimensional structural analysis, and develop analytical models by which we can incorporate the fracture mechanics concepts through adaptive methods so that as a crack propagates through the structure, the mesh is adapted to the new geometry.

Figure 9 illustrates an example of one of the pressurized fuselage issues, in which there is an exaggerated view of the radial expansion, illustrating deformations in the frame elements and perhaps some nonlinear responses in the thin skin sections.

Figure 10 illustrates the idea of embedding a mesh surrounding the tip of a crack in the fuselage skin, so that as a crack propagates, the

mesh is reconfigured to make predictions about crack growth and to conduct a fracture and fatigue analysis on a large-scale structure.

This summarizes the scope of the structural mechanics program in terms of the fracture and fatigue analysis and planned testing program within NASA. Our program will include testing of small scale coupons up through biaxial testing to some panel testing and perhaps some small elements in a shell structure test.

NASA does not have the resources or the facilities to conduct large-scale tests on fuselage structures, and the optimum way for NASA to work with industry is to have industry fabricate the test panels and to conduct some of the panel tests and large scale fuselage element tests and for NASA to participate in a cooperative manner. Although we have had initial discussions with some of the airframers, we certainly would welcome opportunities to discuss interactions with others within the airframe industry.

Another aspect of the structural mechanics program conducted by the Lewis Research Center is focused on probabilistic structural analysis methods. In a probabilistic scheme, you don't assume that there is a specific pressure level or a specific geometry or perhaps a specific environment, but that there is a stochastic variability associated with these parameters, and their variability is included in the analysis. And so the stochastics associated with a pressure level, the defect size and location, components, the material properties including not only the metallic, but also the integrity of bonded configurations and the fastener loading conditions, are parameters that would be incorporated into the stochastic model. The approach that we propose is to use the probabilistic model to predict structural response and verify the model on small-scale test elements and then apply these results to large-scale tests.

An example of how probabilistic structural analysis has been used in the past is on the space shuttle main engine blades. The blades operate in a very complex environment in which they experience thermal as well as mechanical loading, and there are a number of variables in terms of material properties and blade geome-

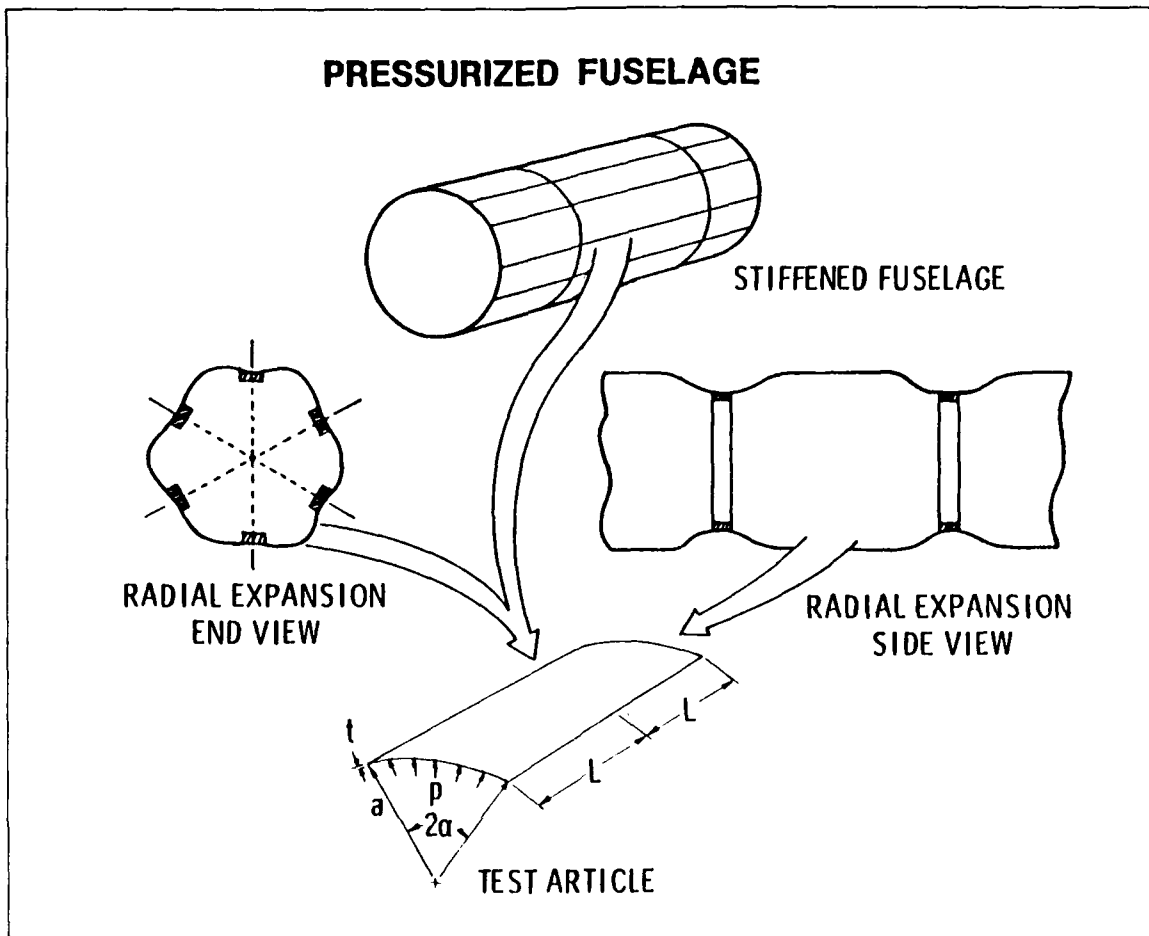


Figure 9 — Pressurized Fuselage

try. Variations in geometry and material properties are incorporated into the model and a prediction in terms of the vibration frequency response, as well as stress levels are computed, not as single parameters, but as stochastic variables. This analysis provides an ability to assess the probability for a given variability of input parameters of failure.

As I have mentioned, the fatigue and fracture analysis and structural life prediction elements have a common focus and the stiffened shell crack growth analysis is one of the tasks that would be pursued as cooperative activities in these two elements. The associated testing of biaxial elements and subcomponent panel verification using stochastic probabilistic life prediction models all lead up to large-scale structural test and verification.

The third element of the NASA program is the Quantitative Nondestructive Examination (QNDE) program. A number of NDE activities are being pursued at the NASA research centers and include thermal nondestructive examination, remote sensing, materials characterization, as well as assessment of damage and residual stresses within structures. These are NDE research areas that we have been working on for some time, and we intend to focus these capabilities on some elements of the aging aircraft problem.

The scope of this activity in the near term will be to transfer to the FAA and industry some of the activities that we have been pursuing in the thermal imaging area. We also intend to develop a number of laboratory devices which will enable us to work with the fracture

Nonlinear Local/Global Modeling Strategy Local Refined Mesh Propagates With Crack

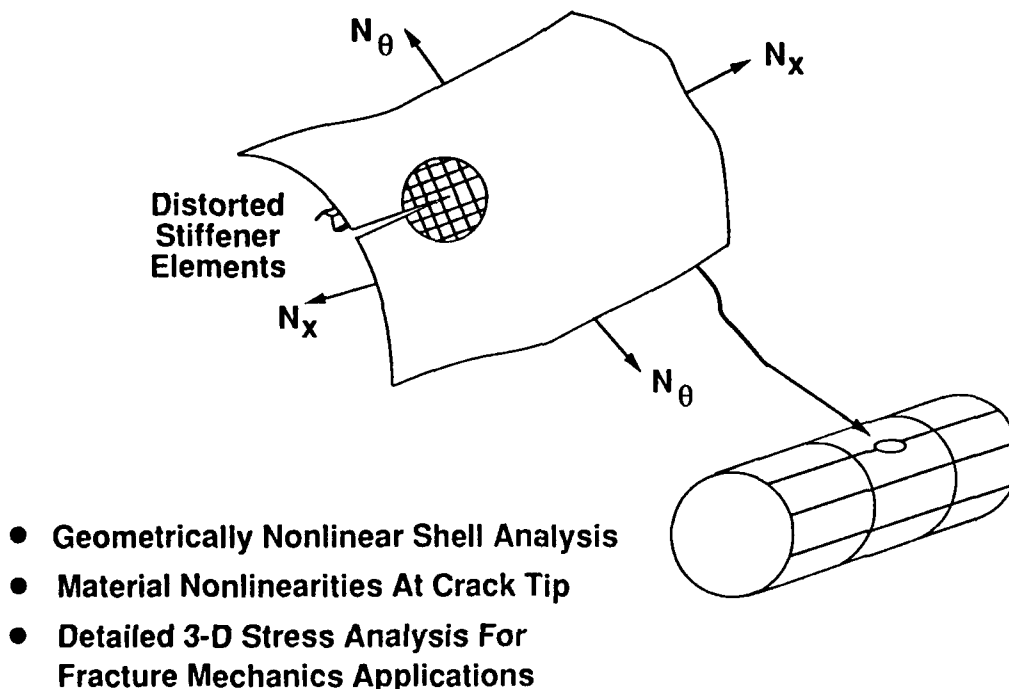


Figure 10

and fatigue analysis program to adequately characterize crack initiation and growth in complex built-up fuselage structures, and to be able to transfer to the field or to industry ways of economically assessing or characterizing aging aircraft.

Our program is focused on developing new capabilities that go beyond the current state-of-the-art systems available today. NASA's goal is to provide a new NDE technology that would be more economic, have a higher efficiency and a higher assurance of being able to find defects within airframe structures.

An example of this research was published recently in *Aviation Week and Space Technology*. The article on aging aircraft showed a panel, which was supplied to NASA by an airframe manufacturer, that represented a bonded and

mechanically attached fuselage panel. One element of the panel was unbonded and the other panel was bonded. Because there's a difference in the thermal images from bonded and disbonded material, it was possible to detect disbands in supposedly bonded fuselage structures.

In addition to measuring thermal images, we are using analytical methods to extract features from these thermal images to enhance our detection capabilities. Another example of thermal imaging research is the ability to take thermal images of samples under test to make observations about the damage site initiation and crack growth and to be able to analyze the thermal image in order to characterize the structure.

Figure 11 is a matrix that shows, across the top, various elements and structures in an

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Technologies	Landing Strut Fatigue	Corrosion Measurement & Assessment	Bonded & Riveted Lap Joint Integrity	Structural Fatigue State	Component & Hardware Fatigue State	Rivet And Bolt Stress State	Stress Sensors & Stress Imaging
Magneto-Acoustic Residual Stress Measurement	✓						
Magnetic Barkhausen Spectroscopy	✓			✓			
Ultrasonic Plate & Surface Wave Phase Propagation		✓	✓				
Thermography With External Heating		✓	✓				
Thermoelasticity With External Stimulus			✓				
Nonlinear Acoustic Techniques			✓	✓			
Critical Fastener Preload & Certification						✓	
Ultrasonic Pulsed Phase Locked Loop - External Stimulus					✓	✓	✓
Retrofit Remote Sensing System	✓	✓	✓	✓			✓

Figure 11 — QNDE Technology Matrix

airframe, and along the left-hand side, various nondestructive examination techniques that are being explored. The chart indicates a number of NDE techniques we see as potential applications for aging aircraft. We are pursuing a number of these technologies at the present time.

An example of one of the NDE technologies we are developing is a phased array, or a large-scale ultrasonic scheme, by which it is possible to examine larger elements of the airframe and be able to detect crack sites as well as corrosion, and that provides high resolution and opportunities for a quantitative measurement through some signal processing schemes that are currently being examined. There are a number of large scale NDE methods such as NDE blankets and concepts that have been applied to various airframe configurations. We are currently exploring some of those for application to aging aircraft.

How the technology that NASA develops would eventually impact the operational sys-

tems, is presented in Figure 12. We intend to develop prototype quantitative NDE instruments for aging aircraft, to evaluate proof of concepts in the laboratory with small scale airframe components, develop prototype field instruments and use baseline samples to make those inspections.

NASA Langley has a Boeing 737 aircraft that gives us an opportunity to conduct these inspections on an operational aircraft and then to move into field test and ultimately transfer the technology out to the airframers and to the manufacturers.

Finally, I'll give a synopsis on the NDE in terms of what our near-term activities are. We are working on a coordinated program with the FAA and participating on the FAA NDE Committee. The three bullets in the lower part of Figure 12 indicate the specific issues that we are addressing in the area of thermal NDE. That includes thermal modeling of lap joints and techniques to analytically extract features from the thermal image in order to measure

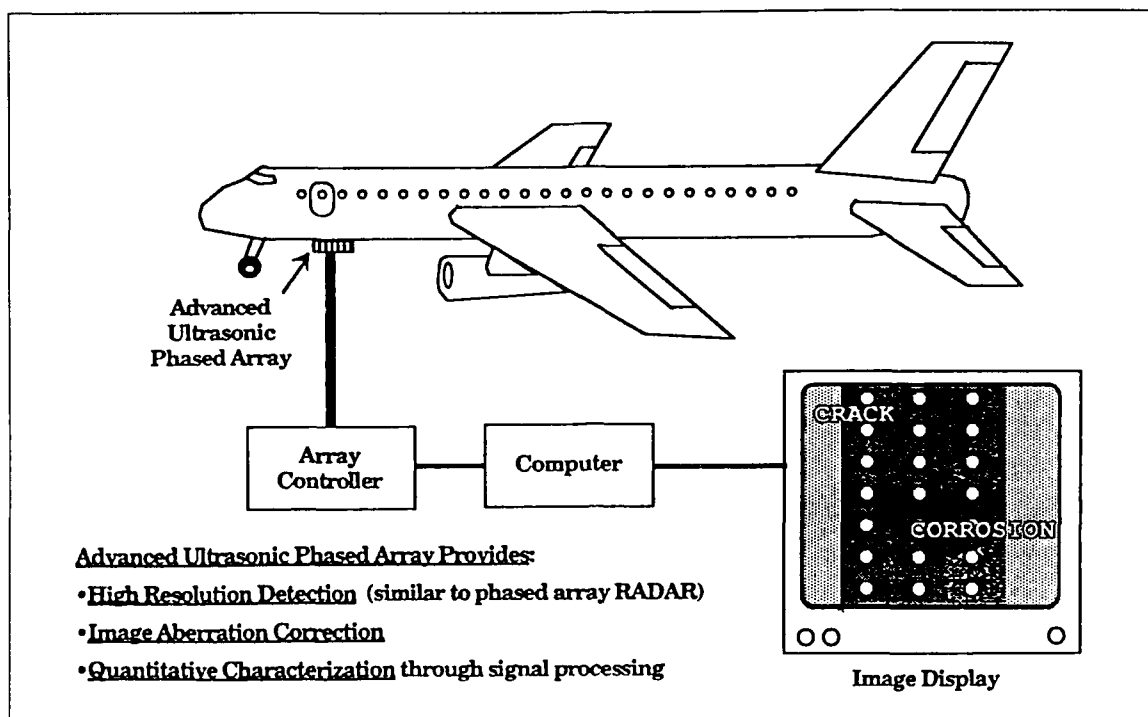


Figure 12 — Advanced Ultrasonic Phased Array Imaging

and characterize properties of specific samples. The results of these studies will permit us to provide suggestions to the FAA for their thermal NDE testing, and to develop a thermal imaging technology and transfer capability to the FAA and industry.

We are working jointly with the industry in this area as well, and Figure 13 indicates our activities for the FAA.

In the total scope of the NDE program, there are a number of activities indicated, including lap joint inspection methods, detection of cracks at fastener holes, inspection and thermal modeling analytical methods, as well as some small scale laboratory experimental techniques. Thermal imaging and optical displacements are being examined as large field measurement systems. The residual preload measurement and load distribution systems are focused on mechanical attachments and fasteners that can be instrumented.

And at the lower end of Figure 13 are some of the longer-term concepts including smart material sensors in which we would envision

instrumenting elements to provide real-time feedback from NDE sensors.

In summary, NASA has initiated a research program in cooperation with the FAA to develop technology for enhanced airframe structural integrity. I mentioned initially that we have a memorandum of agreement to address the three technical areas that I discussed earlier in the presentation. We also have a memorandum of agreement to work elements associated with loads and loads measurements. Mr. Terry Barnes of the FAA will be discussing that aspect in some detail.

We have a NASA/industry cooperative analysis and test program proposed for large-scale verification test. As I mentioned, we've had discussions with industry to identify opportunities for us to verify fracture and fatigue analysis as well as NDE methods on large-scale structures.

The technology transfer methods identified for NDE, fracture and fatigue analysis, and structural life prediction are through our interactions with the ATA, through our discussions

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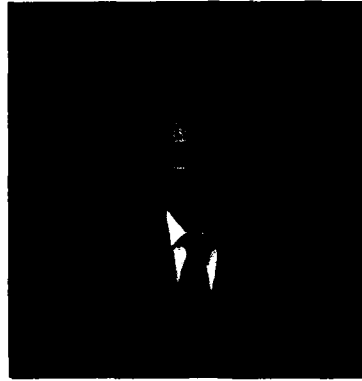
FY 89	FY 90	FY 91	FY 92	FY93	FY 94	Anticipated Results
	LAP JOINT & CRACK NDE, INVERSION MODELING, CORROSION PROFILE					FIELD & NDE DEVICES TO & ASSESS DAMAGE
	THERMOELASTIC STRAIN OPTICAL DISPLACEMENT/STRAIN SYSTEM SENSOR					NONCONTACTING LAB & FIELD SENSORS FOR DISPLACEMENT/STRAIN
	RESIDUAL, PRELOAD & LOAD DISTRIBUTION MONITORING					FIELD STRESS INSTRUMENTATION
			SMART MATERIALS SENSORS			INTERNAL NERVOUS SYSTEM MONITOR OF STRUCTURAL HEALTH

Figure 13 — NDE Program

with industry and in cooperation with the FAA. We view this conference as a good opportunity for us to provide further interaction with in-

dustry and to identify opportunities for us to work together and transfer the technology being developed in the NASA program.

Session I: Structural Fatigue



CHAIRMAN THOMAS SWIFT

FAA National Resource Specialist

The first session this afternoon is the first session of the research and development series of panel discussions and presentations. Session I is related to structural fatigue.

With us today are Dr. Ulf Goranson from Boeing Commercial Airplane Company, Dr. Pin Tong from DOT Transportation Systems Center, and Ben de Jonge from the National Aerospace Laboratory in the Netherlands.

There has been a lot of discussion in this meeting about the aging airplane program having been initiated by the Aloha accident but the message I have is that the aging aircraft program didn't really start with the Aloha accident; it started many years ago. I thought I'd remind you about that fact before we continue.

Continuing Airworthiness of Aging Jet Transports



ULF G. GORANSON, PH.D.

Manager, Damage Tolerance Technology
Boeing Commercial Airplane Company

Economic and market conditions have resulted in the use of commercial jet airplanes beyond their original economic design life objectives. The average age of the world airline jet transport fleet has increased from 8 to 12 years since 1980. Standard Boeing practices to support continuing airplane structural integrity include inspection and overhaul recommendations contained in maintenance manuals and service bulletins. As airplanes exceed their economic design life objectives, the incidence of fatigue increases and corrosion may become more widespread. This presentation is focused on recent special activities to assess the condition of the aging airplane fleet and other joint Boeing, airline and airworthiness authority reviews of service bulletins, corrosion control programs, basic maintenance and supplemental structural inspection programs and structural repair quality. These initiatives will provide timely preventive maintenance recommenda-

tions that will support continued safe operation of aging jet transports until their retirement from service.

Introduction

Boeing continually reviews reported service data and other firsthand information from customer airlines in order to promote safe and economic operation of the worldwide fleet. The active service life of commercial airplanes has increased in recent years as a result of low fuel costs, and increasing costs and delivery times for fleet replacements, (Figure 1). Air transport industry consensus is that older jet transports will continue in service despite anticipated substantial increases in required maintenance. This paper is focused on recent initiatives to enhance aging airplane safety in addition to standard Boeing practices to support continuing

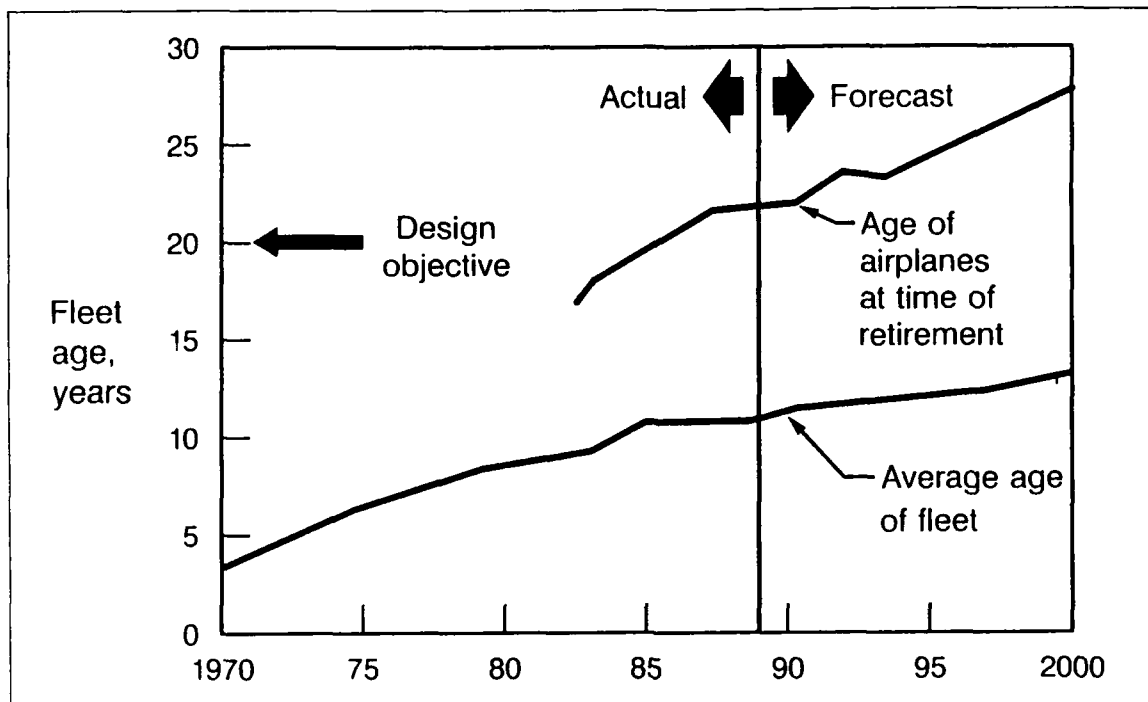


Figure 1 — World Jet Fleet Age

structural integrity by inspection and overhaul recommendations contained in maintenance manuals and service bulletins. These actions include fatigue testing and teardown inspections of high-time airframes retired from service; timely development of Supplemental Structural Inspection Documents applicable to selected older airplanes; and a 2-year surveillance of 76 airplanes distributed throughout the world to gain an engineering assessment of the condition of older Boeing airplanes. Concerns have resulted in Boeing initiatives and joint manufacturer, airline and airworthiness authority actions. These actions are focused on mandatory modification rather than continued inspection defined in service bulletins for airplanes exceeding design life objectives; development of improved mandatory corrosion control programs; reviews of basic maintenance programs and supplemental structural inspection programs; and development of guidelines to determine the adequacy of structural repairs in relation to damage tolerance and long-term operation.

Structural Safety

Criteria and procedures used in commercial airplane design over the last three decades have produced long-life damage-tolerant structures with an excellent safety record (Figure 2). This has been achieved through diligent attention to detail design, manufacturing, maintenance, and inspection procedures. Structural safety has been an evolutionary accomplishment, and attention to detail design the key to this achievement. These design concepts, supported by testing, have worked well due to the system that is used to ensure that the fleet of commercial jet transports are kept flying safely through their service life. This system has three major participants: the manufacturers who design, build, and support airplanes in service; the airlines who operate, inspect, and maintain the airplanes; and the airworthiness authorities who establish rules and regulations, approve the design and promote airline maintenance performance, (Figure 3). Airplane structural safety depends on diligent performance of all

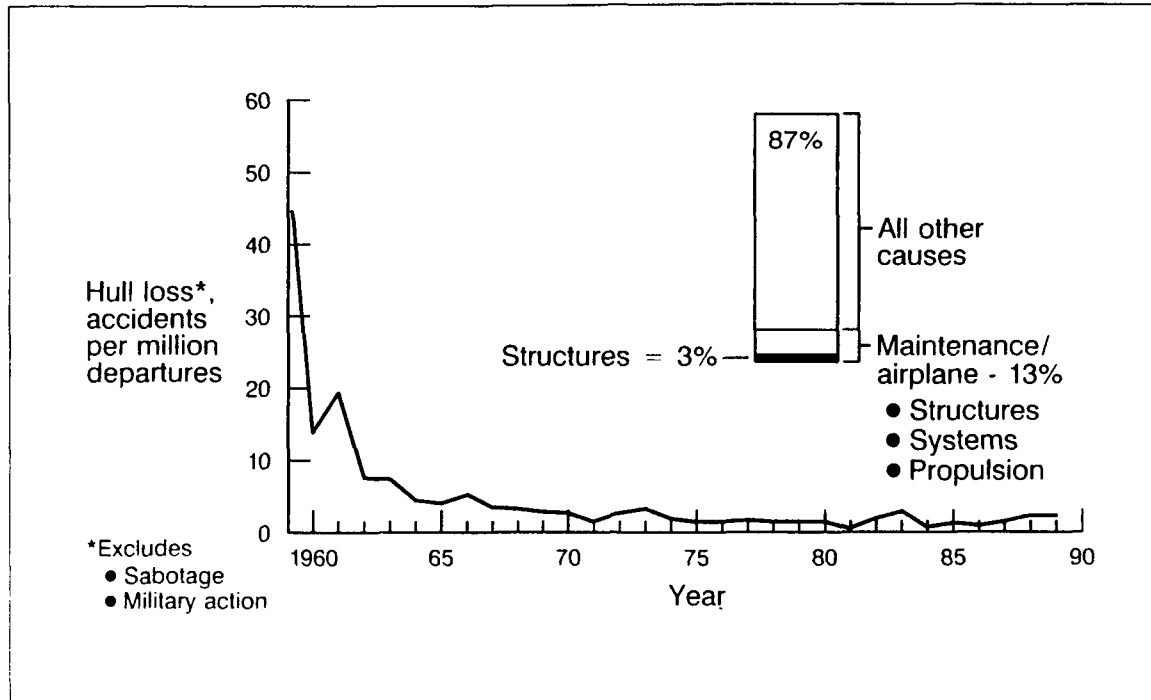


Figure 2 — Commercial Aviation Safety Record

participants in this system and the responsibility for safety cannot be delegated to a single participant.

All Boeing jet transports are designed to be damage tolerant, a principle that has evolved from the earlier fail-safe principle. On the whole, service experience with fail-safe designs has worked very well with thousands of cases where fatigue and other types of damage have been detected and repaired. The question being debated between experts in the industry, is whether or not the fail-safe design practices used in the 1950s and 1960s are adequate as these airplanes approach or exceed their original economic life objectives, (Figure 4). Boeing jet transports are designed for a minimum 20 years of economic operational service. It should be noted that there is no limit to the service life of damage-tolerant designed airplane structures, provided the necessary inspections are carried out along with timely repair or replacement of damaged structure or preventive modifications for airplanes exceeding economic design life objectives. Operational efficiency is im-

pacted by the cost and frequency of repair; durability may, therefore, limit the productive life of the structure.

Test Verification

It is impractical to conduct verification testing of all critical conditions and portions of the airplane structure. Analysis methods and allowables are therefore verified by test and the airworthiness certification substantiated by analyses. Development and verification tests comprise small laboratory test specimens, large panels and major components representing wing, empennage, and fuselage structure, and full-scale airframes.

Full-scale static testing of new models is conducted to verify limit load carrying capability and to satisfy certification requirements. In addition, full-scale fatigue tests are conducted. The primary objective of these major cyclic tests is to locate areas that may exhibit early fatigue problems. The testing is accelerated

Structural Safety System

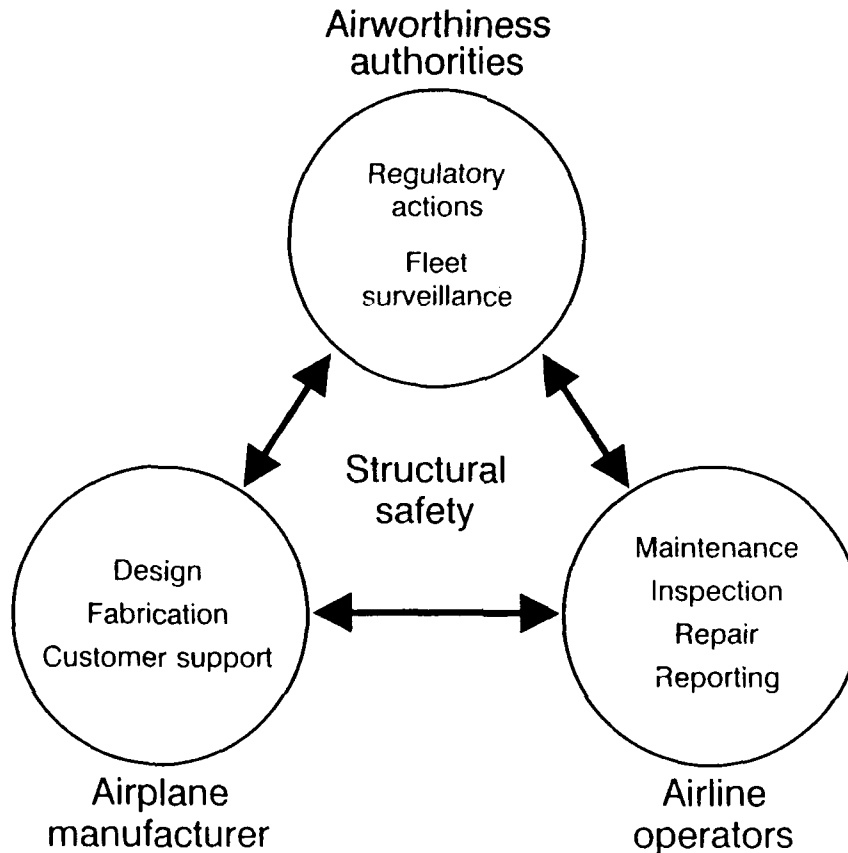


Figure 3 — Structural Safety System Interaction

relative to fleet usage with more than 10 years of repeated load experience completed before the first revenue flight. This provides timely opportunities to develop necessary modification of details that might exhibit early cracking and to demonstrate compliance with economic fatigue design life goals. Additional objectives of the full-scale fatigue test are to help develop and verify inspection and maintenance procedures. Full-scale fatigue tests are not intended to demonstrate "safe-life" limits of structures certified as damage tolerant, nor are they an alternative to the inspections required for continued safe operation of aging airplanes. Test-

ing of new airplane structures does not incorporate corrosion or accidental damage that can accelerate fatigue cracking. In addition to new model fatigue tests conducted prior to service introduction, similar tests are conducted on older airframes to gain insight into the problems that might be experienced on high-time airplanes with repairs and service-caused defects. These tests provide valuable information but do not account for typical airplane-to-airplane variability.

A test was completed in 1987 on an 18-year-old 737 with 59,000 service flights, (Figure 5). The aftbody section was used as a test fixture

Boeing Jet Fleet Status

June 1989

Airplane model	Initial service date	Active (total)  commercial fleet		Economic design life  objective	Number of airplanes exceeding given percent of design objective	
		Number of operators	Number of airplanes		75%	100%
707 	September 1958	85	221 (728)	20,000 flights 60,000 hours 20 years	180 155 209	80 59 173
720 	July 1960	6	12 (153)	30,000 flights 60,000 hours 20 years	11 10 12	3 0 12
727 	February 1964	125	1,643 (1,819)	60,000 flights 50,000 hours 20 years	244 891 893	12 431 589
737 	February 1968	138	1,632 (1,698)	75,000 flights 51,000 hours 20 years	80 281 310	1 62 161
747 	January 1970	59	604 (639)	20,000 flights  60,000 hours 20 years	111 248 209	11 103 0

 Airplanes known to have flown during the past 12 months.

 Excluding -SP and -SR derivatives.

 At this point in the airplane lifetime, some initial fatigue cracking might occur.

WEL 11/85/06 14/87

Figure 4 — June 1989 Fleet Status

for damage tolerance tests of the aft pressure dome and fatigue testing of typical fuselage pressure structure. Cracking in a longitudinal body lap splice expanded the focus of the test to include close monitoring of these monocoque details. At 79,000 total cycles, corresponding to 24 years of service, multiple site damage (MSD) of approximately 0.09-inch length beyond the fastener head was visually detected in the skin at seven upper row countersunk fasteners along stringer 4R. This equates to a 0.43-inch tip-to-tip crack, (Figure 6). The cracking pattern after linkup is depicted in Figure 7 in two similarly stressed adjacent tear strap bays, either side of a frame. Approximately one-third of the fasteners in the critical row developed cracks. Test data comparison with crack growth analysis prediction, assuming a short linkup period from crack lengths 1 inch to 5 inch, is shown in Figure 8. The damage detection period prior to linkup (during which safety inspections are carried out) ranges from 10,000 to 40,000 flight

cycles, depending on lap joint condition (corrosion, disbond), (Figure 9). Following crack linkup, insulation blankets were installed to simulate service conditions and prevent obvious pressure loss. These cracks (and others developing later) were allowed to grow unrepaired. The major crack reached a longitudinal length of 32 inches with three tear straps failed before a change in crack direction caused "skin flapping" and safe decompression at 100,600 total cycles equivalent to about 30 years of typical service usage, (Figure 10) (7 years without repairs since initial crack detection).

Repairs were made to permit continued testing of the aft pressure dome to an equivalent of 40 years of typical operator service usage or 130,000 total pressure cycles. The crack growth testing of the elliptical aft pressure dome structure followed 90,000 fatigue pressure cycles including the cycles experienced by the airplane during fleet service. Since no naturally occurring fatigue cracks were

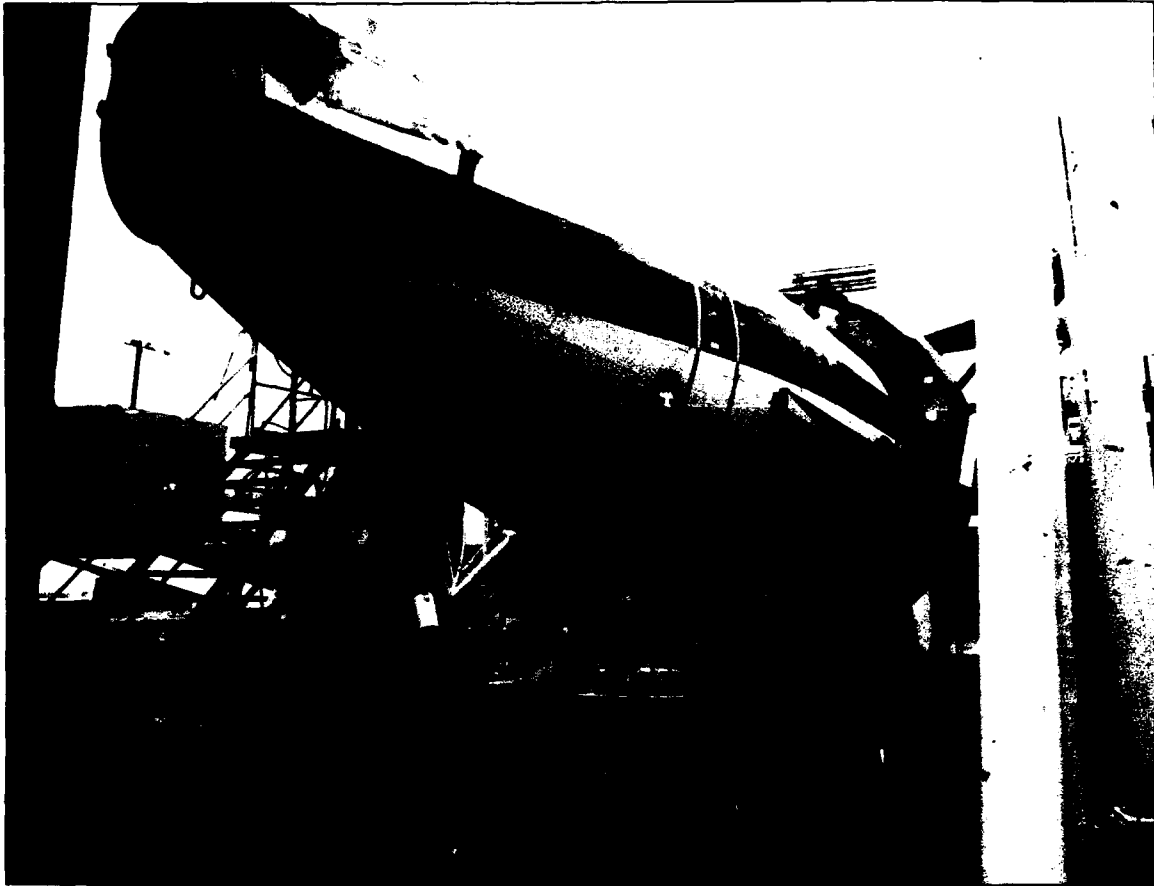


Figure 5 — Retired 737 Aft Fuselage Fatigue Test Article

Initial 737 Stringer 4 Lap Splice Cracking
79,033 Cycles

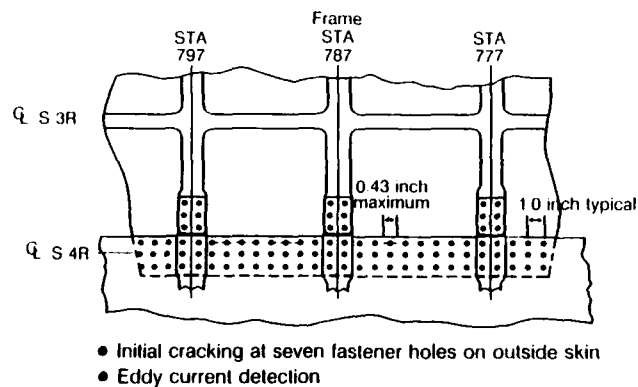


Figure 6 — Initial 737 Stringer-4 Lap Splice Cracking

737 Stringer 4 Lap Splice Cracking 100,290 Cycles

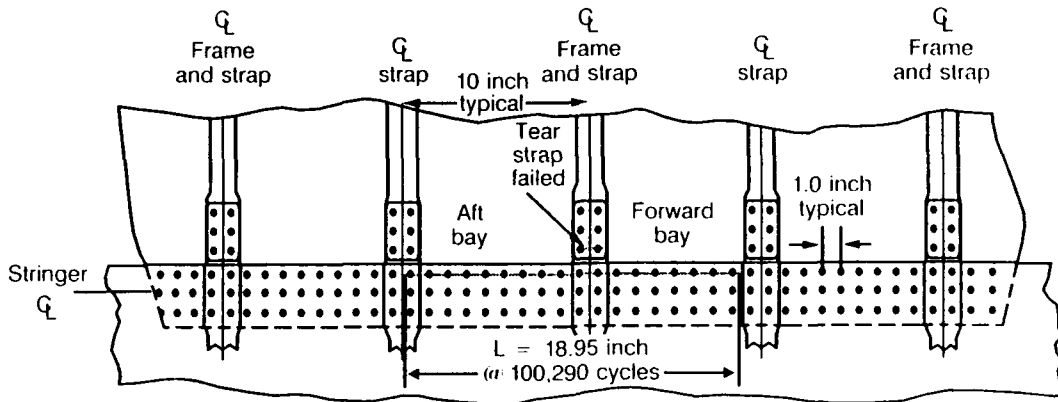


Figure 7 — 737 Stringer-4 Linkup of Multiple Site Cracks

Fuselage Lap Splice MSD Analysis and Test Data

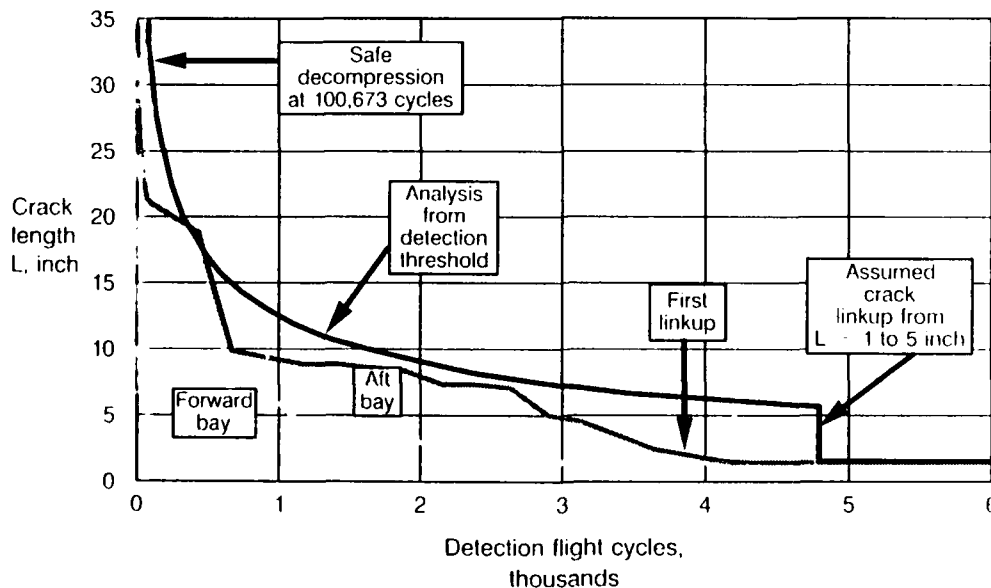


Figure 8 — 737 Stringer-4 Lap Splice MSD Analysis and Test Data Comparison

737 Lap Splice Crack Growth Data

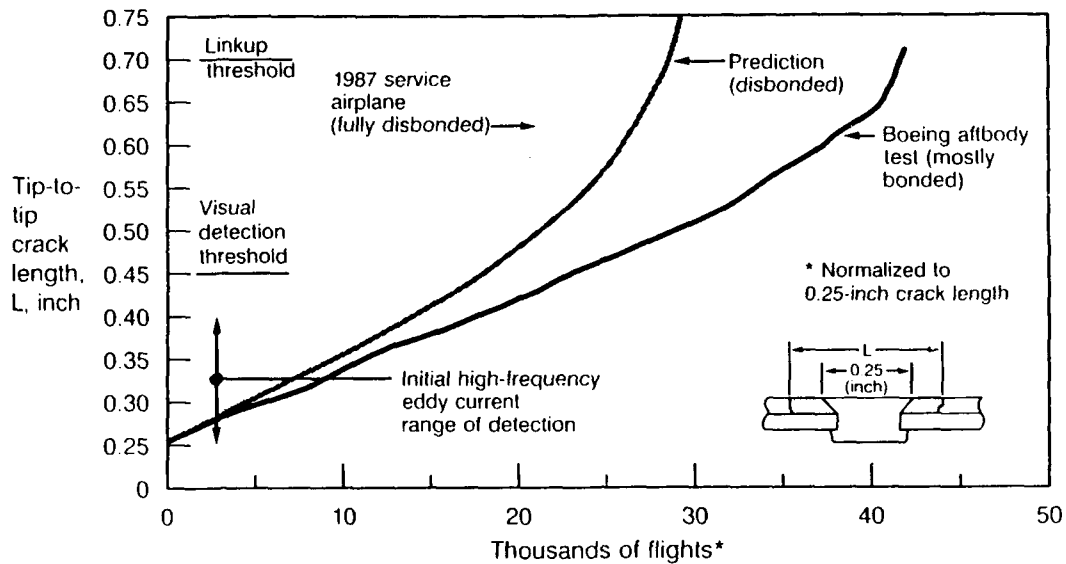


Figure 9 — 737 Stringer-4 Detection Opportunities Before Linkup

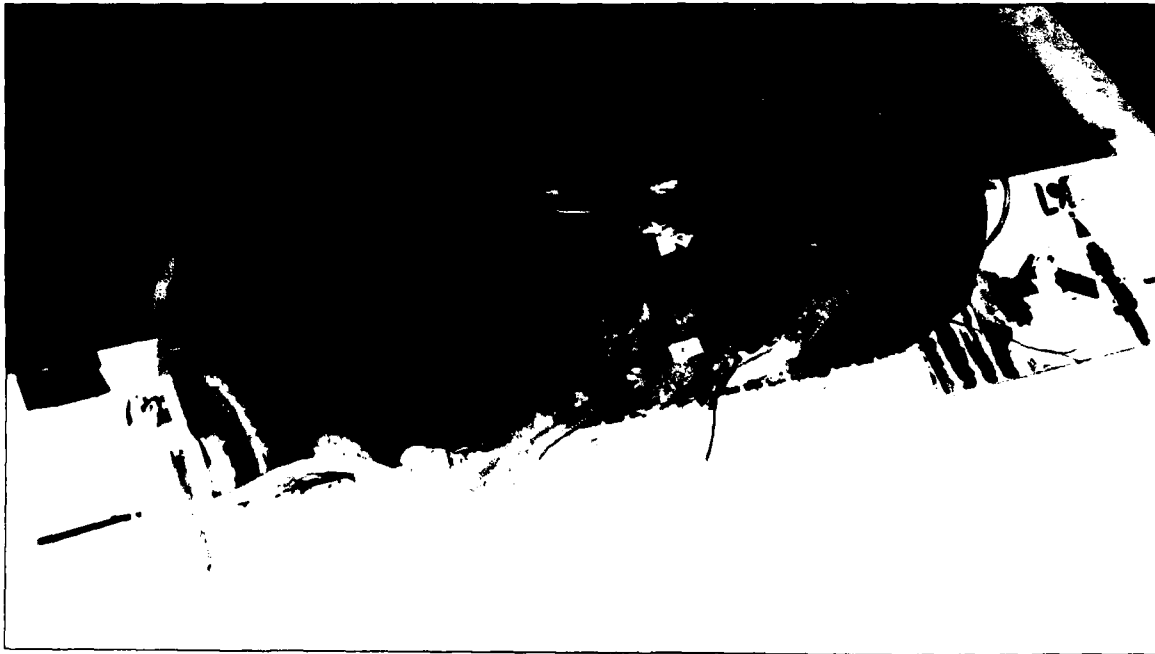


Figure 10 — Controlled Decompression of 737 Fuselage Test Article

Ulf G. Goranson

detected in the pressure dome by this time, saw cuts were introduced to simulate large detectable cracks in the dome skin lap splices. Five tests were completed that included four tests of bay centered radial saw cuts simulating cracks along the radial lap splices and one test with two radial saw cuts centered in adjacent bays along another lap splice. A view of the dome, pretest stress survey strain gages and saw cut testing locations can be seen in Figure 11. Most of the testing was performed in the middle bay and one in the inner bay of the dome, as these are the highest stressed regions and the most likely place for cracking to occur during the life of the structure. A summary of the tests performed is listed in Figure 12. Tests 4 and 5 had shorter initial crack lengths, but were tested under the same conditions as tests 1 and 2 respectively. These tests were done to determine crack growth rates for shorter cracks. The difference between visible and hidden fastener

rows in a splice is related to the accessibility for inspection of the structural detail. Figure 13 shows the visible interior aft side of the pressure dome. Hidden fastener row cracks are buried between the exterior skin in the splice and the internal radial stiffener. Before testing, commercial insulation blankets, as used in production airplanes, were installed to provide a realistic air seal. Pressure cycling was stopped at scheduled intervals to facilitate detailed inspections and measurement of crack length. Portable eddy current inspection equipment was used to detect and locate the crack tips, and crack length measurements were made visually using a steel scale. These pressure dome tests confirmed analysis procedures used to determine supplemental structural inspection recommendations.

The model 747 has now been in service for over 20 years and a high-time airplane retired from service was acquired by Boeing in 1988

Pressure Dome Structure, Strain Gage and Test Locations

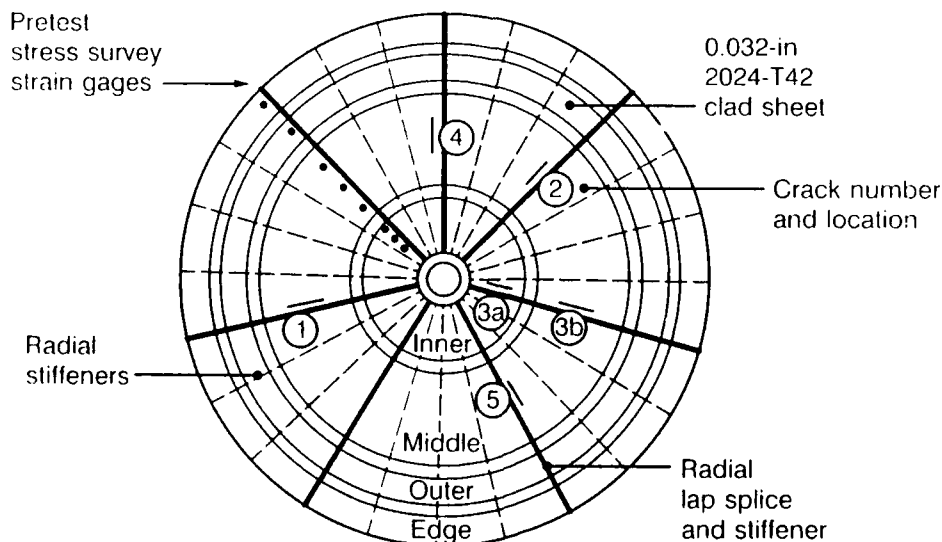


Figure 11 — Pressure Dome Structure, Strain Gage and Test Locations

737 Elliptical Pressure Dome Test Summary

Test number	Test bay	Splice row	Initial sawcut length, inch	Final crack length, inch	Crack growth test cycles* N
1	Middle	Visible	9.3	19.4	11,800
2	Middle	Hidden	9.4	18.1	4,800
3	A	Inner	5.3	12.6	26,100
	B	Middle	5.3	15.5	19,200
4	Middle	Visible	4.3	5.95	29,100
5	Middle	Hidden	4.3	4.6	24,300

*90,000 fatigue pressure cycles applied prior to crack growth testing

Figure 12 — 737 Elliptical Pressure Dome Test Summary

Radial Stiffener and Crack Locations

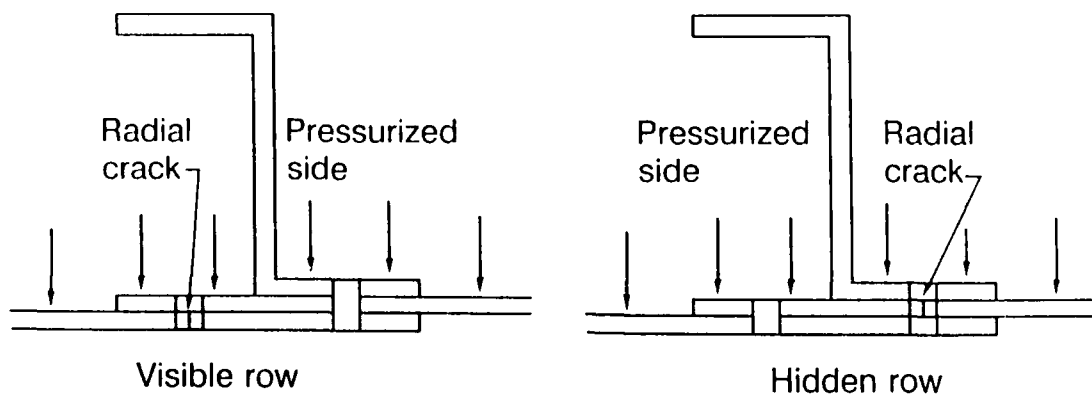


Figure 13 — Radial Stiffener and Crack Locations

Ulf G. Goranson

after accumulation of 25,000 short-range service flights during 15 years. The fuselage structure is currently being subjected to pressure cycling to explore extended fleet usage beyond the original economic design life objectives of 20,000 flight cycles and 60,000 hours. These activities are progressing and are scheduled for completion in 1989 (Figure 14). Upon completion of fatigue testing, several damage tolerance tests are planned and the fuselage will then be disassembled and inspected by mid-1990.

Teardown Inspections

Since the introduction of the 707, Boeing has conducted several teardown inspections and evaluations of high-time airplanes as a

part of a continuing assessment of airplane structure. These inspections permit a detailed examination of structural performance, and provide much useful information for forecasting future structural maintenance requirements. Sophisticated inspection techniques, capable of finding smaller cracks than typically found during routine airline inspections, are used on the disassembled structure. Teardowns also provide an excellent database for calibrating analysis tools, and for developing structural modifications on future production airplanes, if required. Major teardown inspections supplementing normal fleet surveillance activities have been conducted on several Boeing models:

- 707: wings including center sections, 1965 and 1968
- 707: wing, center section, and fuselage, 1973

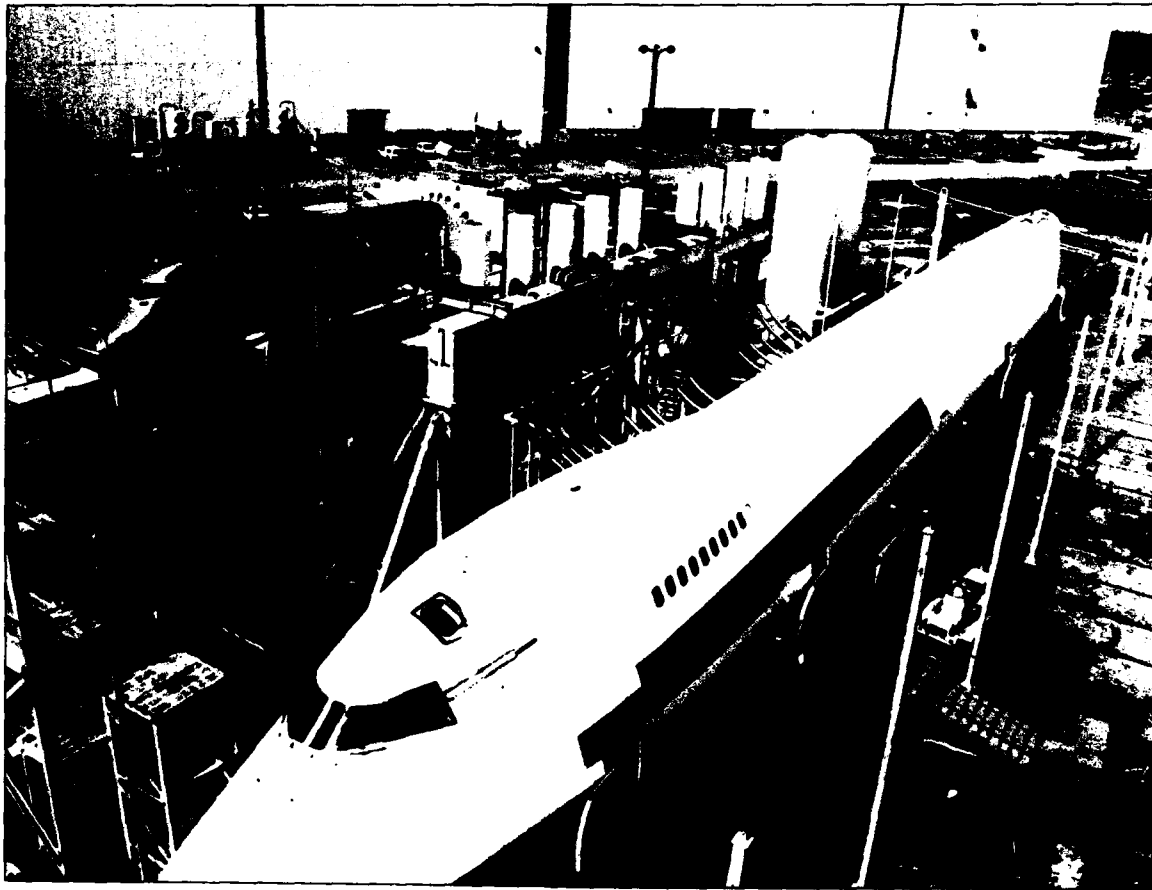


Figure 14 — Retired 747 Fuselage Fatigue Test Article

Second Annual International Conference on Aging Aircraft

- 707: empennage, 1978
- 727: forward fuselage (after fatigue testing), 1978
- 737: forward fuselage, wing, and empennage, 1987
- 737: rear fuselage (after fatigue testing), 1988
- 747: wing and empennage, and fuselage (after fatigue testing), 1988 through 1990

Recent concerns related to an increased number of airplanes being used beyond their original design life objectives have spurred further activities to obtain airframes, retired from service, for teardown inspections. As was mentioned previously, a 737 was damaged beyond economic repair in late 1986 and purchased by Boeing for pressure cycling of the aft fuselage section and teardown, Figure 15. Most

of the structure inspected was found in good condition with little corrosion. Most findings on this 737 airframe, with 59,000 flights and 42,000 hours accumulated during 18 years of service, were in previously known problem areas. While of no immediate safety concern, some new findings emerged that have been corrected in subsequent derivatives and retrofit kits made available to operators. The teardown activities spanned a 2-year period. A 747 retired from service in 1988 is currently being disassembled for detailed wing and empennage inspection, Figure 16. The fuselage will be inspected after completion of cyclic pressure testing now in progress.

Boeing will continue to monitor the aging fleet to verify the effectiveness of preventive modifications incorporated as retrofit on older models or new model production improve-

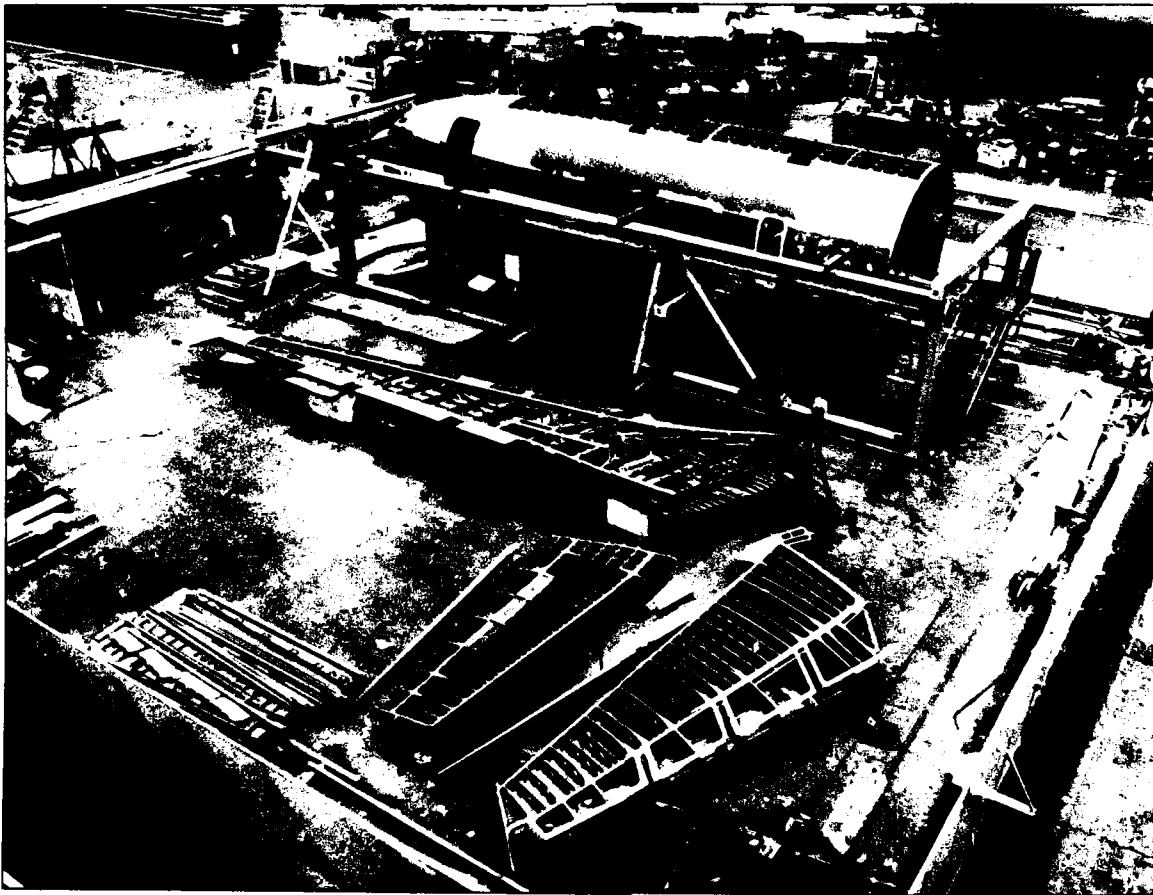


Figure 15 — 737 Teardown Site, Before Disassembly

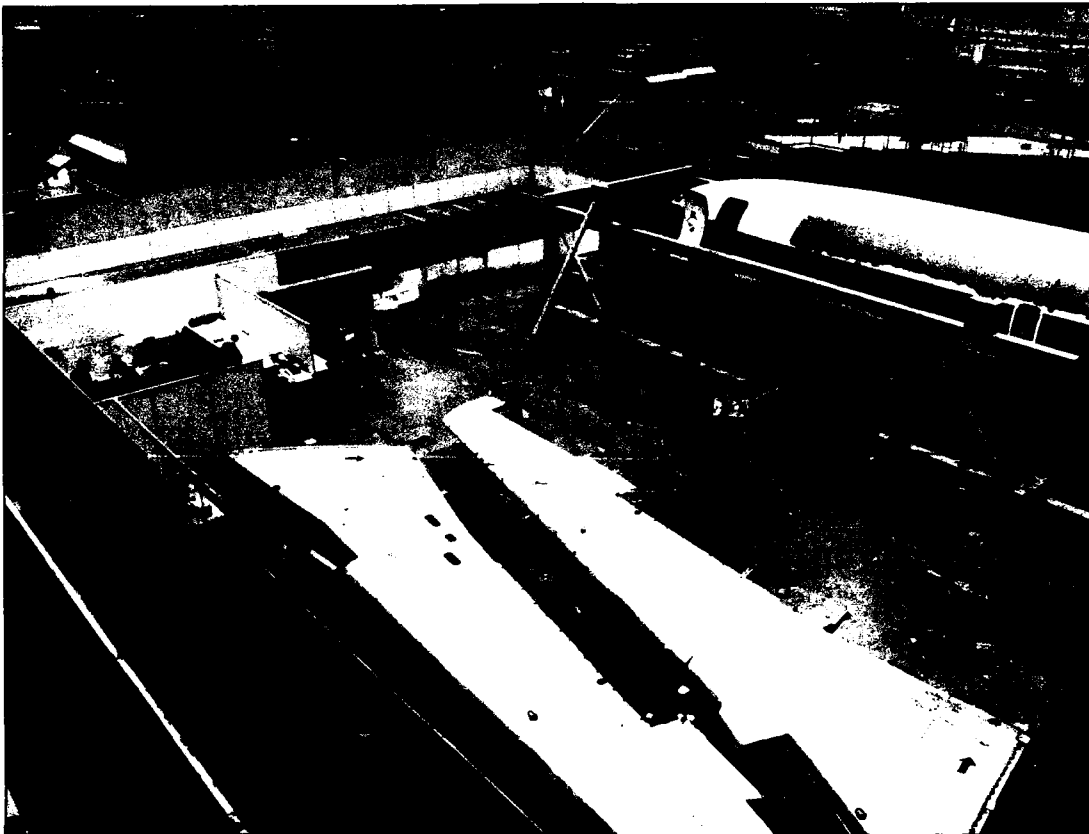


Figure 15 (Continued) — 737 Teardown Site, After Disassembly

ments. Findings will be disseminated to operators by service bulletins as required and incorporated in maintenance recommendations issued by Boeing.

Supplemental Structural Inspection Programs

The continued structural airworthiness of aging transport airplanes has been the subject of considerable discussion among experts in the industry and airworthiness authorities. Attention has been focused on the adequacy of inspection programs for timely damage detection in support of fail-safe design practices used during the last three decades. CAA Airworthiness Notice 89 and FAA Advisory Circular 91-56 allow structural reassessments,

including recommendations for any necessary supplemental structural inspections, as an alternative to imposing service life, operational or inspection limitations. The resulting structural inspection program supplements existing operator maintenance programs that generally have been very effective in maintaining the inherent damage tolerance of Boeing jet transport structures. Model specific documents provide inspection options for selected structurally significant items (SSI) that will ensure timely detection of fatigue damage in older airplanes. This is achieved, where required, by use of more refined inspection techniques within the operator's existing scheduled maintenance program, or by supplemental inspections. These inspection requirements are applicable to those high flight cycle airplanes termed candidates since these are the most likely to experience the

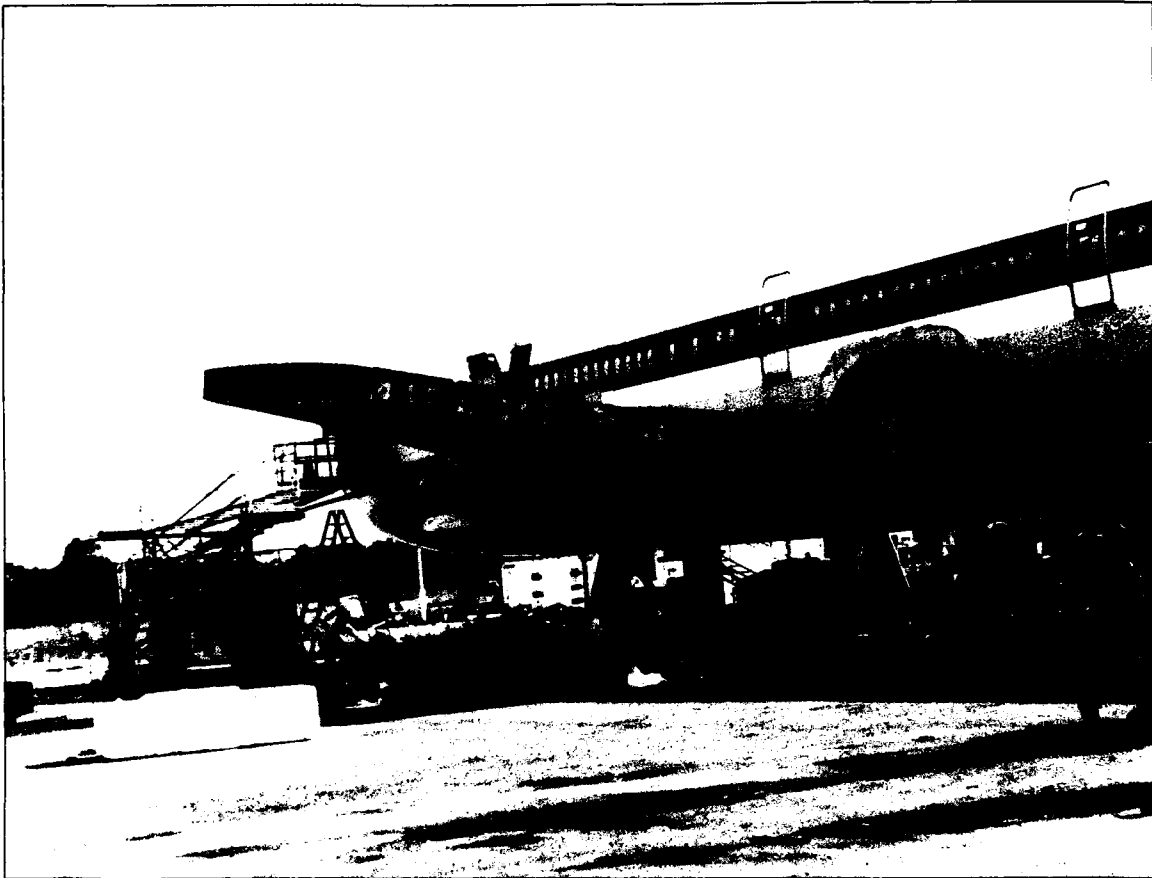


Figure 16 — 747 Test/Teardown Airplane Disassembly

earliest fatigue cracking in the fleet, Figure 17. When cracking is detected and reported, necessary action is taken to safeguard the total fleet.

The supplemental structural inspection documents (SSID) for models 727, 737, and 747 were released in 1983 and contain usage procedures, lists of candidate airplanes, structurally significant item (SSI) information with example maintenance program requirements, and a discrepancy reporting procedure. The SSID for model 707 was first released in 1979 but is less sophisticated in terms of the inspection options that are provided. The basic information and approach is, however, similar and several updates have been issued to reflect fleet composition changes. SSID inspections have been mandated on selected 727, 737, and 747 airplanes since 1984 and on selected 707 airplanes since 1985.

When a discrepancy is detected in an SSI, it

is essential that timely action be taken to safeguard the total fleet. Reported information is used to establish a threshold and a method and repeat interval for inspections to find all discrepancies in the fleet. Several structural item interim advisories (SIIA) and service bulletins have been issued to ensure proper attention in the total fleet based on discrepancies that have been found, Figure 18. The 707, 727, 737, and 747 supplemental structural inspections augment existing inspection programs and provide a valuable contribution towards maintaining fleet safety.

Aging Fleet Survey

Boeing continually reviews reported service data and other firsthand information from

Supplemental Structural Inspection Program (SSIP)

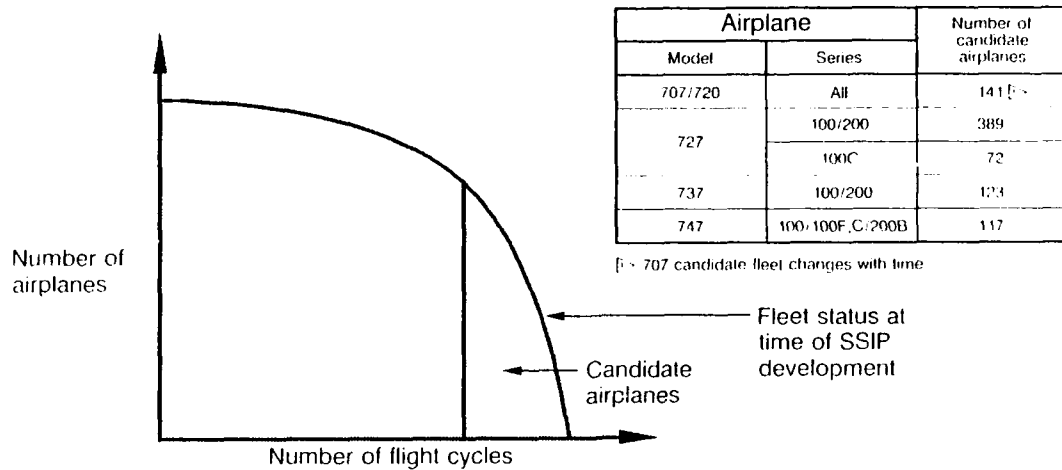


Figure 17 — Supplemental Inspection Candidate Airplanes

Model	Structure			
	Wing	Fuselage	Empennage	Strut
727	4	10	1	N/A
737	3	6	0	0
747	0	11	0	0

Figure 18 — Significant Supplemental Structural Inspection Findings (1988)

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customer airlines in order to promote safe and economic operation of the worldwide fleet. As a result of current fuel costs, and increasing costs for equipment replacements, the active service life for commercial airplanes is gradually being extended. The average age of the world airline jet transport fleet has increased from 8 years in 1980 to 12 years in 1989 and, based on projections from the Boeing fleet summary shown in Figure 4, this upward trend in airplane operating age is likely to continue. In order to further expand existing Boeing knowledge of aging airplanes and those factors influencing maintainability of structures and systems, a 2-year Aging Fleet Evaluation Program was implemented in June 1986. The specific objectives of this program were

- To gain an engineering assessment of the condition of older airplanes with emphasis on structures and systems.
- To observe the effectiveness of Boeing corrosion prevention features and other corrosion control actions taken by the operators.
- To acquire additional fleet data that will be used to improve maintenance recommendations and promote improved design of new airplanes.

Program Participation

A representative cross section of operators with airplanes approaching the economic design life objectives participated in the program. By September 1989, 80 airplanes from models 707, 727, 737, and 747 had been observed, Figure 19. Although a small percent of the active Boeing fleet, the airplanes inspected represent about 15 percent of those airplanes exceeding 75 percent of the economic design life objectives in flight cycles. The surveys covered a wide variety of operating environments and conditions, and involved 50 operators in 27 countries, Figure 20.

Survey Procedure

Survey teams were dispatched to observe airplanes during scheduled heavy maintenance checks. Six experienced structures, systems,

and maintenance engineers recorded their observations in survey documents unique to each airplane model and covering up to 350 structure and 150 system items. Typically, 60 percent to 80 percent of the items were surveyed since access was not available to all areas during the period that the team was on site. The survey included a review of airline practices regarding airplane usage, maintenance program, and dispatch reliability. The operators were briefed by the teams on their findings upon completion of each survey.

All significant findings pertaining to a specific visit were reported upon return to Boeing and assigned to appropriate organizations for necessary action. The collected data have been pooled for fleet evaluations to determine if there are trends requiring additional actions by Boeing or the operators. A number of detailed action items have resulted from the surveys and their applicability has been reviewed across all Boeing models. To ensure anonymity, all identifiable operator/airplane data are treated as confidential.

Survey Results

Operator response to the program has been favorable, with full participation and excellent cooperation. The survey teams paid special attention to the condition of structurally significant items such as wing and empennage box structures, major bulkheads, fuselage monocoque structure and primary systems such as landing gear, flight controls and avionics.

There have been a number of significant findings and this presentation will focus on some of those that relate to airplane structures and systems. Considerable variation has been observed in both airplane condition and airline maintenance procedures, such as inspection intervals and corrosion prevention measures. The condition of the structure was good in many cases but considerably below expectation in a few. As a result of the observed variation, the following findings are worthy of note:

- The most significant finding has been the relatively poor condition of a limited number

September 1989:

- 80 airplanes surveyed
- 50 operators visited in 27 countries

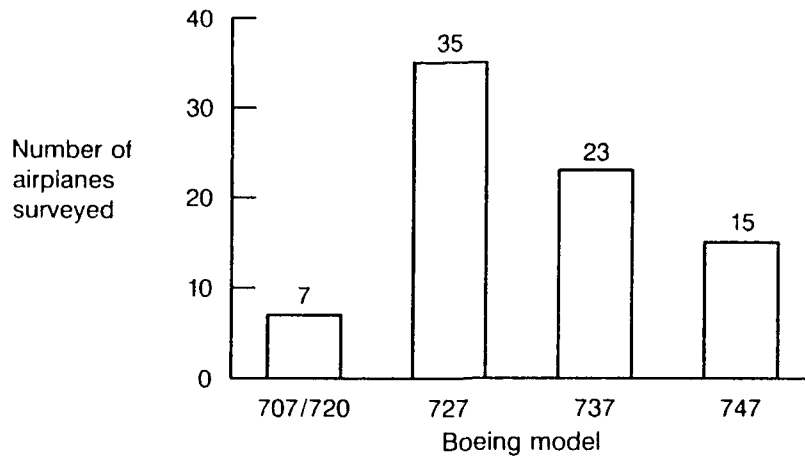


Figure 19 — Boeing Aging Fleet Survey Status

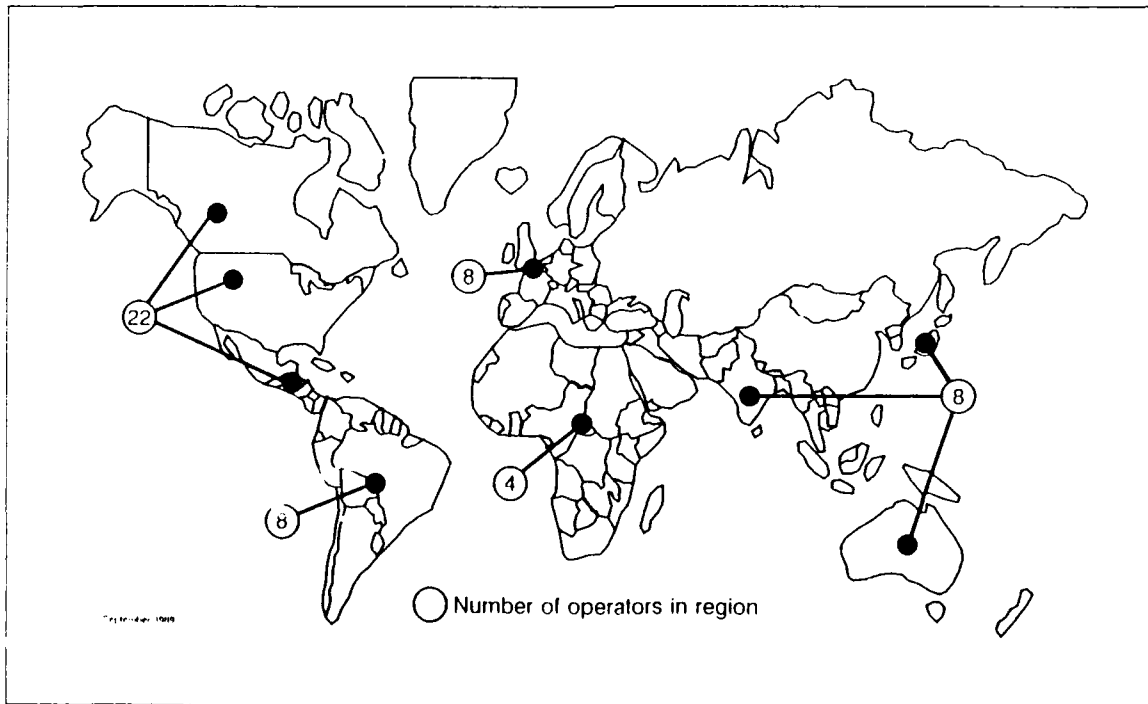


Figure 20 — Boeing Aging Fleet Survey Participants

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of the airplanes. The teams observed that the incidence and extent of discrepancies, particularly corrosion, was more than would be expected on a well maintained airplane. There is evidence that, in these cases, repair action was not taken in a timely manner.

Figure 21 shows corrosion in a fuselage stringer on a 707 airplane belonging to a small charter airline. It can be observed that much of the cross section has disappeared. Similar problems were observed at other locations on the same airplane. The maintenance program on this airplane was based on flight hours. Because the annual utilization of the airplane was relatively low, almost 10 years had elapsed since the previous internal inspection of the fuselage. Special maintenance programs have been developed for low-utilization operators that define appropriate calendar-based inspection intervals, helping to ensure that corrosion is kept under control.

Significant corrosion of system items was limited to control system cables, and usually only those passing under or near the lavatories. Minor corrosion, which had no effect on component performance, was found on the accumulator cylinders and on some landing gear hydraulic components. These corrosion problems are being reviewed to determine if additional maintenance recommendations are needed.

Figure 22 shows corrosion in a lower fuselage cargo door frame on a 727 airplane belonging to a major airline with an excellent maintenance program. The reasons for the extent of the damage on this airplane cannot be ascertained. It is, however, apparent that corrosion can affect all operators, large or small, and that none are immune. Lower fuselage areas are particularly vulnerable to corrosion attack since condensation and spillages naturally tend to flow to the lowest point on the structure.

Corrosion prevention and control meas-



Figure 21 — Fuselage Stringer Corrosion



Figure 22 — Cargo Door Frame Corrosion

ures must be aggressively pursued to reduce the need for extensive repair, and to promote continued airworthiness.

- Most fatigue cracking observed during the surveys was previously known and action identified to the operators by means of service bulletins. While a few new fatigue problems were identified, none were immediate safety of flight concerns. Figure 23 shows an example of a fatigue crack on a fuselage frame of a 737 airplane. This problem had first been observed on an aging fleet survey and on the 737 rear fuselage fatigue test within the space of a few weeks. The same problem has since been observed by two additional survey teams. Fatigue cracking has been attributed to the effects of a stress concentration at a fuselage frame splice. Service actions in the form of a service bulletin have been developed and changes to the production line have been made to eliminate the problem from new deliveries of the 737 airplane.
- The accomplishment of service bulletin action varies with airline and ranges from as low as 20 percent to 80 percent. Service bulletins often give alternative compliance procedures in the form of repair or additional inspections. It was observed that airlines frequently chose the option to continue inspection rather than perform the specified repair action that would permit a return to normal maintenance inspection procedures and intervals.
- There is concern over the number of repairs found in close proximity to each other on some airplanes. The damage tolerance of the structure may be impaired in such circumstances even though each repair may be satisfactory in isolation. Figure 24 shows sections from a lap joint on a 727 airplane.

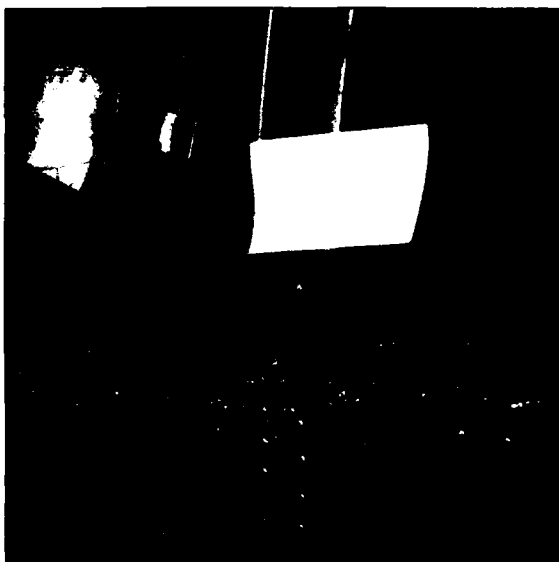


Figure 23 — Fuselage Frame Crack

This joint has two previous repairs. Further cracking has occurred in close proximity to these repairs, leading to additional repair activity at the same location. Incomplete removal of corrosion damage during repair is also frequently encountered. Unless extreme care is taken during corrosion re-

moval, it is inevitable that the problem will recur.

In addition, a number of airplanes were found with improper modifications or repairs. Examples include excessive use of blind rivets and improper rivet patterns in primary structure, improper use of screws to attach repairs in primary structure, applying sealant or paint over existing corrosion, and creating knife edges at fastener holes by using countersunk rivets in thin skins.

- Some airplanes subject to short-term changes of owner or operator did not appear to receive adequate maintenance. Figure 25 shows an example from the fuselage of a 737 airplane that had changed hands several times during the last 10 years. It is apparent from the corrosion and tear strap disbonding that was observed that little attempt had been made to maintain the airplane. Lack of continuity in maintenance seems particularly prevalent when it comes to leased airplanes. With the steady increase in leased airplanes in worldwide service, the average condition of the fleet could worsen unless steps are taken to

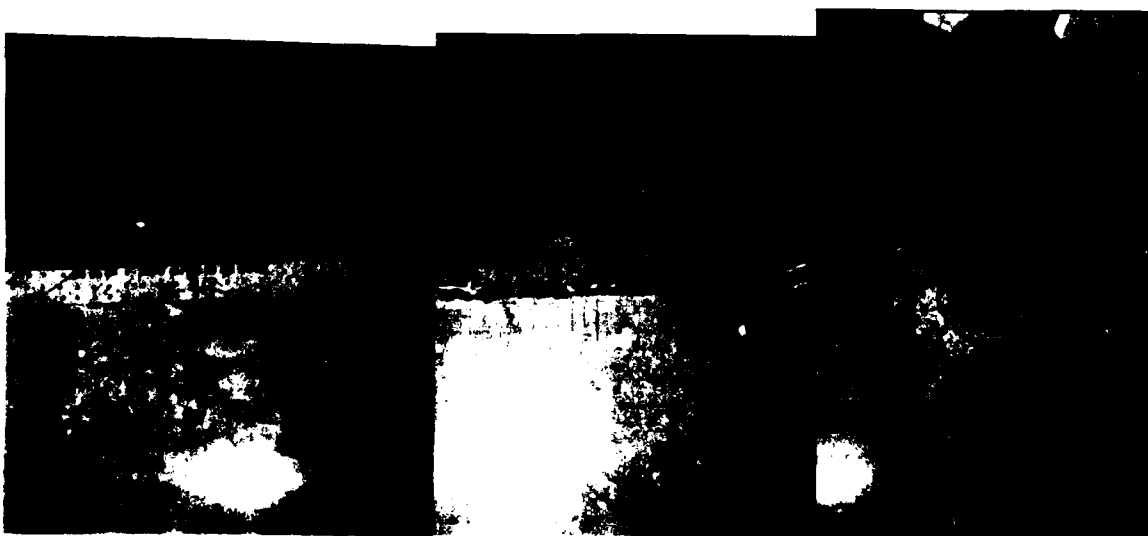


Figure 24 — Multiple Repairs to Fuselage Skin Joint

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ensure that these airplanes receive the required levels of maintenance. Adoption of the previous operator's maintenance program, which is often the case, may not always be appropriate, particularly if there are significant differences in the type of operation. For example, a maintenance program developed for a major carrier with extensive capabilities may not be suited to a small, low-utilization operator who lacks sophisticated inspection equipment.

- A few airplanes were found to be out of compliance with current airworthiness directives. As an example, H-11 steel bolts were installed as original equipment on some Boeing models but were found to be susceptible to stress corrosion cracking in service. Appropriate service bulletin and airworthiness directive actions required that these bolts be removed from the fleet. It has become apparent, however, that stocks of spare parts are not always purged from

inventory. As a consequence, the H-11 bolts were found to have been reinstalled on a few airplanes. The need to remove these bolts from inventory has been re-emphasized. A similar system example is the use of certain three-phase circuit breakers in restricted high-amperage applications. On several aircraft these breakers have been observed in one or two positions where they should have been replaced. Additionally, some system revisions were observed to be only partially installed. These installations are thought to occur due to line-type maintenance after original installation. An example is the 727 ground spoiler hydraulic line installation that was required to be suitably marked or the fittings revised to prevent cross-connection of the up and down ports. Subsequent replacement of one or more of these tubes, using different criteria, can negate the required change.

- The airplane systems observed are consid-

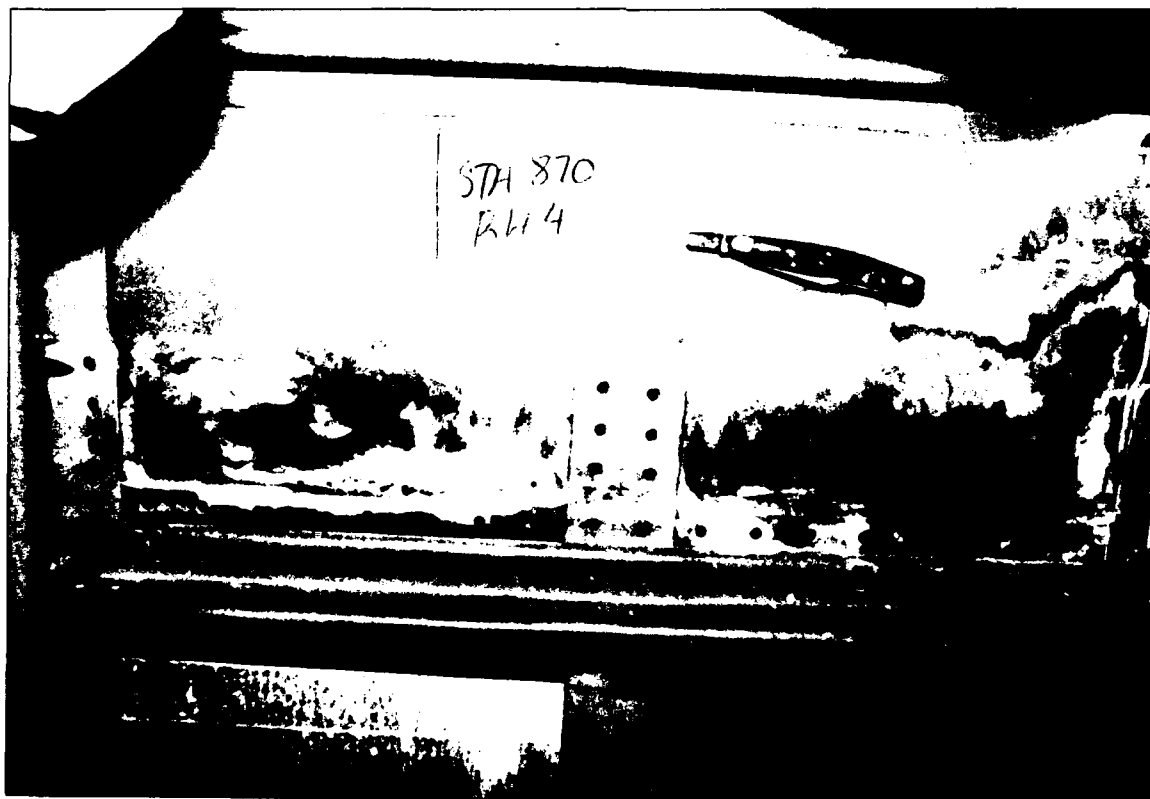


Figure 25 — Fuselage Corrosion and Tear Strap Disbonding in Leased Airplane

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ered to be generally in good to serviceable condition. However, portions of some systems, especially those where performance of function is not dispatch-critical, were observed to be in unsatisfactory condition. Similar discrepancies were reported on a number of surveys and it was obvious that these discrepancies existed for a long period of time.

Some of these areas are:

—Placards: Placards for flight deck, payloads and service areas were missing, damaged or faded to the point that negated the installation. Sometimes, several placards in one area were illegible.

—Air-Conditioning Ducts: In several cases, air-conditioning system distribution ducts, especially the 727 sidewall "Y" ducts, were in poor condition. The extent of these discrepancies will have a significant impact on the air-conditioning system.

—Cargo Areas: On a large number of surveys, the cargo door seals were found to be damaged or deteriorated to a point that would significantly affect their ability to limit air exchange to acceptable rates. Also, the cargo bay floor and liners had unacceptable penetrations due to damage.

Although these discrepancies were corrected during the heavy maintenance check, it is obvious that their condition had existed for a long time. Maintenance of these type items should be accomplished at intermediate maintenance points and not allowed to accumulate to the extent observed.

- Design details may restrict accessibility to certain structures and systems limiting the frequency of inspection and increasing the cost to the airlines. Improved access is a design requirement in later Boeing models and is being re-emphasized as a significant issue in future design reviews. For those areas where easy access cannot be provided, further improvements in corrosion prevention measures and fatigue margins will be made. Other, specific findings are

also under review for necessary action. These findings address service bulletin and service letter recommendations, production line changes, spares support, customer and design manual revisions and specific customer concerns. To obtain maximum benefit from the program, actions have been distributed to ensure consistency between airplane models.

Boeing has committed to a continuation of the Aging Fleet Evaluation Program with the objective of expanding knowledge of the effects of age on jet transports.

Maintenance Actions For Aging Fleet

Recent aging fleet concerns have resulted in both specific Boeing initiatives and joint industry, airline, and airworthiness authority actions. Boeing formed a special Corrosion Task Force. In addition, meetings were held with airline maintenance executives as a result of the aging fleet survey findings. The conference on aging airplanes, held in Washington, D.C., in June 1988, resulted in the following recommendations by the airlines and manufacturers:

- Continue to use present system of maintenance and inspection with diligence and thoroughness. Find out why a single airplane suffered major structural failure and adjust system as necessary.
- Initiate research to find better ways to assess structural condition and detect structural problems.
- Continue to pursue concept of teardown of oldest airline airplane to determine structural condition and conduct fatigue tests on older airplanes.
- Pursue transfer of available body of knowledge of NDT and its application to airplane inspection.
- Put research and development money into improving NDT techniques and methods.
- Examine all aspects of human factors in-

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volved including training and qualification of airline inspectors.

- Ensure that the communications systems among airlines, the manufacturers and the regulatory authorities are adequate.
- Establish task forces from the airlines, manufacturing industry, FAA, and NASA to continue the work begun at this conference.

Working groups were formed in August 1988 with the charter to foster a consistent approach to the aging fleet concerns for each major manufacturer of commercial airplanes, Figure 26. The task groups for each Boeing model comprise about 15 airline representatives and Boeing structural specialists. The airline members were selected to provide a good representation of fleet experience with a particular model. These groups have been meeting monthly in Seattle to:

- Select service bulletins for high-time airplane modification based on potential safety problems, probability of occurrence, and inspectability.

- Develop directed corrosion inspection and prevention programs based on fleet data.
- Review adequacy of SSID programs in terms of candidate fleet coverage and inclusion or deletion of significant structural items.
- Develop comprehensive maintenance recommendations for older airplanes in the fleet.
- Assess structural repair quality relative to long-term operation.

Service Bulletin Reviews

As airplanes age, the incidence of fatigue increases and corrosion becomes more widespread. Problems are often addressed in isolation during the early service use of airplanes. With age, two or more problems in an area may degrade airplane structural fail-safe capability. This increases the need to incorporate preventive modifications in areas with known problems.

The criteria for selection of service bulletins for high-time airplane modification were based on considerations such as:

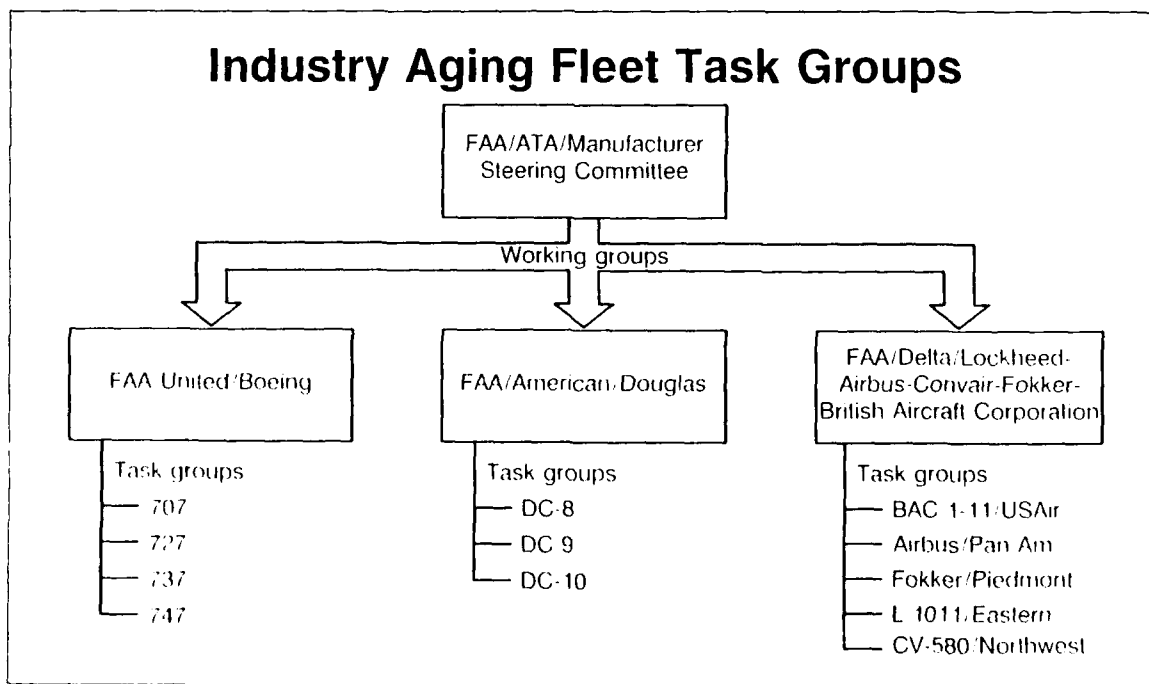


Figure 26 — Industry Aging Fleet Task Groups

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- Safety problem potential.
- High probability of occurrence.
- Difficulty of inspection.

A candidate list of service bulletins was established by Boeing as a baseline after a thorough review of service bulletins for long-term operation applicability, Figure 27. These service bulletins were reviewed by the respective working groups for selection of those recommended for terminating actions. The thresholds for these mandated repairs/modifications were typically selected as the life goal objectives in flight cycles for fatigue related problems. Earlier thresholds may be necessary for items driven by corrosion or stress corrosion considerations. The resulting service bulletins for which mandatory modifications are recom-

mended are shown in Figure 28. These selections were guided by a rating system developed by working group members to reflect their own experience. Summary documents of affected service bulletins have been issued for each Boeing model. These serve as a reference for airworthiness directive action by airworthiness authorities.

Corrosion Prevention and Control Requirements

Boeing aging fleet evaluations have shown that some operators do not utilize a proven corrosion prevention and control program. If allowed to continue, this can lead to unacceptable degradation of structural integrity and, in an extreme instance, result in loss of an

Candidate Service Bulletins For Mandatory Modifications

Model	Bulletins reviewed	Initial candidates
707	327	192
727	286	81
737	189	66
747	228	83

Figure 27 — Initial Selection of Service Bulletin Candidates for Mandatory Modifications

Structures Working Groups Service Bulletin Review Actions

Model	Candidate bulletins	Mandatory modification recommended	Other action 
707	197	133 	31
727	113	74	15
737	80	56	19
747	83	31	27

 Change inspection interval or method

 Address 80 specific structural problems

Figure 28 — Service Bulletins Recommended for High-Time Airplanes

airplane. The Boeing aging fleet working group charter therefore included the development of a mandatory corrosion-directed inspection and prevention program for each airplane model.

Boeing established a special team of engineers to identify all known corrosion problems that could affect continuing airworthiness of the aging fleet and to summarize existing maintenance recommendations. The following tasks were accomplished in preparation for working group reviews:

- Interrogate Boeing data on repeated corrosion problems.
- Compile list of known corrosion problems grouped in general areas for each model, Figure 29.
- Combine general areas into suitable major airplane zones based on similarities between corrosion prevention and control or inspection access requirements.

- Prepare a summary of each major airplane zone for task group reviews.

Following review, an industry approach has been developed. This consists of a minimum baseline program including an implementation plan, thresholds and repeat inspection intervals for basic corrosion control/prevention tasks. Full details of the tasks will include inspection, repair, application of prevention standards and reporting. The thresholds and repeat intervals are defined in calendar periods, i.e., independent of flight cycles or flight hours. Operators who continue to experience significant corrosion must make appropriate adjustments to their program to prevent or control the problem. The priority for implementing the program and alternative means of compliance will be subject to negotiation between operators and appropriate airworthiness authorities.

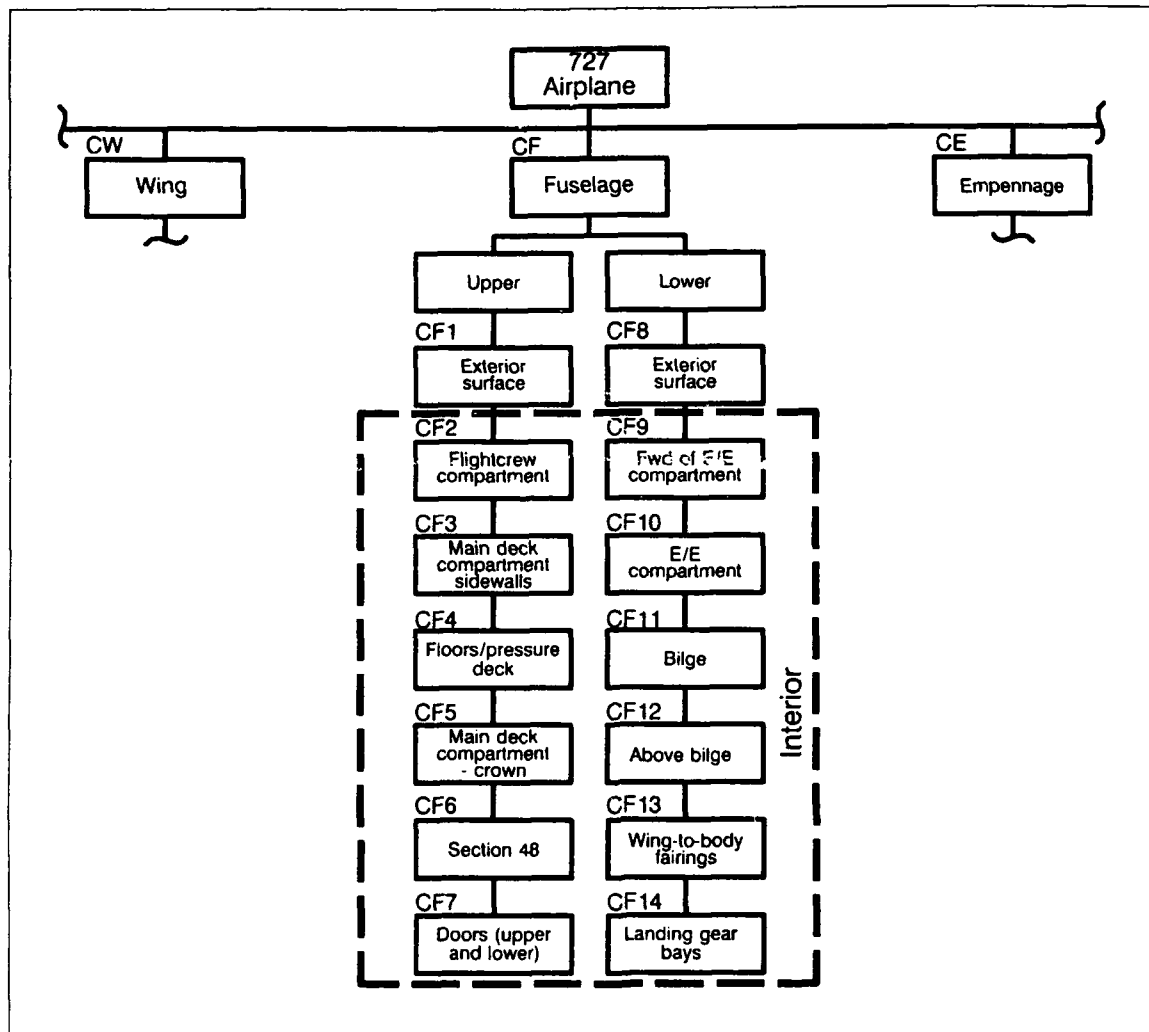


Figure 29 — Structural Breakdown for Corrosion Exposure and/or Access Assessment

Although this corrosion control and prevention program addresses the aging fleet, it is imperative that it is implemented early due to the insidious nature of corrosion. This means thresholds of 5 to 6 years for some structures, Figure 30. These programs define minimum requirements for continuing airworthiness. However, additional and more frequent tasks may be required for an economically balanced program. Less stringent requirements may apply to operators with established corrosion prevention and control programs that have proven to be successful.

Supplemental Structural Inspection Program (SSIP) Reviews

The major issues of the SSIP reviews planned are:

- Adequacy of the present candidate fleet for fleet leader sampling.
- Inclusion or deletion of significant structural items.

The candidate fleet for models 727, 737, and 747 were those airplanes that were fleet leaders at the time of initial Supplemental Structural

Corrosion Inspection Thresholds and Inspection Interval, Years

General area		707/720		727		737		747	
		Threshold	Repeat	Threshold	Repeat	Threshold	Repeat	Threshold	Repeat
Wing	Outer-external	10	4	10	5	8	4	10	2
	Leading edge interior	8	2	10	5	8	4	6	1.5
	Outer-main box interior	10	8	10	10	10	10	20	10
	Trailing edge interior	8	2	10	5	8	2	10	2
	Center section interior	10	8	10	8	10	8	20	10
Fuselage	External (including doors and landing gear bays)	6	2	6	1.5	5	1.5	10 upper 5 lower	5 upper 2 lower
	Flightcrew compartment	Opportunity inspections and selected out-of-service/retired airplanes							
	Upper lobe interior	8	8	10	8	8	8	15	8
	Lower lobe interior (except bilge)	6	6	6	6	6	5	6	6
	Lower lobe - bilge	6	3	6	3	6	2	6	4
	Section 48 interior	10	5	10	5	8	4	10	5
H/V Stabilizer	External surfaces	10	2	10	2	10	2	10	5
	Leading edges	10	8	10	8	10	8	15	8
	Main box interiors	10	8	10	8	10	5	15	8
	Trailing edges	10	8	10	4	10	5	10	5
	Center section	10	5	10	5	10	8	10	8
	Center engine inlet duct	-	-	10	8	-	-	-	-
Nose and main landing gear		Landing gear overhaul		Landing gear overhaul		Landing gear overhaul		Landing gear overhaul	
Powerplant and strut		4	2	5	2	Engine change		7	3

Note: Some specific areas/items within the general areas have independent thresholds and repeat intervals.

Figure 30 — Corrosion Inspection Thresholds and Inspection Intervals (Years)

Inspection Document (SSID) releases in 1983. Boeing periodically reviews the candidate airplane list for any significant changes in fleet distribution, composition, or utilization. To date, only minor changes have occurred in the active candidate airplanes subject to SSID compliance. Although some noncandidate airplanes have overtaken candidate airplanes in terms of flight cycles, less than 10 percent would be affected in a simple replacement of candidate airplanes with noncandidate airplanes having higher flight cycles.

Some Structurally Significant Items (SSIs) were not incorporated in the SSIDs based on obvious damage containment capability providing damage detection without directed inspections. Recent concerns on the extent of corrosion that has been observed and the probable interaction with fatigue damage warrant a detailed review to determine if any additional SSIs should be included in SSID updates. Thin

gauge fuselage lap splices are an example of this category of structure.

Another class of SSI is selected on the basis that the primary crack origin is in the most difficult area of structure to inspect, for example, internal structure. Cracking is assumed to spread into adjacent, external structural elements that are more readily inspectable. Detection of a crack in the adjacent element should lead to a thorough investigation of the extent of damage, and as a result, the primary crack origin should be detected. One such example is fuselage frame cracking with secondary skin cracking. However, experience has shown that multiple frame cracking can occur prior to any significant external secondary skin cracking.

Inspection for Multiple Site Damage (MSD) is a key consideration to ensure structural integrity of areas with numerous identical details operating at similar stress levels. Full-scale

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fatigue testing of aging airplane structures has demonstrated that rapid linkup in local areas may occur (test verification) and analysis criteria based on this behavior, developed since original SSID releases, will be used as part of a review of SSI coverage.

Old Airplane Maintenance Programs

Comprehensive maintenance program guidelines acceptable to the airlines, airworthiness authorities and Boeing do not exist that properly address older airplanes in the fleet. The Supplemental Structural Inspection Program, for example, addresses one issue, namely fatigue cracking, in isolation. It is also perceived that maintenance intervals on older airplanes should be reduced as a function of age. Some sampling inspection programs should be revised or there should be a reversion to full fleet inspections. An activity is in progress to review existing recommendations with a view to resolving these deficiencies.

Structural Repair Quality

Major repairs are performed and validated based on existing FAA approved data such as service bulletins (SB) and structural repair manuals (SRM) or require new substantiating data approval by Designated Engineering Representatives (DER), repair approval authority (SFAR36) or other means. Aging fleet concerns have been raised about the quality of repairs with regard to damage tolerance relative to long-term operation. Repair evaluations will be focused on damage tolerance analyses of typical major repairs of significant structure, particularly involving patches or splices. These evaluations will provide recommended mandatory inspection requirements in terms of methods, thresholds, and repeat intervals. The airplane operators will complement this activity by documenting major repairs, based on visual inspections and airplane records, within a specified time period for external repairs and when areas are accessible for any reason for internal repairs. These repairs will also be verified to be in compliance with FAA approved

data, or have DER or SFAR36 approval on an individual basis.

A parallel activity to provide guidance material to classify major repairs has been addressed by a joint industry/operator task force. Guidelines in the form of a logic system will be provided in Air Transport Association report (51-10-01). Application of the guidelines will exempt air carriers from the criteria for major repairs (FAR Part 43 Appendix A).

Summary

The Boeing Company is dedicated to design and manufacture safe commercial jet transports. The successful discharge of this responsibility over the last three decades, Figure 31, has contributed significantly to a position of industry leadership and reflects the top priority given to safety. This paper illustrates that assurance of the structural integrity of commercial airplane structures is a very serious and disciplined process. High standards must be maintained to ensure the safety of aging airplanes until economics dictate their retirement. Standard Boeing practices to oversee the continuing structural integrity of the commercial fleet include:

- Structural maintenance programs that recommend airline inspection and overhaul requirements.
- Ongoing communication between field service representatives and the customer support organizations.
- Formal notification to airlines of additional recommended actions through service letters, structural item interim advisories and service bulletins.

To help identify potential problems associated with the aging jet transport fleet, Boeing has four other special activities:

- Supplemental structural inspection programs that require airlines regularly to inspect structurally significant items on selected older airplanes and report defects to Boeing for prompt fleet action.

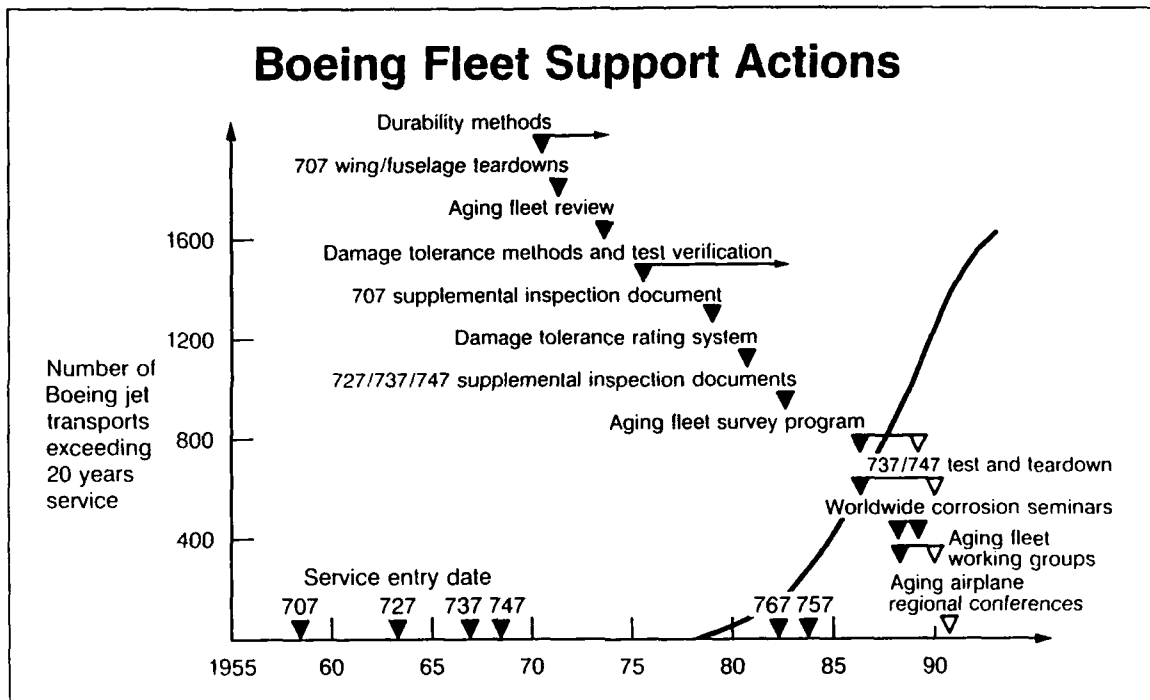


Figure 31 — Boeing Fleet Support Actions

- Teardown of older airframes to help identify corrosion and other structural service defects.
- Fatigue testing of older airframes to determine structural behavior in the presence of service-induced problems such as corrosion, repairs and loose or missing fasteners.
- An engineering assessment of the condition of a representative sample of older Boeing airplanes in the fleet to observe effectiveness of corrosion prevention features and to acquire additional data that might improve maintenance recommendations to the operators.

Recent aging fleet concerns have also resulted in joint industry airlines and airworthiness authority actions. Special task forces consisting of representatives of airlines, Boeing and the FAA have been assigned the following tasks:

- The selection of service bulletins for which

suggested modifications should be made mandatory at some threshold.

- The development of mandatory corrosion inspection, prevention, and repair programs.
- Reviews of the supplemental structural inspection programs for completeness and clarity.
- The development of comprehensive maintenance guidelines for older airplanes in the fleet.
- The development of guidelines to determine the adequacy of structural repairs in relation to damage tolerance and longterm operation.

These initiatives, guided by a joint industry steering committee, will provide timely preventive structural maintenance recommendations. These will permit continued safe operation of aging jet transports until their retirement from service.

Multiple Site Damage



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Sixteen months ago at the first aging airplane conference, the Federal Aviation Administration and the aeronautics industry made a commitment to carry out research and development necessary to maintain the structural integrity of the older transport category airframes which continue in service. ("Proceedings of the International Conference of Aging Airplanes", DOT-TSC-FA890-88-26, June 1-3, 1988). The private sector and the public sector both went quickly into action, in response at least in part to the recent in-flight structure failure in the N73711. The plane in Figure 1 is a Boeing 737, owned and operated by Aloha Airlines.

My prepared remarks today will address a major element of the FAA programs: research to understand the behavior of multiple site damage, in short MSD, how to find MSD during airframe inspection and how to avoid MSD in future designs. Under each of these headings, I will try to summarize what has been done and what is planned.

I define MSD as a group of small cracks that appear in the airframe about the same time and

that originate from similar structure details near one another. After some period of stable crack growth, the MSD still consists of small cracks similar in size or may consist of a large crack growing toward a group of small cracks. Neither situation is specifically addressed in the current damage tolerance requirements for transport category airplanes. (FAR 25.571 and FAA AC 25.571.1, Military specification, "Airplane Damage Tolerance Requirements," MIL-A-83444 (USAF), 1974.) Those requirements consider only the isolated cracks which constituted the airframe service fatigue experience base up to the mid '70s.

Post-accident photographs of the N-73711 fuselage show the presence of MSD in locations adjacent to or similar to the location where the in-flight failure originated. Special inspections following the N-73711 accident have revealed MSD in other airframes, including models other than the Boeing 737. Also, retrospective consideration of the 1983 failure of the special repair in the JAL-747 aft pressure bulkhead and earlier Air Force assessment of the widespread



Figure 1 — Aloha Airlines N73711

cracking limits of the original KC-135 and C-5A suggest that MSD can occur in highly stressed airframe components other than the fuselage. Thus, we must assume that MSD may not be isolated to one model or one manufacturer, but has the potential to appear anywhere in the nation's older fleet. (See Figure 2.)

Understanding MSD Behavior

To meet damage tolerance requirements requires an understanding of the behavior of any crack or group of cracks such as the detectable and critical sizes. Detectable size, defined as the largest crack size likely to escape detection, depends on the inspection method, procedure, inspector skill level and other human factors. The critical size is defined as the smallest crack size(s) that would precipitate unstable fracture when subjected to expected flight load stresses and the number of flights and flight hours of slow crack growth between these limits.

On the practical side, there is also a need to identify those aircraft and structural details which have significant potential for MSD. Several research efforts on these topics are in progress.

Fleet Data Bases

One of the activities is to establish a data base containing the information for character-

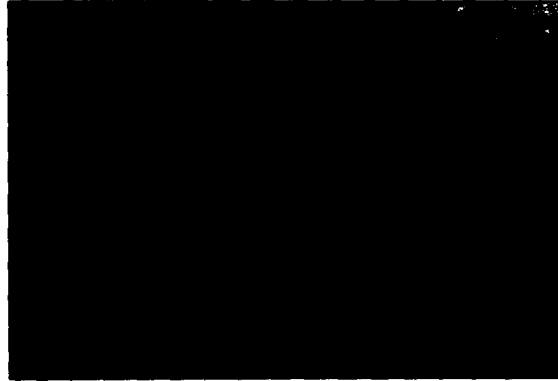


Figure 2 — Multiple Site Damage in N73711

Photographs of several rivet details in two areas of the N73711 fuselage adjacent to the in-flight failure area. Several MSD cracks are visible.

(Photographs courtesy of T. Swift, FAA.)

izing the aging fleet. The potential for MSD in existing aircraft is evaluated by means of airframe inspection. To be practical, however, such inspections should fit into the airlines' established schedule for D-check. A fleet data base will help the FAA to prioritize the special inspection efforts and integrate them with the airlines' schedules.

To date, research has concentrated on approximately 5,000 transport category airplanes currently operated by the nation's major air carriers. A current inventory has been produced by airplane type, serial number, flights, flight hours and so on. These are the basic elements of information required to group the aircraft in age categories. (See Figure 3.)

Additional information will be needed to

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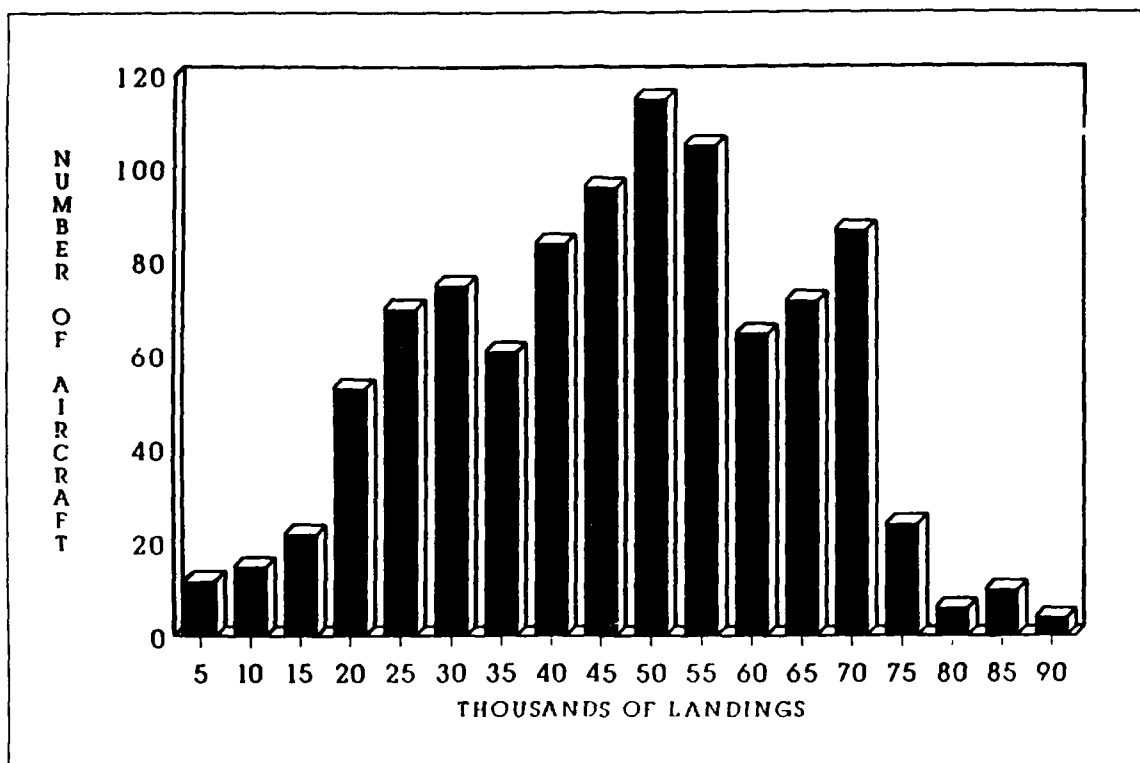


Figure 3 — DC-9 Fleet Age Status

The data reflect the fleet as of October 31, 1988. The DC-9 design goal was 45,000 landings, each assumed to represent a maximum service pressure cycle on the fuselage.

further group these aircraft in subcategories relating to MSD potential. The additional elements include model and sub-model (down to the level of significant differences in the primary structure) and, for each individual airplane, a history of its major repairs and the implementation of major structural AD and service bulletin actions. (See Table 1.)

Other existing data bases such as the Service Difficulty Report (SDR) and aviation safety analysis system (ASAS) are being searched for these kinds of information. Currently, the ATA has an Airworthiness Assurance Task Force which has formed various committees to look into data analysis problems. The Transportation Systems Center (TSC) is a participant on the subcommittee to define the data format and what data is required for analysis.

In the coming years, the data base development will also be extended to the commuter

aircraft. Preparation is underway for a preliminary survey of the commuter fleet by a team of independent experts. The objective of the survey is to identify those models that may have sufficient potential for cracking to warrant implementation of a SID program. Over the next six to nine months, the expert team will be visiting about 17 manufacturers to review about 59 aircraft models for this purpose.

Tear Stop Effectiveness

Another area of research is to examine the effectiveness of tear straps. The ability of tear straps to contain fuselage fracture precipitated by MSD linkup is of great concern. The transport fuselages in service today are damage tolerant in the meaning of the term as established by two decades of design practice.

AGING AIRPLANE FLEET DATA BASE

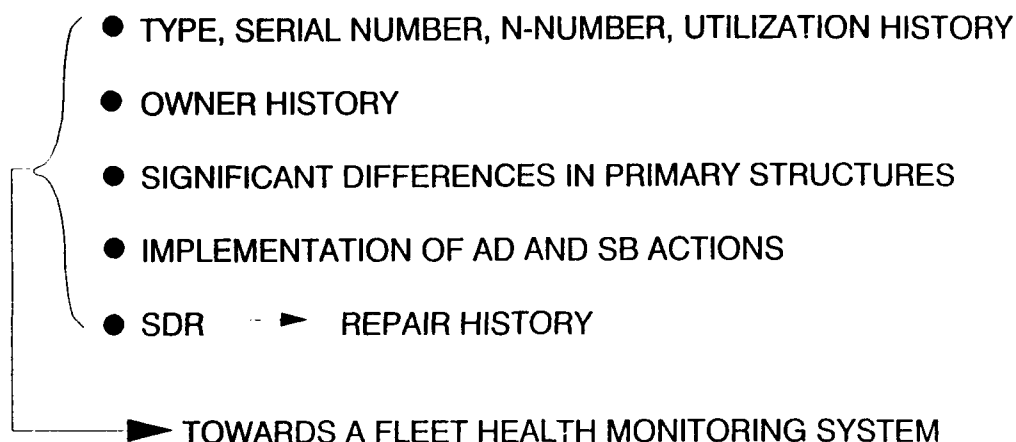


Table 1 — Aging Airplane Fleet Data Base

(Thomas Swift, "Damage Tolerance in Pressurized Fuselages," 11th Planerna Memorial Lecture, 14th symposium of the ICAO, Ottawa, Canada, June 1987). Specifically, these structures are able to contain up to a two-bay fracture at 110 percent of design maximum pressure. In other words, the damage tolerance requirement really is focused on protection against isolated damage. (See Figure 4.)

The objective of the present research is to determine how effectively tear straps can contain a fracture in the presence of MSD. The general scenario assumes a fracture resulting from a linkup of a group of MSD cracks. The fracture in this case lies along a skin splice, rather than in the middle of the bay, as is usually assumed in present design practices. In the MSD scenario, the fracture is assumed to be advancing toward adjacent bays which contain additional MSD cracks. (In broad outline, the scenario resembles the adjacent panel cracking considerations raised during Air Force structural integrity assessments of the C-5A and C/KC-135 wings.)

The subject of tear strap effectiveness will be investigated by means of full-scale compo-

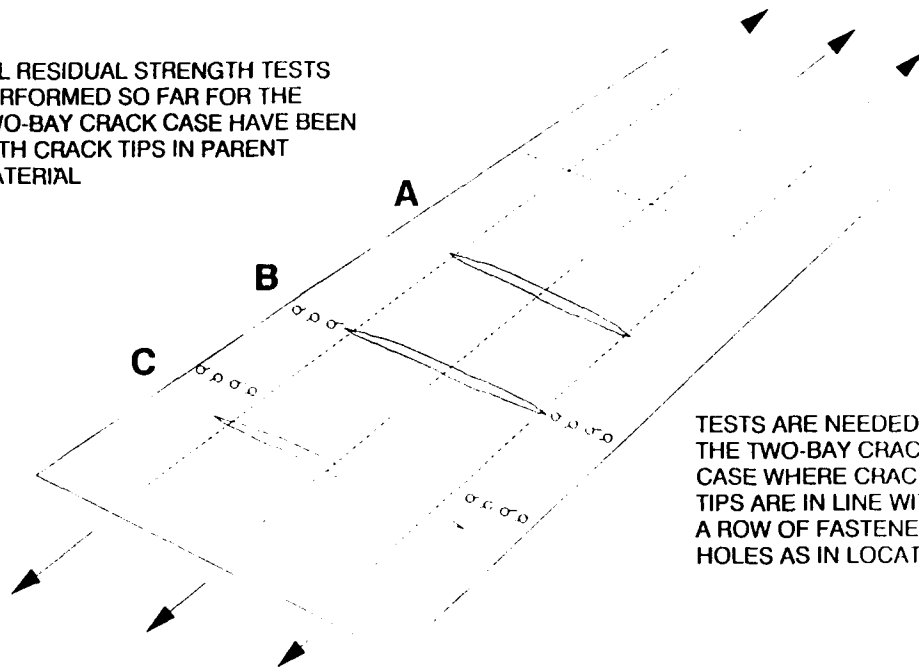
nent tests. A special fixture presently under construction (Figure 4), will accommodate curved panels which are 66 inches in circumference by 120 inches axially. The fixture will be able to subject the panels to pressure loading, plus small amounts of shear and/or bending. Over the next few months, several simulated MSD fracture tests will be performed on this fixture. (See Figure 5.)

Improved Analysis Methods

Another area of research is to improve analysis methods. Fracture analyses of stiffened panels have been used to correlate test data and predict design performance over two decades. The models most widely used for these analyses are based on the so-called displacement compatible method (Thomas Swift, "Damage Tolerance in Pressurized Fuselages," 11th Planerna Memorial Lecture, 14th symposium of the ICAO, Ottawa, Canada, June 1987) by our chairman, Tom Swift, and others.

But recent work has shown that advanced finite element methods (P. Tong, "A Hybrid

ALL RESIDUAL STRENGTH TESTS
PERFORMED SO FAR FOR THE
TWO-BAY CRACK CASE HAVE BEEN
WITH CRACK TIPS IN PARENT
MATERIAL



TESTS ARE NEEDED FOR
THE TWO-BAY CRACK
CASE WHERE CRACK
TIPS ARE IN LINE WITH
A ROW OF FASTENER
HOLES AS IN LOCATION B

RESIDUAL STRENGTH TEST WITH CRACKS IN LINE WITH ROW OF CHORDWISE HOLES

Figure 4 — Airframe Structural Integrity Program

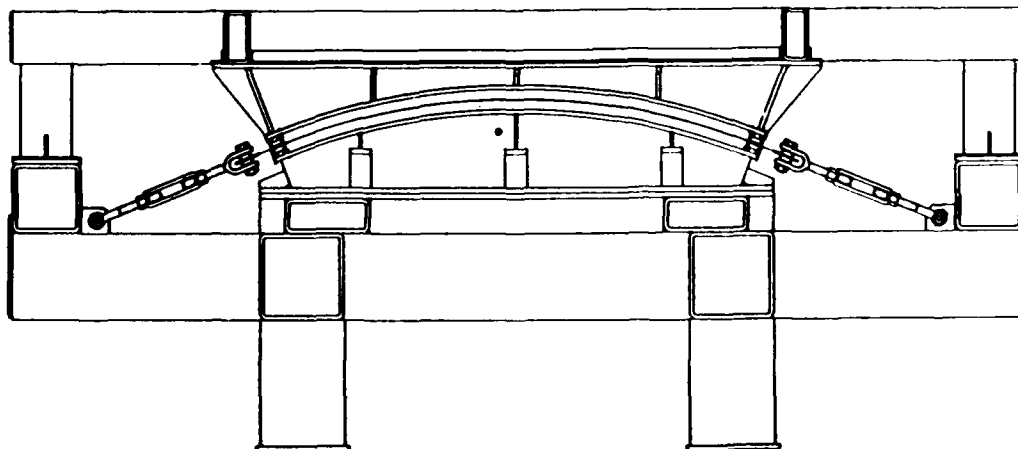


Figure 5 — End-view Details of Test Fixture

Pin Tong

Finite Element Method for Damage Tolerance Analysis," Computers and Structures, Vol 19, No 1-2, pp. 263-269, 1984) can provide equal or better results more efficiently. Both the panel displacement method and the finite element methods are able to model realistically the construction details such as stringers and frame offsets, load transfer through rivets, load transfer through bond and fastener or bond flexibilities. The ability to do so is the result of years of research effort. This model's ability carries over to the MSD situation because the basic structural details do not change. (See Figure 6.)

Conversely, the ability to model the curvature of the fuselage panel requires further research to make the extension to MSD, because

the curvature interacts with cracks to affect properties such as fracture resistance. Flat panel models must, therefore, be empirically calibrated by comparison with curved panel tests in order to predict fracture resistance and correction factors. The correction factors previously developed are valid for single bay cracks. To establish similar factors for MSD would require equally extensive testing.

The research objective in this case is to develop better analysis methods to account for curvature effects based on established principles of mechanics. The field of computation mechanics has advanced considerably since the flat panel models were developed. It is now possible to apply these advances to develop a

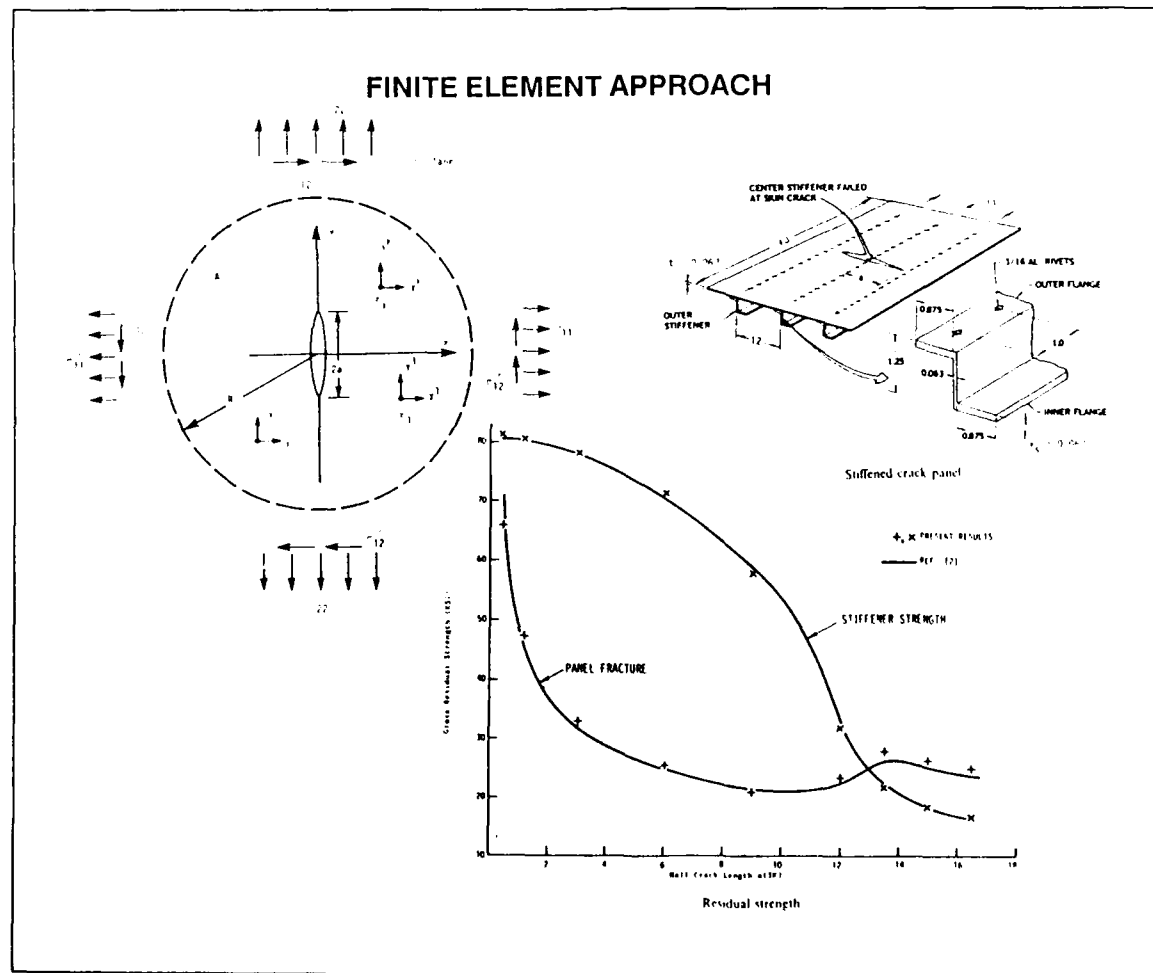


Figure 6 — Airframe Structural Integrity Program

curved panel model. The type of behavior which can now be incorporated in the model includes bulging near the cracks and plastic collapse.

The development of curved panel models was started recently, and preliminary results should be available in one year. Curved panel fracture resistance analysis will still require checking against test results. However, model validation should proceed rapidly because of reduced dependence upon the empirical correlation.

Basic Fracture Resistance

Another element of research is to define the fracture resistance characteristic. A better understanding of the basic fracture resistant property is required in order to predict the resistance of a panel to MSD linkup. Panel fracture predictions are currently made by means of R-curve methods, which account for the fact that a crack in the thin ductile skin can extend at stress levels below the fracture stress. The data from which the R-curves are derived come from tests of wide panels containing large initial cracks. These results are applicable to conventional damage tolerance assessments, but recent calculations based on the N-73711 accident suggest that MSD fracture resistance estimates based on the conventional R-curve are not conservative.

Therefore, laboratory test programs have been started to investigate the possibility of deriving the special R-curve for MSD situations. The objective of a better understanding for the MSD situation should be obtained in about one year. (See Figure 7.)

How to Inspect for MSD

Just as Ulf Goranson showed in one of his figures, there is no reason why a modern airframe should not continue to be flown indefinitely, provided that it is properly maintained and inspected. I think the last part of the statement is the key phrase, when we come to consider the implication for aging airframes with MSD potential.

Preliminary tests and the calculations based on the N-73711 experience show that MSD must be detected at very small crack lengths and in much shorter time than an isolated long crack, if MSD is to be found and repaired before linkup and fracture occurs.

The detection requirements for MSD basically preclude reliance on the visual inspection. The only alternative which has been reduced to practice in the airlines' maintenance shop and repair stations involves use of hand-held eddy current probes. The eddy current method, as we all know, is tedious to apply and can lead to human factors problems.

Nondestructive Inspection

Better nondestructive inspection (NDI) methods must be sought to arm the airlines with procedures that are both proper and economical for MSD. The FAA and NASA have been pursuing complementary programs in the NDI area. The details of this program will be discussed in a session specifically devoted to NDI.

But I want to discuss an alternative to NDI, the so-called pressure proof test. Proof testing was recently proposed as an interim means to protect the safety of certain older airframes which are deemed to have high MSD potential, until terminating actions specified by airworthiness directives have been taken on those airframes. The proposal calls for a one-time test in which a fuselage would be pressurized to 1.33 times its maximum design pressure differential.

Proof testing is designed to eliminate the uncertainty of NDI. If the structure does not fail, when loaded to the proof test level on the ground, then fracture mechanics can be used to evaluate a safe interval for further flying because passing the test establishes a precise upper limit on the size of any cracks which may be present.

The concept is certainly valid at large ratios of proof load to maximum service load, but from a practical point of view, the ratio has to be limited by the need to avoid the damage to adjacent structures during the test. Also, stable

crack extension or even MSD linkup without a large fracture during the test may not give any obvious signs that something has happened.

The FAA is evaluating the fuselage pressure proof testing proposal. An analytic damage tolerance assessment was recently completed and is being reviewed by the oversight group on aging aircraft.

Curved panels will also be fabricated for experimentation on other aspects of the questions raised about proof testing structures with MSD. The proof test evaluation work is expected to be complete in four months.

How to Design for MSD Resistance

Besides responding to the problems associated with MSD potential in the existing fleet, the FAA research program also has the objective of fostering improvement of design and fabrication practices to avoid MSD in the future. The goals apply to repairs as well as to new design.

A conceptual model has been developed to provide a quantitative ranking of the MSD potential of competing design and details. The research will be continued in the direction of experiments in which MSD is induced in simulated design details. The development is expected to take 18 to 24 months.

Repair Practices

Another aspect of the research concerns repair. Many major repairs to airframes are designed to be installed by the airline maintenance repair station personnel. The repair designs generally have static strength equivalent to the original airframe's static strength. Such repairs can induce subsequent fatigue damage in adjacent areas unless they are designed for damage tolerance as well as static strength. However, the maintenance organizations are not equipped to conduct elaborate damage tolerance assessments. The research objective in this area is to provide a handbook-type of guideline for damage tolerance repair design. Fracture mechanics analyses of typical

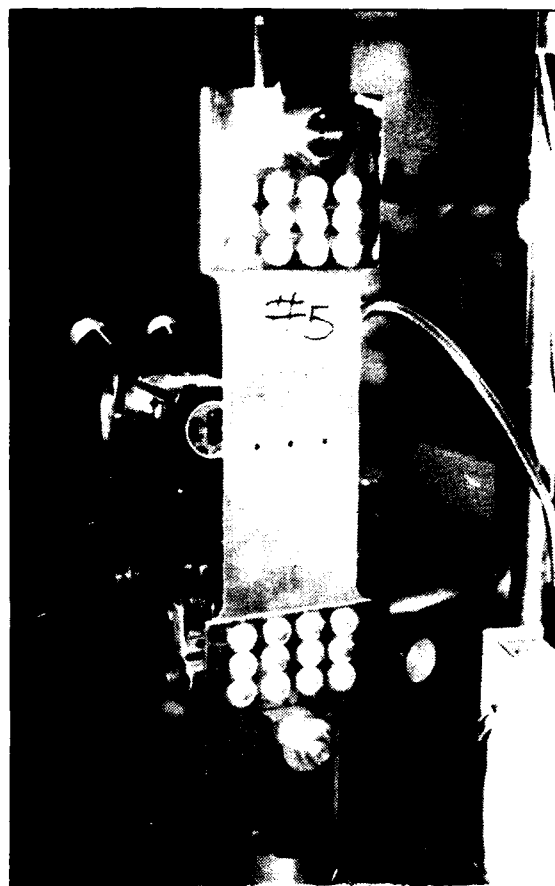


Figure 7 — Simulated MSD Coupon Specimen

repairs will be used to identify critical design variables and their damage sensitivities. The analyses will be validated by means of flat and curved panel tests. The validated models will then be used to produce design charts for the handbook. The target date for completing this handbook is October 1992.

A part of the activity will also examine the question of whether terminating actions such as specified in the 737 fuselage splice AD are fully terminating. It has been suggested that fatigue cracking might reappear in a repair splice (perhaps at the fastener row not involved in the original MSD).

The question is open, of whether reappearance of MSD should be expected in the remaining service life of the airplane. Tests of flat panels simulating pre-AD service, the repair,

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and post-AD service will be conducted to answer this question. Results are expected in about 18 months.

Concluding Remarks

The present research effort is directed by the FAA Technical Center and the key staff of the research team at TSC, including Dr. Orringer, Dr. Sampath, and Mr. Bobo. The work is also supported by many independent experts including the Technical Oversight Group on Aging Airplanes (TOGAA) and other research organizations such as FractuREsearch, Foster Miller, ADL, Battelle, SRI, and several universities.

The FAA research on aging airplanes, particularly MSD, is fast-paced and realistic. It

addresses a major issue which was raised by the N-73711 accident. We hope that industry will study the program results, as they are developed, and take the final step to reduce those results to practice for specific designs and maintenance actions.

We invite you to hear the first detailed report on results at a symposium on structural integrity of aging airplanes, sponsored by the FAA Technical Center, and which will be hosted by Georgia Tech in Atlanta, Georgia, on March 20-22, 1990. The symposium will cover the topics of mechanics of MSD, damage tolerance of structures with MSD, structural integrity of commuter airplanes, effects of corrosion on structural integrity, repair, maintenance, life enhancement schemes and life prediction methodologies.

Proof Testing of Pressure Cabins



J. BEN DE JONGE

Netherlands National Aerospace Laboratory (NLR)

I would like to give you a brief review of research on the topic of proof testing that is currently carried out at our laboratory under contract with the Civil Aviation Department in the Netherlands. I would also like to give a brief statement of the reasons why one might consider proof testing of pressured cabins. I will discuss briefly some of the associated problems, potential problems, and the open questions there are, followed by a review of NLR's test program that we have carried out in the beginning of the year.

Why consider proof testing? As has been brought up on several occasions today, the aging aircraft cabin structure is prone to multiple site damage because of the repetitive nature of the structure itself, the uniform loading of that structure, and also the relatively low number of load cycles for which the structure is actually designed to, 100,000 cycles, make it a kind of low-cycle fatigue that is associated with relatively little scatter. For that reason, you may expect multiple site damage.

It is clear that the inspection for multiple site damage becomes increasingly difficult, complicated and expensive and these are rea-

sons why one might consider the usefulness of proof testing as an alternative inspection method.

Proof testing cannot be called a non-destructive testing method, but it is not a purely destructive testing method either. It is a very peculiar type of testing. It saves good structures and it destroys the bad ones. But, fortunately, it does that on the ground and not in the air, and that is an essential point.

Actually, the cabin is well-suited for proof testing in the first place. The proof loading and its normal maximum is well defined. Loading is relatively easy. You only need a pump and perhaps a piece of rope to bind the valves.

And as an additional advantage, proof load may considerably retard or even stop the growth of existing cracks. We will come back to that later.

However, there are a number of associated problems and questions, (see Figure 1). In the first place, one might consider the possibility that rather than retarding the crack, you may also have a crack jumping, a static crack extension during your proof loading so that after the proof loading you have actually a more damaged structure than before the proof loading.

Problems and Questions

- Static crack extension
- Introduction of new damage or new damage initiation points
 - Original structure
 - Repairs and modifications
- Effect on cold worked holes?
- Damage to corrosion protection?
- Cracking of anodizing layer

Determination of proof test level and proof test frequency

Figure 1 — Problems and Questions

One might question whether the proof loading itself might introduce new damage or new damage initiation points, and I think there we have to make a distinction between original structure and repairs and modifications. I make this distinction because the original structure is proof loaded. Every aircraft cabin structure has been proof loaded after its production, before delivery. So every structure has seen 1.33P and it is not dangerous to repeat that condition somewhere in the airplane's life if the structure has seen already that amount of loading.

There is a difference perhaps in repairs, and by that I mean bad repairs or poor modifications that might be damaged by proof loading, but one might ask whether it's not an interesting observation then to do such a test and find that the modification was a poor one. If it was poor, you might expect fatigue trouble in that area in the near future anyway.

There are a number of other questions you might put forward. What would be the effect of the proof load on cold worked holes? Might it reduce its enhancing effect? What damage could be done to the corrosion protection system? And, associated with that, could it cause cracking of the anodizing layer for corrosion protection? The cracking of the anodizing layer might cause fatigue initiation in itself. These things have to be considered, and are worthwhile considering in more depth.

Another aspect is the effect of the proof test level and the proof test frequency on subsequent crack growth, specifically if there is the potential for retardation of the crack growth.

Figure 2 schematically illustrates the principle of proof testing. Here you have the correct growth curve and the upper curve indicates the decrease in strength with growing crack size. Suppose that the failure occurs at this crack length (Point A). The strength would have dropped to the proof pressure level, whereas you would need a crack of that length (Point B) to fail the structure under normal pressure.

But that is only one aspect. Because of the proof load, you might have a considerable retardation. The crack grows slower and you have much more time available before you have to repeat your proof loading.

In order to get some indications and quantification of the potential retardation, and to get an idea about the potential hazard of the crack jumping, the NLR started a pilot test program. I will give you some information about that program now. (See Figure 3). We carried out a simple pilot test program on a specimen con-

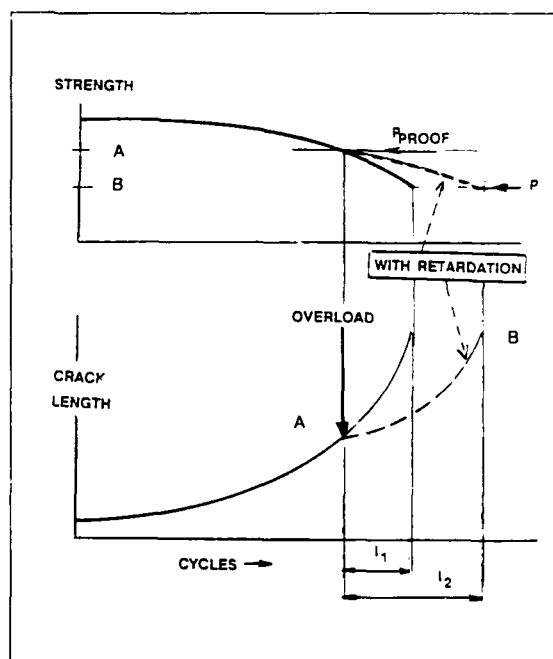


Figure 2

- Specimen
 - Row of open holes in 1mm sheet
 - Central hole with saw cuts
- Loading
 - C.A. loading, $R = 0.1$
 - Apply first overload when half crack length = 10 mm
 - Repeat overload after number of cycles
- Variables
 - Stress level at P: 100 MPA and 120 MPA
 - Overload level: 1.33 P and 1.50 P
 - Overload frequency: once per 10,000, 5,000, 2,000 cycles

Figure 3 — Pilot Test Program

sisting of a sheet, shown in Figure 4. It is a 2024-T3 sheet, 1 millimeter thick, with five open holes, a pitch of 20 millimeters, and you can see the central hole was provided with little saw cuts as crack starters.

That is the specimen, and on that specimen we did a number of tests. Constant amplitude loading and then the application of an overload when the half crack length had reached a length of 10 millimeters, and then we repeated that overload after a number of cycles.

We had a number of variables. In the first place we applied two different stress levels. We investigated two overload levels, the 1.33P that has been mentioned before and a higher one, the 1.5P level. And we varied the overload frequency. We considered 10,000, 5,000, and 2,000 cycles followed by a repetition of the overload.

Figure 5 shows some results of the 1.33P condition. We applied the first overloads when the crack length was 20 millimeters, the half crack lengths of 10 millimeters. The result for the overload after 10,000 cycles and 5,000 cycles and 2,000 cycles is shown. And you will notice, specifically in the case of repetition of the overload every 2,000 cycles, there is a tremendous retardation of the crack growth.

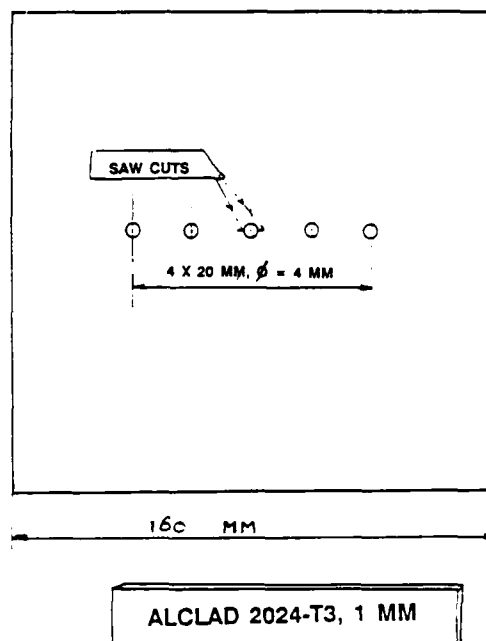


Figure 4

To be specific, in the no overload condition the crack ran into the outer holes after about 18,000 cycles, whereas with an overload every 2,000 cycles, you had to go in the order of 64,000 cycles.

The same type of result is shown in Figure 6 in the case of the overload of 1.5P, and there the retarding effect is considerably stronger. The life goes up to 180,000 cycles at the overload of 1.5P at a frequency of 5,000 cycles. And we didn't try here to do it every 2,000 cycles.

Figure 7 shows the highest stress level, 120,000 cycles, and you see the comparison between no overloads, the 1.33P and the 1.5P cases, and again you see that you have more retardation if you have a higher overload. In the case of the 1.33P you have considerable retardation in the order of a factor of 2 compared to the no overload case.

Figure 8 is a summary of the results. In the case of no overload, you had crack growth from

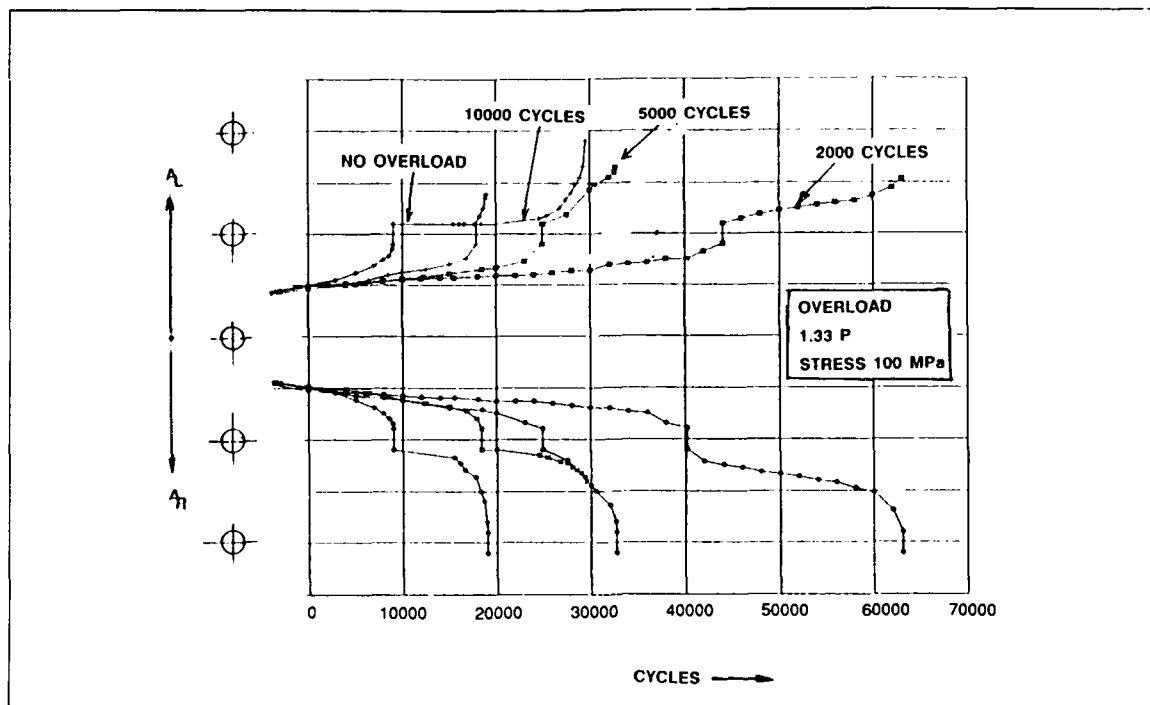


Figure 5

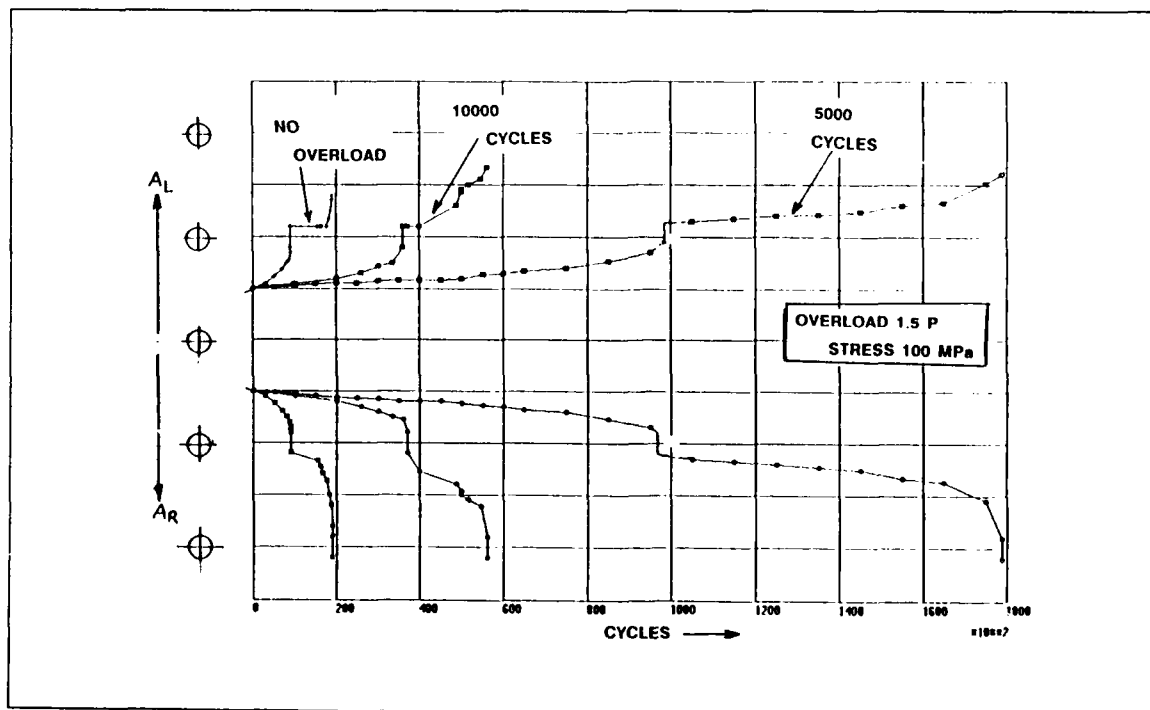


Figure 6

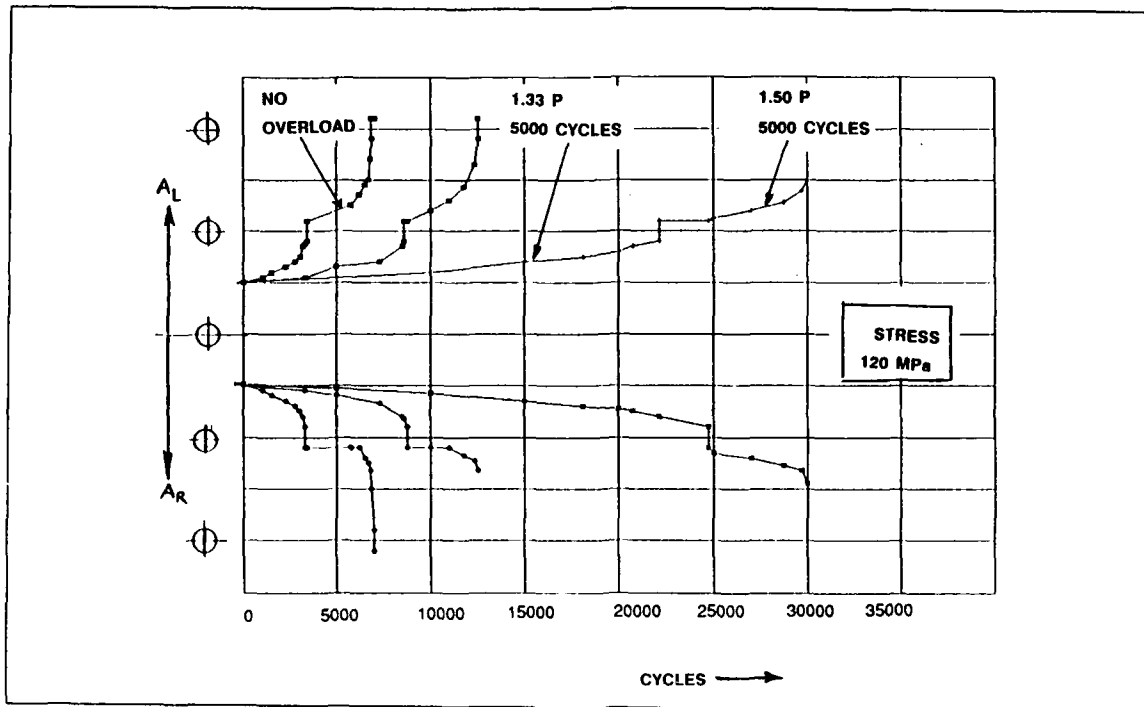


Figure 7

OVERVIEW OF MAIN TEST RESULTS

STRESS LEVEL	PROOF LOAD LEVEL	PROOF LOAD FREQUENCY	CRACK GROWTH (CYCLES) FROM A= 10 MM TO 42 M
100MPa	1.33P	10000	19000
		5000	29500
		2000	32000
			62000
	1.50P	10000	56000
	1.50P	5000	179000
120 MPa	1.33P	5000	7000
		5000	12300
		5000	30000
		2000	40000

Figure 8 — Overview of Main Test Results

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10 millimeters to 42 millimeters, in the order of 19,000 cycles, and that increased with overload. And the more often you apply the overload, the more retardation you have. If you apply an overload every 2,000 cycles it results in a considerable increase in retardation.

I have to stress, of course, that these are very preliminary results. This was a very unrealistic configuration, just open holes, but I wanted to give you some feeling about the amount of retardation that can be expected. And with regard to the crack jumping, we did not observe any at all. You might have seen that also from the figures. The way the crack ran into the next hole was not influenced by the proof loading at all.

The results of this elementary series of tests showed important retardation due to overloads and no static crack extension was observed. We feel that these test results justify further research in the viability of proof testing.

At NLR we have plans to continue this test program in the near future and we intend to do tests on more representative configurations such as riveted lap joints of larger-scale with natural crack initiation to include real multiple sites damage situations, and in those conditions we would again investigate the effect of proof loading on the retardation effect.

The next step will then be to investigate, and to do the same type of tests by actual loading to see whether that has any influence which could be the case. Then there is the possibility to extend that testing to the condition of curved panels under biaxial loading, with pressurization.

That's enough about the test program. I would like to say a few things about the proof

test level. Our design limit load is 1.33P, and the design ultimate load is 2.00P. With regard to the fail-safe load, there is little difference between the FAR requirements and the JAR requirements. And every new cabin is proof tested up to 1.33P. I understand that that's standard practice, although it's not actually in the requirements.

We have to keep in mind that we expect every undamaged structure to be able to withstand the ultimate load or to withstand 2.00P. We also say, and it came up also in Ulf Goransson's presentation, whenever damage is found in a structure that might reduce the strength below ultimate load, or in this case below 2.00P, we must effect repairs. And in any case, it's normal practice that we expect every structure to be, in all conditions, able to withstand the limit load, and, in this case that would be 1.33P.

If you consider these things, you would say there is no reason to be afraid of applying, now and then, that 1.33P load to your structure just to show that it is able to withstand what you expect from the structure.

Proof testing may offer an interesting alternative to other inspection methods. We feel that our pilot test results support its potential usefulness, and we feel that further investigations are required to get the answer to the potential problems that we defined.

My recommendation is to try and coordinate the worldwide R&D efforts on this subject so that we do not repeat or carry out the same tests. Let's try to find some coordination in this area. I think the results should become available as soon as possible as we might need that type of alternative test procedure.

Session II: Loads



CHAIRMAN TERENCE J. BARNES

FAA National Resource Specialist

I am honored to be chairing this session and am pleased to present three very qualified speakers for you today. Tom DeFiore of the FAA Technical Center will be followed by NASA's Norm Crabill. The third presentation will be by Ben de Jonge who spoke yesterday in Tom Swift's session.

Since this year the specialist sessions are running sequentially, so all the conference attendees are able to be present at all the sessions. For this reason, and because this is the first time that we have had this subject, "Loads," I've elected to take just a few minutes to explain exactly what we are doing in this session.

As you will hear from Norm Crabill later, we had a NASA program which was abruptly stopped in 1982. (This is probably a good point to tell you that in this program we're not actually going to measure loads. We're actually going to measure more measurable items such as altitude, speed, CG acceleration, et cetera.)

What we are planning to do now is to build

onto the early data base that we had, which was pre-1982. The data base was mostly pre-jet and mostly pre-deregulation.

We have the potential, after collecting the data, to improve our design criteria.

It's possible that we may be able to determine more precise inspection requirements. We can validate our test spectra and some other items which are fallouts of this type of program, and we can avoid operating airplanes in particularly severe environments, if this is possible. Furthermore, we have the opportunity to investigate flight incidents that may be abnormal.

Figure 1 is included so that everyone can understand how we plan to get reliable loads data from relatively simple measured parameters. I'd like to point out that the key to this whole process is actually in the hands of the manufacturer.

When we look at design loads, we first get design flight load condition data. Airplane speed,

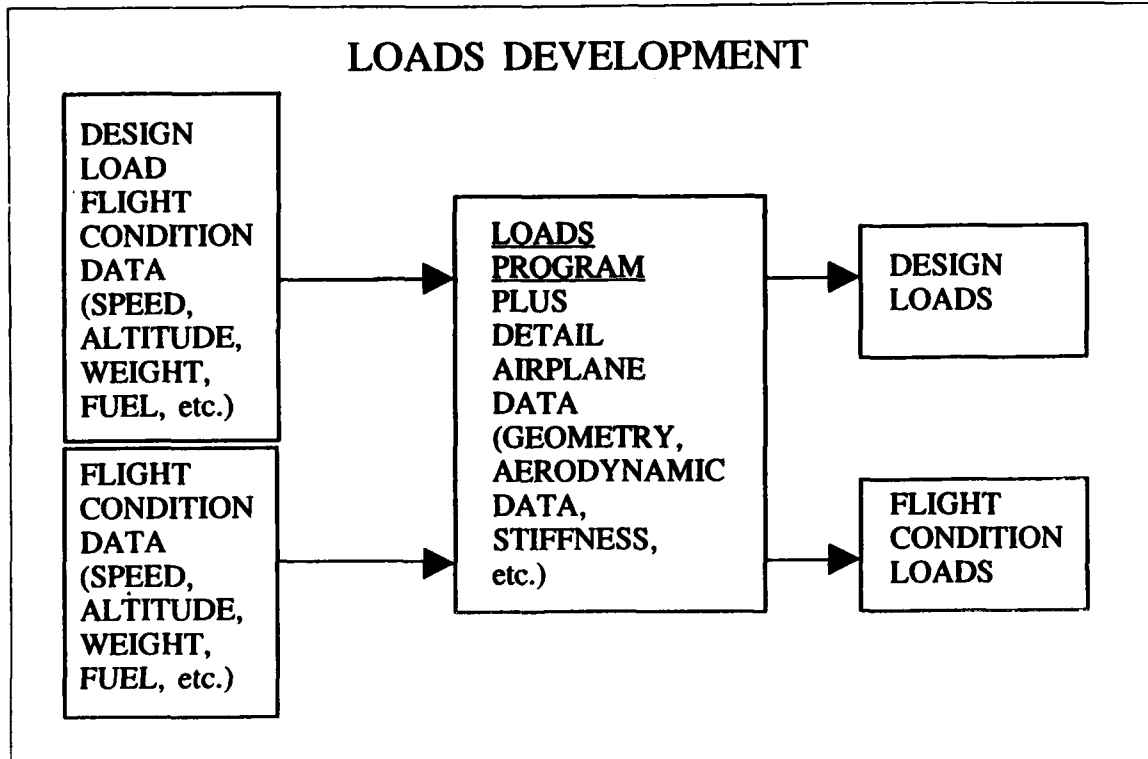


Figure 1 — Loads Development

altitude, weight, fuel, et cetera. These parameters are fed into the loads program. In addition to the program, there are detailed data that the airplane manufacturer has.

With that, we get design loads. It is therefore possible to take any flight condition data — the same parameters such as speed, altitude and weight — run those parameters through that same program, and get flight condition loads. This is why we will be monitoring data and then handing the operation of actually calculating the loads to the manufacturer using this critical group of loads programs and individual airplane data.

As I pointed out, the key to this whole process is the validated loads program that the manufacturer has.

To validate the loads program we start with the ground calibration of the airplane and with strain gauges on the airplane, (see Figure 2). You can actually measure flight test stresses, run those through the equations that were de-

veloped based on the ground load calibration and come up with so-called measured loads.

If at the same time you get the flight condition parameters — the accelerations, speeds, altitude, et cetera — and feed those through the loads program that the manufacturer has, you can then develop calculated loads. Since you have taken the stresses at the same time as you have identified the flight condition data, you can then come through this process and at the end you can compare the measured loads developed using the strain gauges with those loads that were calculated. By this means you are actually calibrating the loads program.

So now we've determined what we're going to do with the data after we get it. Let's actually see where we go with the collected data.

As Figure 3 shows, I've partitioned this into three areas. The independent group, the airline, manufacturer and FAA group, and the airlines and the FAA group.

The airlines and the FAA will be respon-

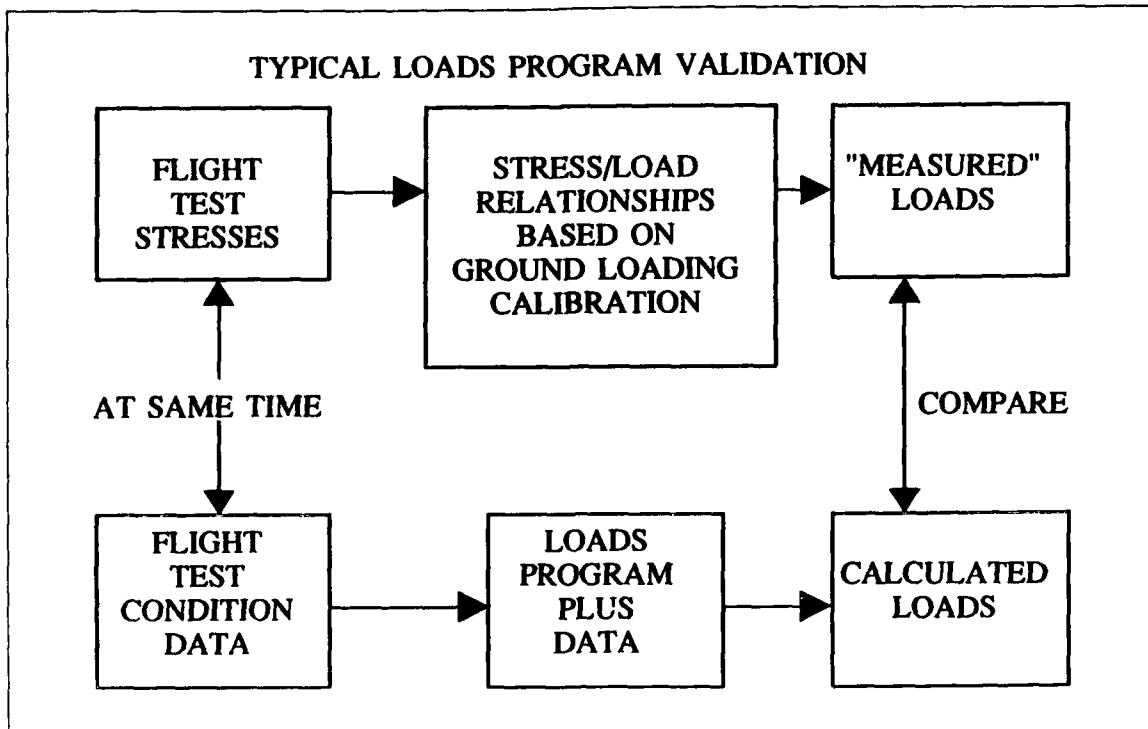


Figure 2 — Typical Loads Program Validation

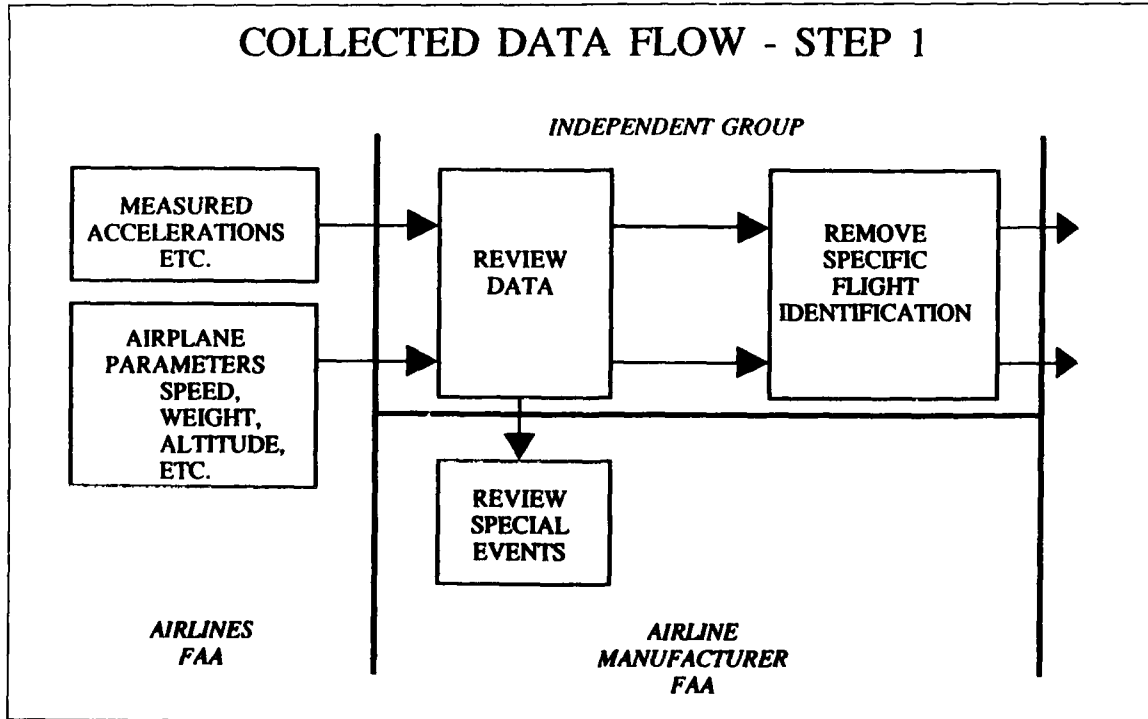


Figure 3 — Collected Data Flow — Step 1

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sible for collecting the data. All the data then will go to this independent group which will review the data. If there are any special events that are of interest, they will be fed back to a group comprised of airline, manufacturer and FAA representatives to review the special events.

Once these have been satisfactorily reviewed, the data will go back into the package. The independent group will remove specific flight identification and then we can start work.

Figure 4 shows the independent group with all the data. The measured accelerations will be filtered to separate gust and maneuvers. The maneuvers can then go back to the manufacturer to be used in developing the component loads using the validated loads program.

Filtering out the gusts, we will have gusts defined as actual accelerations. Then, through the use of the airplane aerodynamic parameters, we can develop gust velocity, derived gust velocities, and these will also be fed to the manufacturer.

At each one of these stages the data that we get will be fed back to the FAA in order to produce the statistics.

The manufacturer with the data produces component loads, and with the validated stress analysis program and detailed design data, the manufacturer can now develop the component stresses. (See Figure 5)

At this point I would like to tell you that from the start of monitoring data we won't expect instant results. Rather than a couple of months we're looking at maybe a couple of years before we get some good data.

Another point is that we did put out a survey through ATA to the airlines and as of last week we had two airlines that had responded favorably. One agreed to help us develop the brass board data recorder and another airline is willing to participate in the monitoring program.

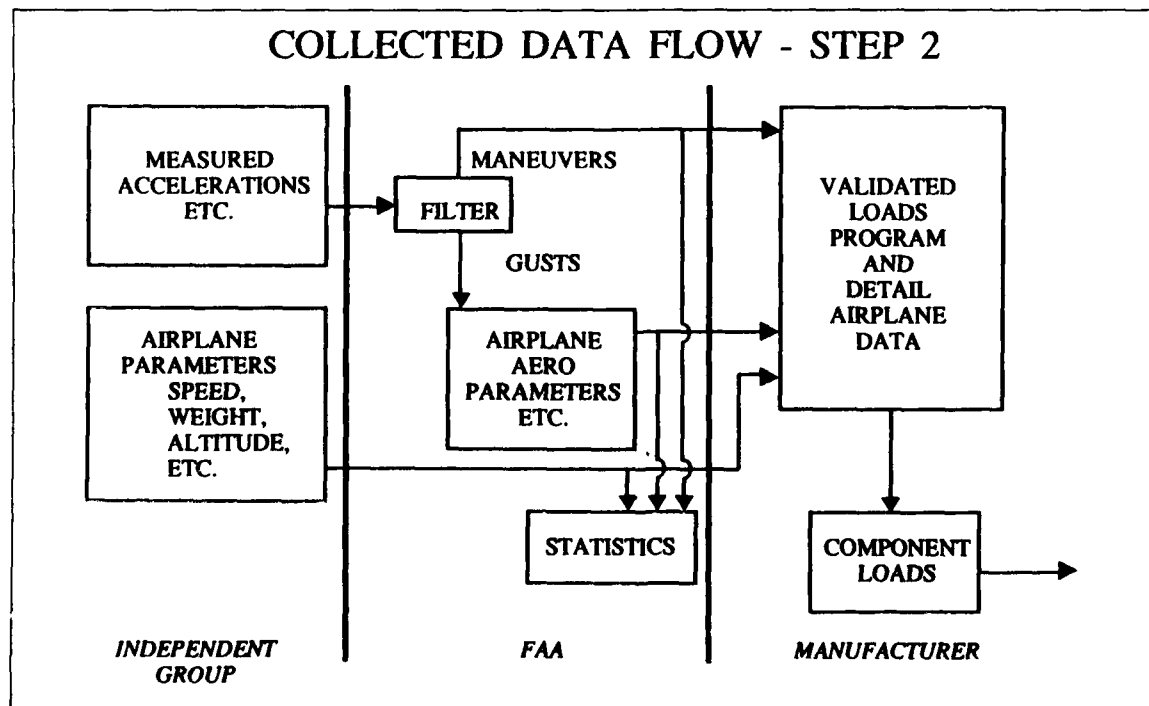
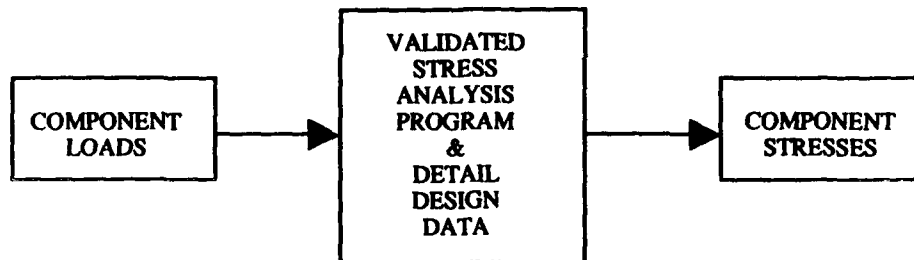


Figure 4 — Collected Data Flow — Step 2

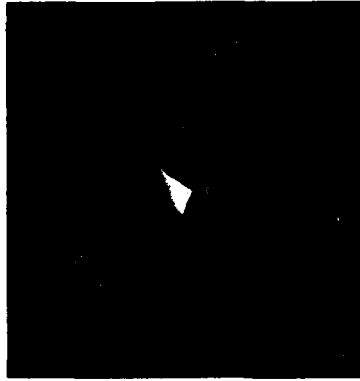
COLLECTED DATA FLOW - STEP 3



MANUFACTURER

Figure 5 — Collected Data Flow — Step 3

Flight Load Data Collection



THOMAS DeFIORE

Flight Loads Program Manager, FAA Technical Center

Good morning. It's a pleasure to be here to speak with you to describe our plans for reestablishing the flight loads data collection program.

My briefing today will cover some of the chronology and activities that we've been involved in in reestablishing our program. I am going to provide a functional description of our planned new flight data recorder, and conclude with some comments and concerns regarding the program integration.

The purpose of the program is to reactivate the flight loads data collection effort by developing and installing a state-of-the-art flight data recorder in transport aircraft: the objective of which is to collect and analyze commercial aircraft in-service flight data and to provide survey data on a continuous basis for airframe manufacturers to review and assess whether typical operating load spectra used in design are representative for the jet transport fleet, and, to develop structural design criteria for future generations of aircraft. In order to accomplish these objectives we've established some working groups. (See Figure 1) The initial working group consisted of Terry Barnes, the

FAA National Resource Specialist on flight loads and aeroelasticity, FAA Headquarters (AIR-107) which provides the support, the FAA Technical Center, engineers who are the program manager for the effort, and NASA who conducted the prior U.S. flight data collection efforts.

We've added the membership of the ATA and the Flight Safety Foundation in August of this year. Mr. Dick Tobiason has agreed to be the ATA focal point with the airlines for the development of this program.

Some of the future membership in our working group will consist of loads engineers from the aircraft manufacturers, the airlines, and AIA/ARINC responsible for the data busses on the aircraft, and the National Transportation Safety Board who have a lot of experience in analyzing and handling flight data.

The contractual support summary for our program appears in Figure 2. Our initial plan was to draw on all the prior experience in U.S. transport flight loads data collection, most of which resides at NASA Langley. We negotiated an interagency agreement with NASA in the spring of 1989. This actually involved the

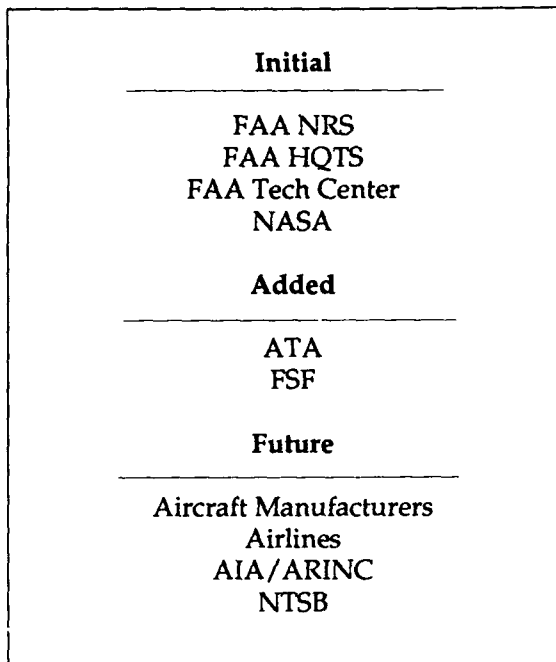


Figure 1 — FAA New Flight Loads Data Collection Program — Working Groups

transference of funds for these specific tasks. This agreement is independent of the memorandum of agreement for joint research between NASA and the FAA for the aging aircraft signed just one week prior to this conference.

Eagle Engineering, staffed with a number of former NASA personnel involved in the prior flight load data collection programs, is providing some of the direct support.

Our own local contractor, Flight Test and Aviation Enterprises, are our consultants for instrumentation.

We plan two additional procurements over the next year or two. The first one will be a competitive procurement for the 24 flight load data recorders which we expect to install in the transport aircraft along with a ground station for data transcription. The second procurement is planned to be a data reduction and analysis contract to analyze the recorded fleet data.

At the FAA Technical Center we have installed a new IBM 4381 computer mainframe which has more than enough processing capa-

Support

- Interagency agreement (NASA)
 - Eagle Engineering
- Flight test and aviation enterprises
- Competitive procurement for 24 flight recorders
- Data reduction and analysis

Figure 2 — FAA New Flight Loads Data Collection Program

bility to handle the volume of data we expect from the 24 recorders.

This reactivation of the flight loads program has been a part of the FAA's aging aircraft program plan from the initial draft back in November 1988. Industry supports this effort. At the March 20-21, 1989 R&D task unit meeting, flight loads was identified as one of the R&D items for aging aircraft.

The R&D task unit recommended a five-year data collection program, the purpose of which is to update the data base from the early 1960s. This scope of effort corresponds with what we have planned at this time.

Some of the chronology of our activities since the March 20-21 R&D summary are summarized in Figure 3. A program initiation and development session was conducted at NASA in March 1989. In April, we conducted a workshop at the FAA Technical Center involving, again, all prior flight loads data collection engineers.

We had an aircraft manufacturer briefing at Boeing to explain our proposed program. We received meaningful feedback indicating the kind of program that would be most beneficial for the industry.

We recently conducted the ATA and Flight Safety Foundation briefing where we found more ATA support for the program than we had originally expected.

Currently, we are in the process of an intensive effort in the systems design. The next speaker, Norm Crabill, and I will be the co-

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Location/Sponsor	Purpose	Date
ATA	Industry R&D	21 March 1989
NASA HQTS	Program Initiation	31 March 1989
NASA Langley	Program Development Meeting	17-18 April 1989
FAA Tech Center	Workshop	3 May 1989
Boeing	AC Manufacturer Briefing	13 June 1989
FAA HQTS	ATA, FSF Briefing	22 August 1989
FAA/FSF	Aging Aircraft Conference	3-5 October 1989
FAA Tech Center/NASA	System Design	Oct./Nov./Dec. 1989
ATA or FAA	Working Group/ Airline Introduction	November 1989
McDonnell Douglas	AC Manufacturer Briefing	November 1989

Figure 3 — Program Activities

designers of the new data collection system, and we'll likely present this design at a future conference in the spring or summer of 1990.

We are also planning to have another working group meeting when we brief our program to the airlines.

The schedule and program tasks and deliverables are listed in Figure 4. NASA refers to tasks within the scope of the Interagency Agreement. The initial task is to publish the reports for the prior NASA collected data on the four aircraft listed on the figure. While the aircraft manufacturers have the reports for their particular aircraft, the data have not been published in a formal report.

The second task will be to publish a methods report. The intent is to document as much of the criteria and analysis, and assumptions that have been a part of both the U.S. and foreign prior data collection programs.

We have draft copies of all four data reports and the methods reports. These are in a final review process at this time and are due out soon.

The other short-term task is to acquire and publish all available flight loads data from foreign carriers. This is part of the FAA Technical Center's effort to become the data archive,

or data repository, of flight loads data and ultimately become the center of information for the international flight loads data collection.

The longer term program efforts are for NASA to develop and install a prototype smart data recorder in one revenue aircraft, to purchase and install the 24 smart recorders over the next four years, (six recorders in each year 1991 through 1994) and to begin the task of collecting and analyzing data.

As Terry Barnes mentioned, we're not going to have any data immediately available for analysis. January 1992 is the earliest likely date to get fleet data. Thus, flight loads data collection is a long term aging aircraft effort.

Before I describe the proposed recorder and what we expect it to do, I do want to define the term "smart" recorder. A smart recorder is an on-board microprocessor-based system with the capability of analyzing and making decisions on what data is meaningful to store for postflight evaluation.

The idea of using the smart recorder is based on the availability and expanded capabilities of off-the-shelf hardware. Some of the characteristics of new recorders are listed in Figure 5. We expect that they will have the ability to recognize the specific aircraft situ-

NEAR TERM

- Publish report for NASA collected data L-1011, B-727, B-747, and DC-10 (1978-1980)
10/89 (NASA)
- Publish Methods Report
12/89 (NASA)
- Acquire and publish flight loads data from foreign carriers
12/90

LONG TERM

- Develop prototype 'smart' data recorder
9/90 (NASA)
- Purchase and install 24 'smart' recorders
12/91
Six in each year (91, 92, 93, 94)
12/94
- Collect and analyze flight data
1/92

Figure 4 — Program Schedule

ation, i.e., climb, cruise, taxi, landing, etc. Then, based on this situation, select the appropriate data reduction algorithms. These can include modifying the data sampling rate, changing input parameters into the processing software and modifying the processing algorithms which provide the information that we need for flight path analysis.

All the data is expected to be processed in real time. The recorders are going to be reprogrammable and upgradable, and there will be no crash recorder requirement for the data storage unit. There will be no interference with the flight operations. All the data we need for the flight recall will be self-contained on the memory storage unit which will be off-loaded periodically.

- Recognize aircraft situation (climb, cruise, etc.)
- Select appropriate data reduction algorithms
- Process data in real time (micro-processor)
- Reprogrammable & Upgradable
- No interference with flight operations
- Applicable for transport and commuter aircraft
- Process/store large amounts of flight data

Figure 5 — 'Smart' Recorder Characteristics

The recorders will be useable on both transport and commuter aircraft, though it will be more difficult to instrument commuters because they typically are not equipped with sophisticated data bases.

We also expect to have the ability to transfer data recorders from one airline to another, one plane to another and from one aircraft category to another. The major benefit of this new program is that we are going to be able to process huge amounts of data in short periods of time, especially when viewed in comparison to some of the prior VGH data processing efforts.

The proposed aircraft interface for transport aircraft is displayed in Figure 6. Before describing plans for the smart recorder data acquisition, I want to describe how data was acquired during NASA's recent DVGH survey.

The crash recorder, named the digital flight data recorder (DFDR), receives its data from three on-board sources: the flight data entry panels; the ARINC 429 data bus which provides most of the flight and control surface information; and the three-axis accelerometer.

These three are fed into the digital flight data analyzer unit (DFDAU). This unit decides which parameters are to be stored on the crash recorder and inputs that information into the crash recorder for storage. Prior survey data was acquired by copying the 30 hours of data onto its own storage unit and then offloading

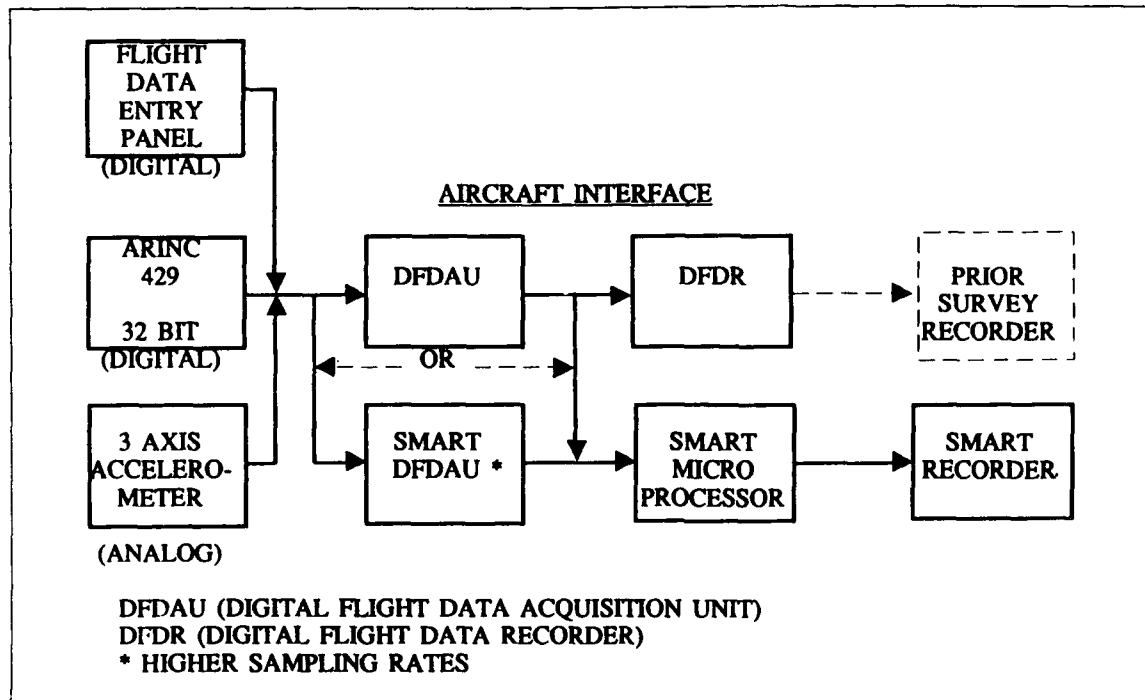


Figure 6 — Aircraft Interface

these every three or four days whenever the storage unit was filled.

We are planning to acquire our smart recorder data in one of two ways: by picking up our data immediately prior to it entering the DFDR or immediately prior to entering the digital flight data analyzer unit. Part of our study is to determine which of these two methods is more cost effective. Choosing the former method will require less hardware but it may require costly additional software, while FAR Part 121 calls for a specific minimum number of parameters for the crash recorder, a number of the airlines have chosen to exceed that minimum. It may turn out that we may need numerous different software sets to accommodate the various airlines and this may not be cost effective.

Choosing the second method involves acquiring data prior to entering the FDAU. Since the ARINC 429 data for all airlines is similar, we'll just need one set of software, though we will need additional hardware. We hope to have a decision on our system design shortly.

Another design feature is that the smart recorder will have to be offloaded only during the "B" level maintenance check, which occurs every 10 or 12 weeks. We plan to size our recorder to store data from up to 500 points. If the 500 seems a little bit small, then we'd appreciate the feedback so we can know what the proper sizing should be.

The data which we plan to collect are summarized on Figure 7. Some of the individual parameters were available on prior surveys, but never collectively as a group. These include: typical flight path parameters, control surfaces, and individual flight data summaries.

The output expected from the program as presented in Figure 8, and to restate it: the entire process will be fully automated with minimal airplane interface. All the data needed will be on our data storage unit which will be offloaded at the "B" level maintenance check.

Some of the aircraft usage characteristics that we will provide are listed on Figure 8. These include: typical flight profile statistics such as frequency distributions, tables of flight

FLIGHT PARAMETERS

Fuel remaining
Absolute cabin pressure
Longitudinal C.G. position
Pressure altitude
Calibrated airspeed
Vertical acceleration
Lateral acceleration
Longitudinal acceleration
Gear squat position
Autopilot status

CONTROL SURFACES

Flap position
Spoiler positions
Rudder positions
Aileron positions
Stabilizer positions
Elevator positions

FLIGHT SPECIFIC DATA

Flight origination code
Flight destination code
Date/time (takeoff and landing)
Gross weight at takeoff
Fuel load (takeoff, landing)

Figure 7 — Measured Data

duration, control surface usages, air speed, altitudes; acceleration statistics for calculating and measuring the maneuver loads and deriving the gust velocities; takeoff and landing parameters, such as distributions of takeoff distance, takeoff velocity, and landing velocity; and, if there is space available on our recorder, special or unusual events. The United Kingdom Civil Aviation Authority (CAA) has a massive program called CAADRP with which they measure at least 25 structural related special events. We plan to look at their program to see what parts of it might be applicable for U.S. commercial aviation.

- Accomplished by fully automated data acquisition and ground computer processing
- Aircraft usage characteristics (summaries)
 - Flight profile data
 - Acceleration statistics
 - Takeoff and landing parameters
 - Special events
- Aircraft in program
 - Initially: B-737 (3), MD-80 (3)
 - Future candidates: B-747, B-757, B-767, MD-11, A-320

Figure 8 — Program Output

The aircraft which we plan to incorporate initially into our program, will be three B-737s and three MD-80s. Some of the future candidates include: B-747, B-757, B-767, MD-11, and A-320, but we haven't firmed up our aircraft selections beyond the original six recorders.

The largest single benefit of using subject-smart recorders is the volume of data which can be collected. A comparison of the data volume from the most recent NASA DVGH survey to what we expect from our new program is presented on Figure 9. NASA's was a two-and-a-half year program, and while I don't know specifically how many manhours or many years were spent, they collected only a little over 5,000 flight hours during their entire program. Our survey program with the new 24 recorders will be expected to provide 30,000 flight hours in just six months. As one can see, when we implement our five-year data collection effort, the volume of data hours collected will leave no doubt as to what is the proper characterization of commercial aircraft fleet or service usage.

I want to summarize with just a number of comments. Our program's primary goal is to collect and characterize typical fleet service usage information and perform some investi-

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NASA DVGH survey (1978-1980):
Collected and processed 5112 flight hours for L-1011, B-747, DC-10, and B-727 aircraft.

New flight loads survey:
New 'smart' flight data recorders are expected to provide 30,000 flight hours in *six months*.

Figure 9 — Data Volume Comparison

gation on the frequency of special or unusual events. We plan to eliminate specific flight information. We don't want to know what day or which pilot, we're interested in understanding only typical flight characteristics. We plan to ask an independent party, such as NASA, the Flight Safety Foundation, or perhaps the ATA, to review the data and remove specific flight identification data so that all we get is the structural usage information. The resultant statistical flight information and analysis will be published periodically.

We are looking for airline volunteers. The ATA's Dick Tobiason, has had some positive feedback from a couple of airlines willing to work with our NASA prototype installation and one or two others interested in hosting the initial six recorders. We're planning a meeting next month with the volunteer airlines and others that are interested and we will provide a more detailed briefing of our program and requirements at that time.

The airline support that we need is listed in Figure 10. We'll provide a kit for installation and it's likely to be simple, involving just one self-contained box no larger than two feet by one half foot square. We'll provide installation instructions and ask the airline personnel to remove the data cartridges periodically, and forward them to the FAA Technical Center. No flight log information will be needed whatsoever. Airlines won't be asked to do anything

- Specific flight identification removed
- Statistical flight data will be published
- Airline volunteers (ATA Focal Point)
 - NASA prototype
 - First six "smart" recorders (B-737, MD-80)
- Airline support
 - Initial installation (kit)
 - Removal/replace data cartridge (memory)
 - No flight log information required
 - Inform FAA if system not operating
- **NOT** a fatigue life assessment program

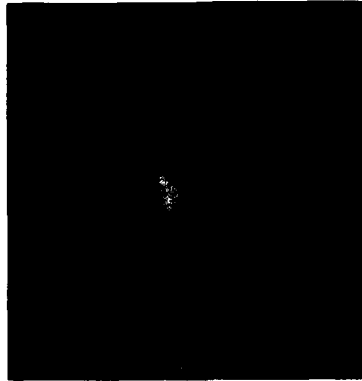
Figure 10 — Concerns/Comments

beyond removing and replacing cartridges and simply informing the FAA if the system isn't working, i.e., a look every now and then to check if the right combination of green, red and amber lights are blinking. If the system is malfunctioning, the FAA will make the necessary repairs.

The support for the NASA prototype system will probably involve more than what's listed on Figure 10, in that during the development process, we're going to need to see the data more frequently than the "B" level 10-week interval.

I want to close with one final comment. This new program is not a fatigue life or structural life assessment program and we have no plans on expanding it into one. Our primary purposes, as I stated in the beginning, are to provide data for the aircraft manufacturer to assess how well the design and the fleet service usage correlate and to develop future design criteria.

Structures Technology



NORMAN L. CRABILL

Aerospace Technologist, Eagle Engineering

I'm going to do a little bit of a retrospective. It is sometimes good to look back and consider what we did before, and how it relates to what we are going to do in the future. So I'm going to talk about the NACA/NASA Air Worthiness Programs, including the loads program and the digital VGH program.

Figure 1 is an overview of NASA in the NACA/NASA Operational Loads Program. As you can see, there has been a long involvement in airplane motions and loads, starting back in NACA Technical Report Number 1, by Hunsacker and Wilson, which looked at the aircraft motions and their response to gusts. This was followed later by the Sharp Edge Gust Response Analysis, the Gradient Gust Analysis and the cosine formulation. These were all for discrete gusts.

The generalized harmonic analysis technique was then applied to estimate the responses of airplanes in continuous turbulence and it was a fortunate thing because about that time airplanes started getting big and flexible.

Changes in measurement techniques followed. We used the state-of-the-art equipment every time. We started out with the basic accel-

erometer, then, the VG recorder, which traced velocity and accelerations directly on the designer's V-N diagram. That's the way you did it in those days. You sketched out a V-N diagram and built the airplane to it. Then you proofed the airplane against the V-N diagram.

So, the VGH time history approach was developed. It went on for quite a few years but was stopped in the late 1970s. The application of the digital VGH, or application of digital techniques to the VGH time history started in the late 1970s, then was terminated abruptly in 1982 just when we were really getting going.

NASA has long been interested in gust loads, maneuver loads and ground loads. I'm not going to detail all the authors and their reports since they are listed on the figure.

The digital VGH program started in 1977 and we decided to use the digital flight data typed from the crash recorder 25-hour loop tape. (See Figure 2) It was readily available if you were out there every two or three days to copy the tape before it got wiped out. But it had a lot of data, more than we could handle at the time.

We started in 1977 with 15 tapes, pur-

SUMMARY OF NACA/NASA OPERATIONAL LOADS SURVEYS ON CIVIL AIRCRAFT

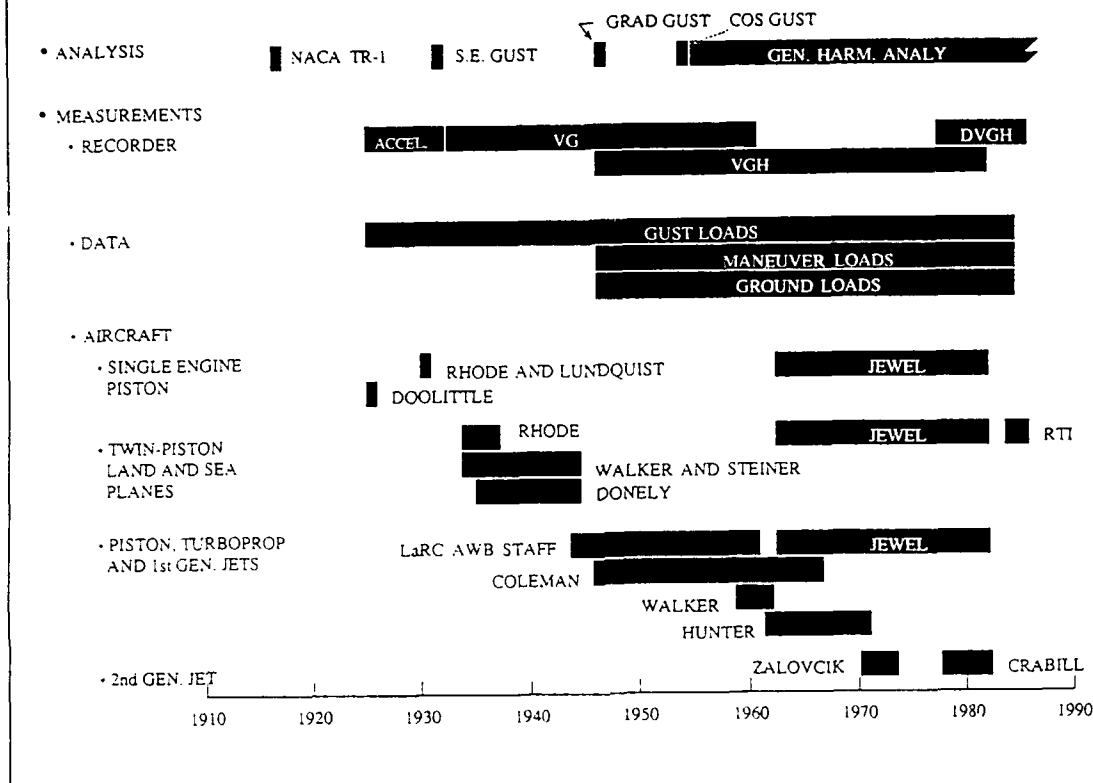


Figure 1 — Surveys on Civil Aircraft

chased from an airline, of flights that were made in 1973, with about 200 hours of data to develop the data acquisition techniques — such as the operational techniques of getting the data from the airlines and all the flight log data that had to go with it because weights and so forth were not on the digital flight data recorder tape.

We developed a lot of analysis techniques, and that meant editing every minute of it because the transcription process of copying the data from the flight recorder onto a copy tape was fraught with all kinds of errors or problems, many of which we solved with a lot of manpower.

We went ahead with Phase I in 1978, buy-

ing new data from several airlines covering the four airplane types. We got about 5,000 hours of data and we worked our way through that and then Phase 1-1/2, which included the ground operation parameters. We got data off ten flights on an L-1011 on Phase 1-1/2.

We determined that we could get rid of a lot of manual labor if we did the processing on-board before the data went to the crash recorder. We looked in real time at the bit stream, and found that it was high quality data. It did not have all of the gaps and the duplications that we got from the copy recorder. Neither did it have the wild point spikes. Most of it was good clean data.

This meant the smart recorder approach

Norman L. Crabill

- Initiated 1977
- Used DFDR data types (25 hour tape from "Crash Recorder")
 - "Readily" available
 - More data types [used 6 or 7 out of available 19]
- Pilot Programs 1977–1978 ~ 200 hours
 - L-1011 — 15 tapes of various aircraft flights in 1973
 - Developed techniques
 - Data acquisition
 - Analysis
- Phase 1.0 1978–1981: Flight Parameters ~ 5000 hours
 - L-1011
 - B-727, 747
 - DC-10
- Phase 1.5 1980–1982: Ground Parameters ~ 10 flights
 - L-1011
- Phase 2.0 1982–1985: SMART RECORDER ~ 200 hours
 - King Air

**Figure 2 — NASA Digital VGH Program
1977–1985**

was feasible, where you take the data in real time, then reduce it down into the statistical data-types and accumulate those as long as it's convenient.

Figure 3 are the parameters we took off the digital flight data recorders in Phase 1. Phase 1 was just the flight parameters, while Phase 1-1/2 included ground operation parameters. We added some data types over here that are not normally carried on the DFDR. We found, for instance, that the nose wheel steering angle was a real convenient indicator of when he got off the runway. We looked at brake pressures and temperatures to help decide when the

landing roll was completed. This was a lot of fun but a lot of work, too.

Figure 4 is an outline of the results from the Phase 1 report. These data are being reported in NASA CR-18-1909 which will be available shortly. We broke the data down into flight profiles statistics and acceleration derived statistics.

These are generally broken down into percent of time or counts per hour — that is, on a time basis — or percent of flights. We looked at entire flights; that is, where the flaps were up or down, and we looked at flaps down only, and we looked at spoiler deflections. This breakdown can give you two things, the percent of time at these gross weight and flight altitudes for climb, level and descent, and percent of time at various air speeds and pressure altitudes for climb, level and decent.

We looked at the weight at takeoff and landing as a percent of flights, and also maximum pressure altitudes as a function of the percent of flights.

The other categories include flap-detents usage in takeoff and landing per time. Gross weight, altitude above ground level, and air speed versus flap-detents in takeoff and landing, spoiler deflections versus calibrated air speed and spoiler deflections greater than ten degrees with a function of altitude were statistically analyzed.

Acceleration derived statistics is another category that is very important and is related to loads. We looked at total normal acceleration, lateral acceleration, and from the normal we got UDE counts.

Then, finally, with flaps down, we looked at normal acceleration versus detent usage for takeoff and landing.

That is a considerable body of data, and the data reports, of up to 170 pages, are pretty thick.

Figure 5 is a simple sample of percent of flights to maximum pressure altitude for an L-1011. As you would expect, most of the time was spent between 35,000 and 40,000 feet.

Figure 6 shows a portion of the flap study. This shows percent of time in the flap detent in percent of total flight time.

In the upper plot, we had about 14.2 hours

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DVGH PHASE I PARAMETERS

	Phase I.0 1978-1982 Flight Parameters				Phase I.5 1980-1982 Ground Parameters
	L-1011	B-747	B-727	DC-10	L-1011
Pressure Altitude	X	X	X	X	X
Airspeed	X	X	X	X	X
Flap position	X	X	X	X	X
Spoiler position	X	X	X	X	X
Vertical acceleration	X	X	X	X	X
Lateral acceleration	X	X	X	X	X
Autopilot on-off	X	X	X		X
Cabin pressure		X	X		
speed brake			X		
Longitudinal acceleration					X
Rudder position					X
Aileron position					X
Stabilizer position					X
Radar altitude					X
Squat switch					X
Main wheel speed					X
Nose wheel steering angle					X
Brake pressure					X
Brake temperature					X

Figure 3 — DVGH Phase 1.0 Parameters

DVGH PHASE 1.0 RESULTS: FLIGHT PARAMETERS NASA CR 181909

Flight Profile Statistics	Percent of Time	Percent of Flights
o Entire Flight (flaps up or down)	o Fig. 13 GW & HP for flight modes o Fig. 14 CAS & HP for flight modes	o Fig. 12 Weight stats (w/ TO & landing) o Fig. 15 Max HP versus duration
o Flaps down only	o Fig. 16 Flap detent usage in takeoff and landing o Fig. 17 GW, AGL, CAS versus detents in takeoff and landing	o Not applicable
o Spoiler deflections	o Fig. 18 Spoiler deflections versus CAS o Fig. 19 Spoiler > HP vs HP	o Not applicable
Acceleration Derived Statistics	Counts per hour	Percent of Flights
o Entire flight	o Fig. 20 Normal acceleration exceedances o Fig. 21 Lateral acceleration exceedances o Fig. 22 U _{dc} exceedances	o Fig. 23 Maximum acceleration
o Flaps down only	o Fig. 24 Normal acceleration vs detents, takeoff and landing	o Not applicable

Figure 4 — DVGH Phase 1.0 Results: Flight Parameters

Norman L. Crabill

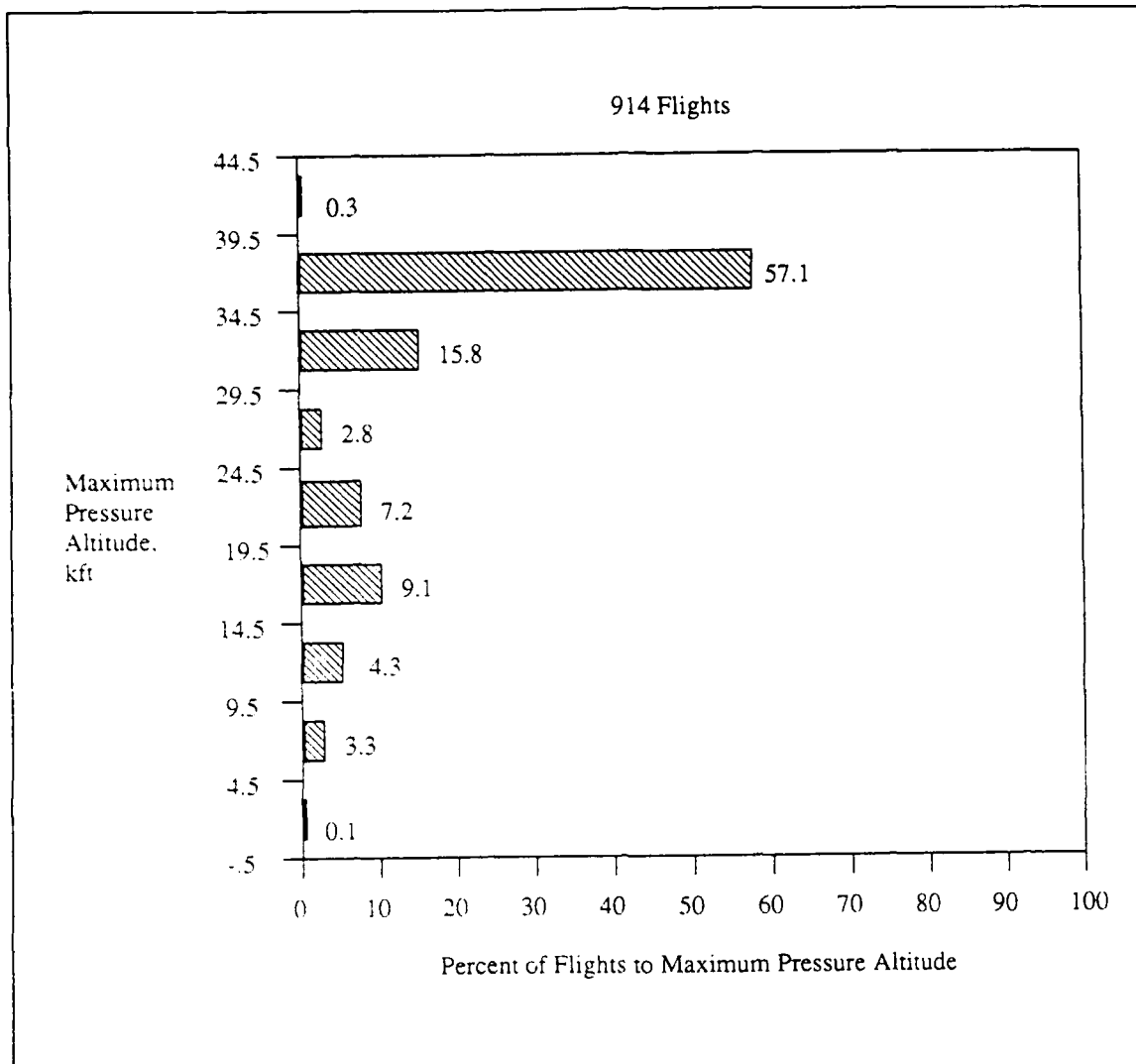


Figure 5 — Phase 1.0 Results: Flight Profile Statistics

of time when the flaps were extended in take-off, and you can see the distribution. Most of the time flaps started at ten degrees and then milked up to four degrees and then the pilot cleaned up the airplane. A couple of flights took off with higher flap settings.

In the lower plot, the flap settings in landing, you can see the most popular ones. The 18 degree and 27 degree flap detents were transited rather rapidly. As the pilot moved from 10 to 22, he went right through 18. So you can get some idea of how long the flaps are used and under what conditions.

Figure 7 shows that normal acceleration exceedences are given on the level crossing count technique and we're showing data for total normal acceleration, maneuver and gusts. The separation was done basically in the frequency plane. We looked at a lot of power spectra of these acceleration data types and found what you would expect, that maneuvers are generally at a lower frequency than the gusts. On this particular airplane about a tenth of a hertz seemed to be the demarcation line.

We then devised two numerical filters, a low pass and a band pass filter, and derived the

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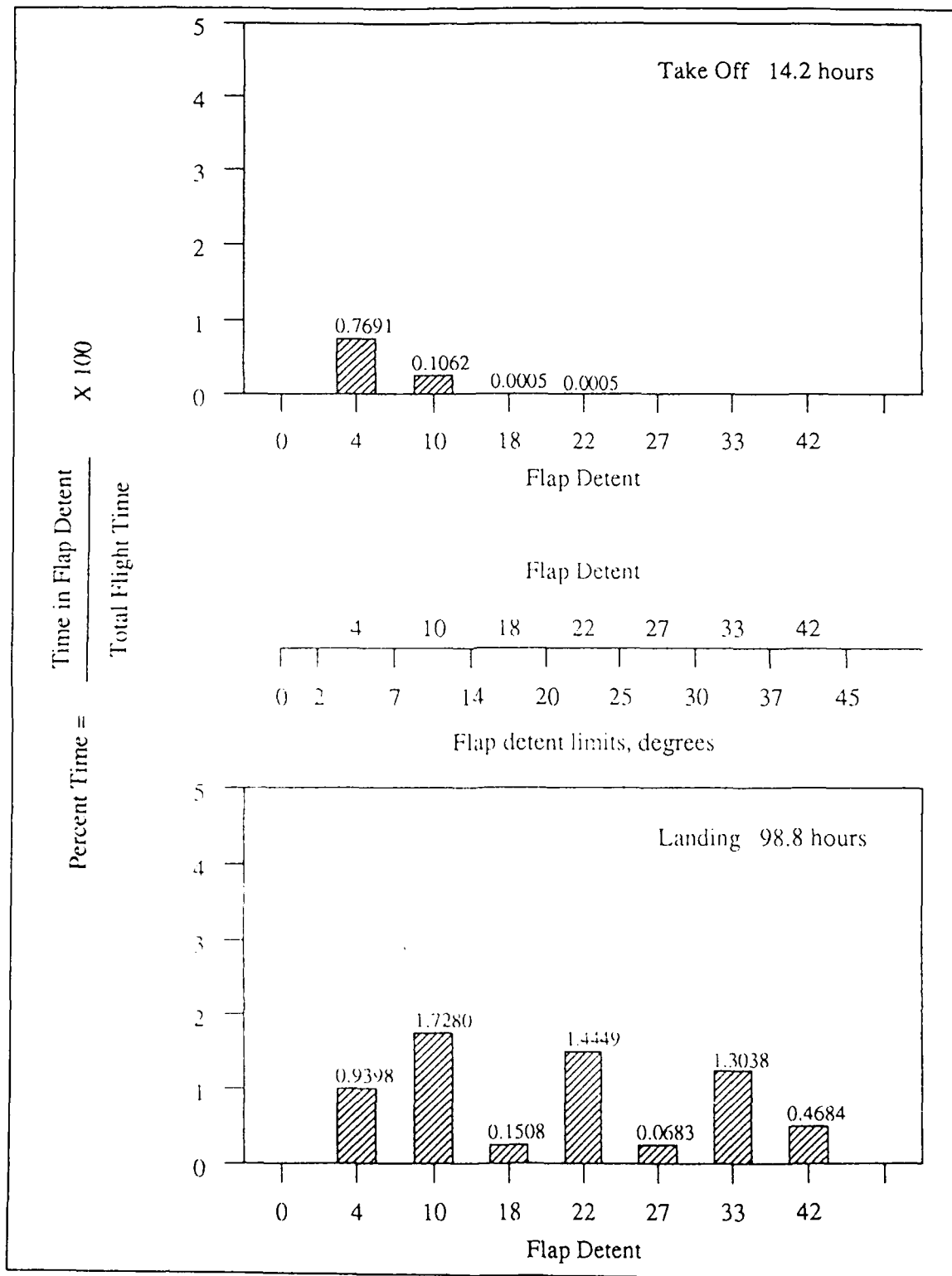
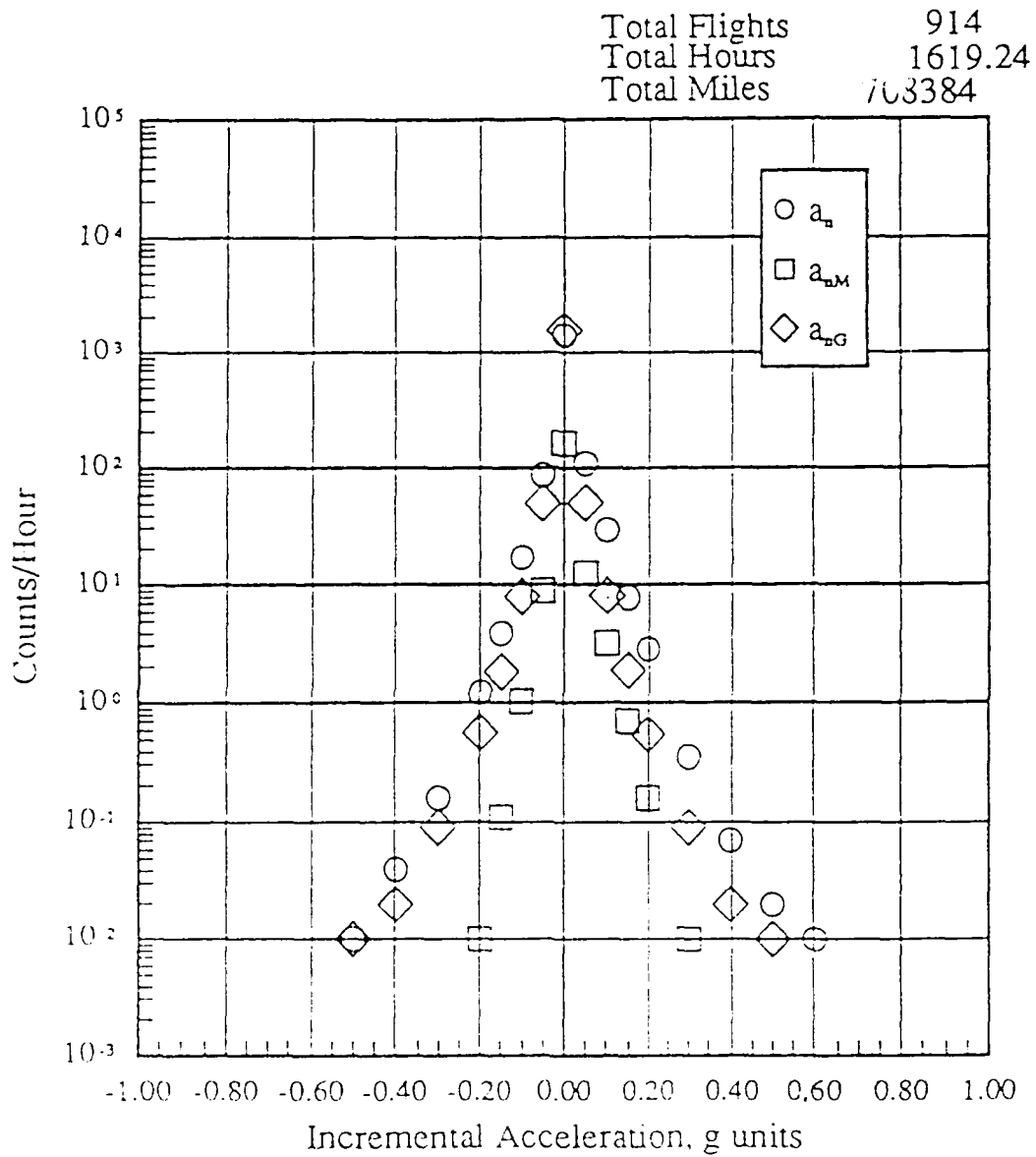


Figure 6 — DVGH Phase 1.0 Results: Flight Profile Statistics



(m) a_n , a_{nM} , a_{nG} , -500 to 44500 feet altitude

Figure 7 — DVGH Phase 1.0 Results: Acceleration Statistics

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maneuver and gust data. The data shown in this plot are the summary from 500 feet to 45,000 feet — 500 feet negative, 45,000 feet pressure altitude. The data for each 5,000 foot altitude band is given in the report.

In looking at miles of paper-time histories (we had special tables that were 60 feet long and we could look at records all day long), we saw a lot of things. We got so that we could walk out to the record room and tell whether it was a revenue flight or a non-revenue flight just by the character of the acceleration time history. We did, by the way, tabulate those non-revenue flights separately from the revenue flights.

We found that on all four types of airplanes there was an occasional limit cycle that showed up in normal acceleration. It appears in Figure 10. The peak amplitudes, are about .1G and about .07 hertz.

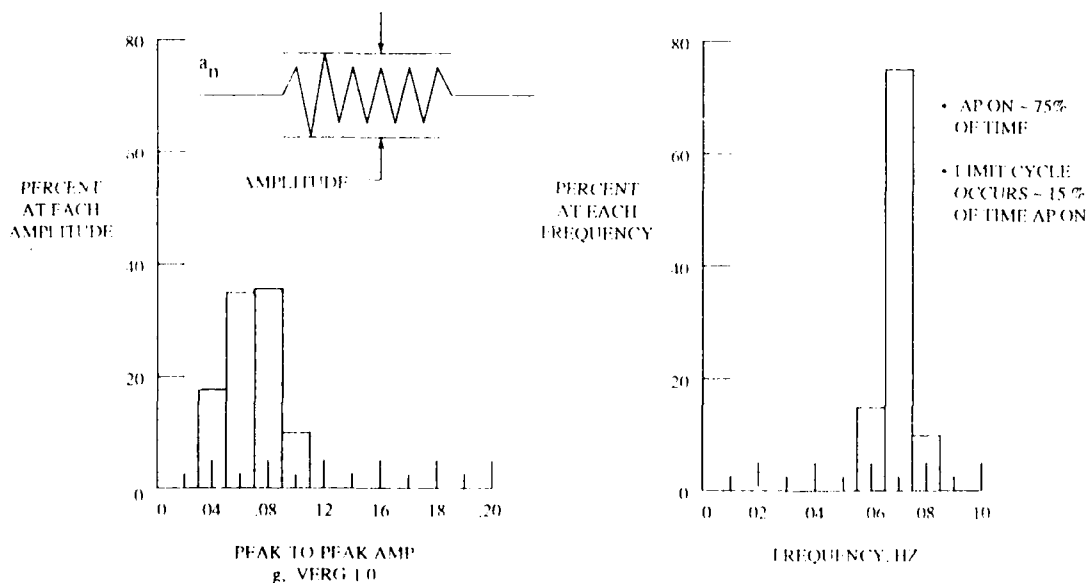
We found out that it was correlated with the autopilot being in the "on" mode. In the

1978 data we were checking autopilot data and found the autopilot was on about 75 percent of the time. Fifteen percent of the time the autopilot was on, we would get this low amplitude oscillation. (Figure 8)

The frequency corresponds with the frequency that you get when you analyze the autopilot loops. The short period mode splits into two modes, one lower than the short period and one higher than the normal, fixed short period.

Figure 9 is a copy of a record that shows an autopilot divergence. It's correlated with the autopilot usage. The airplane climbed to about 35,000 feet and leveled off, and the autopilot was engaged. There were several oscillation episodes where there was some activity. It got rather abrupt and the autopilot was shut off, which damped the motion. When the autopilot was reengaged, it seemed to behave fairly well.

Figure 10 shows a rough ride all the way up to cruising altitude. Some maneuver loads are



ALTITUDE HOLD LIMIT CYCLE DATA FROM 373 HOURS 1-10-11 1978

Figure 8 — DVGH Phase 1.0: Other Results

DVGH PHASE 1.0: UNUSUAL EVENTS

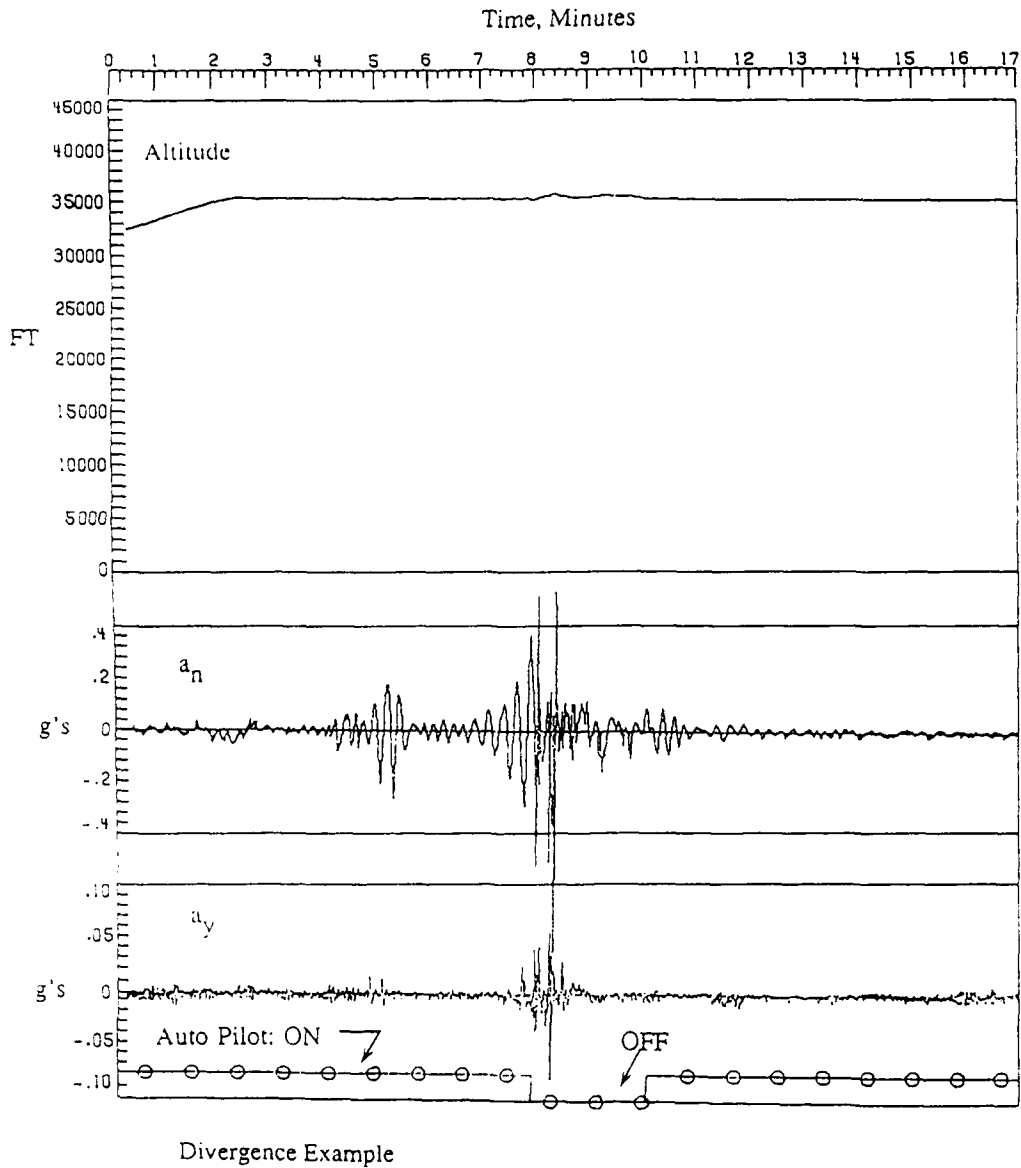


Figure 9 — DVGH Phase 1.0: Unusual Events

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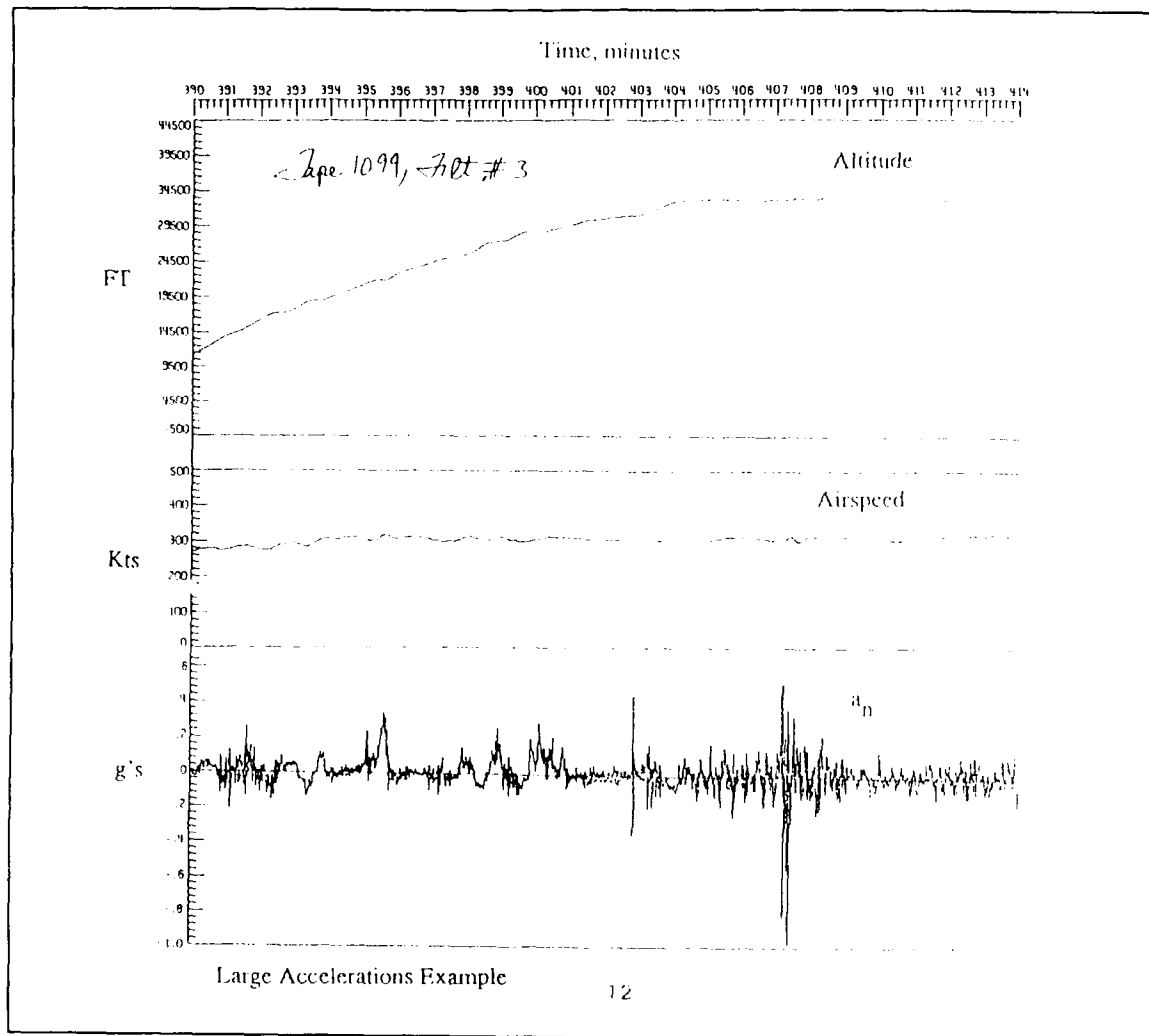


Figure 10 — DVGH Phase 1.0: Other Results

due to the turbulence, and then we see a pretty hefty negative G load at time 407. A coffee slosher.

In Phase 1-1/2 we took data on ten flights. (See Figure 11) We looked at takeoff parameters versus distance. We did histograms of ground speeds at liftoff and at takeoff, takeoff distance durations and accelerations. We did the similar things for landings. The data were not published. It was only ten flights. In Figure 12 (page 128) you'll see that there is a lot of granularity in the data because of the small number of samples.

In Phase 2, we investigated the smart re-

corder concept that Tom DiFiore discussed earlier.

We had a great thing going, but it took a lot of manpower. In fact, that was one of the reasons the program was cancelled. (See Figure 13) The idea was to develop an automated system and demonstrate an automated data acquisition and analysis system. To do that, you obtain, analyze and store the data in the memory on board the aircraft with a minimum of ground processing.

In 1982, we had the design review. The program was implemented through NASA Wallops, which had a contract with the Re-

Analyzed 10 trips — unpublished

Takeoff ground speed versus distance histories

- Histograms of
 - Ground speeds at liftoff
 - Gross weight at takeoff
 - Takeoff distance
 - Takeoff durations
 - Longitudinal accelerations at lift-off

Landing ground speeds, brake pedal pressures, heading vs. distance

- Histograms of
 - Touchdown CAS
 - Gross weight at touchdown
 - Landing distances
 - Landing times
 - Maximum longitudinal accelerations
- Correlations of
 - Takeoff speed vs. distance
 - Takeoff distance vs. gross weight
 - Takeoff distance vs. takeoff time
 - Touchdown velocity vs. gross weight at touchdown
 - Touchdown velocity vs. landing roll out distance
 - Maximum decelerations vs. landing roll-out distances

Figure 11 — DVGH Phase 1.5 Ground Parameters: Results

search Triangle Institute in North Carolina. They built a brass board version. We received 200 hours of data in the King Air in 1984 and 1985 and the data are reported in NASA CR 168353, in March 1988.

The conclusion was that this methodology was a practical way to go.

Figure 14 is a schematic of the system. We took data on the King Air from cockpit aircraft sensors with tees into the existing signal lines. Sensors like accelerometers were added to the aircraft. King Airs don't normally come with accelerometers.

The data goes into a signal conditioner unit like a flight data acquisition unit and into the smart recorder and on into the bubble memory. At that time bubble memories were all the rage and we thought "this is going to be great, we'll use bubble memories." Well, that's not the way you want to go today. But in 1982 it was. We called it the plug-a-bubble because we could remove the bubble without tying up the airplane, put another in, and bring the removed unit to a ground processor and print out the statistical data types.

Figure 15 shows smart recorder results. It's reported in the NASA CR 168353. This particular data set is the percent of time at indicated air speed versus altitude bins.

Figure 16 is acceleration exceedances. This was done on the level crossing counts per hour basis. The data looked good. We monitored the data screen to make sure that there were no spikes. You don't want spikes showing up on this. It will skew the data. It was good clean data.

NASA has had a long involvement in airworthiness programs both in the analysis and the measurement techniques. (See Figure 17) At one time VG was the state-of-the-art. I still think it was a good invention. But we ended up with the smart recorder, and I think that is a good invention too. NASA is looking forward to this cooperative program with the FAA to continue to provide airworthiness data. The first part of this program is the production of the digital VGH results. The second part of it, the long-term part, is the support of the measurements program involving the smart recorder concept.

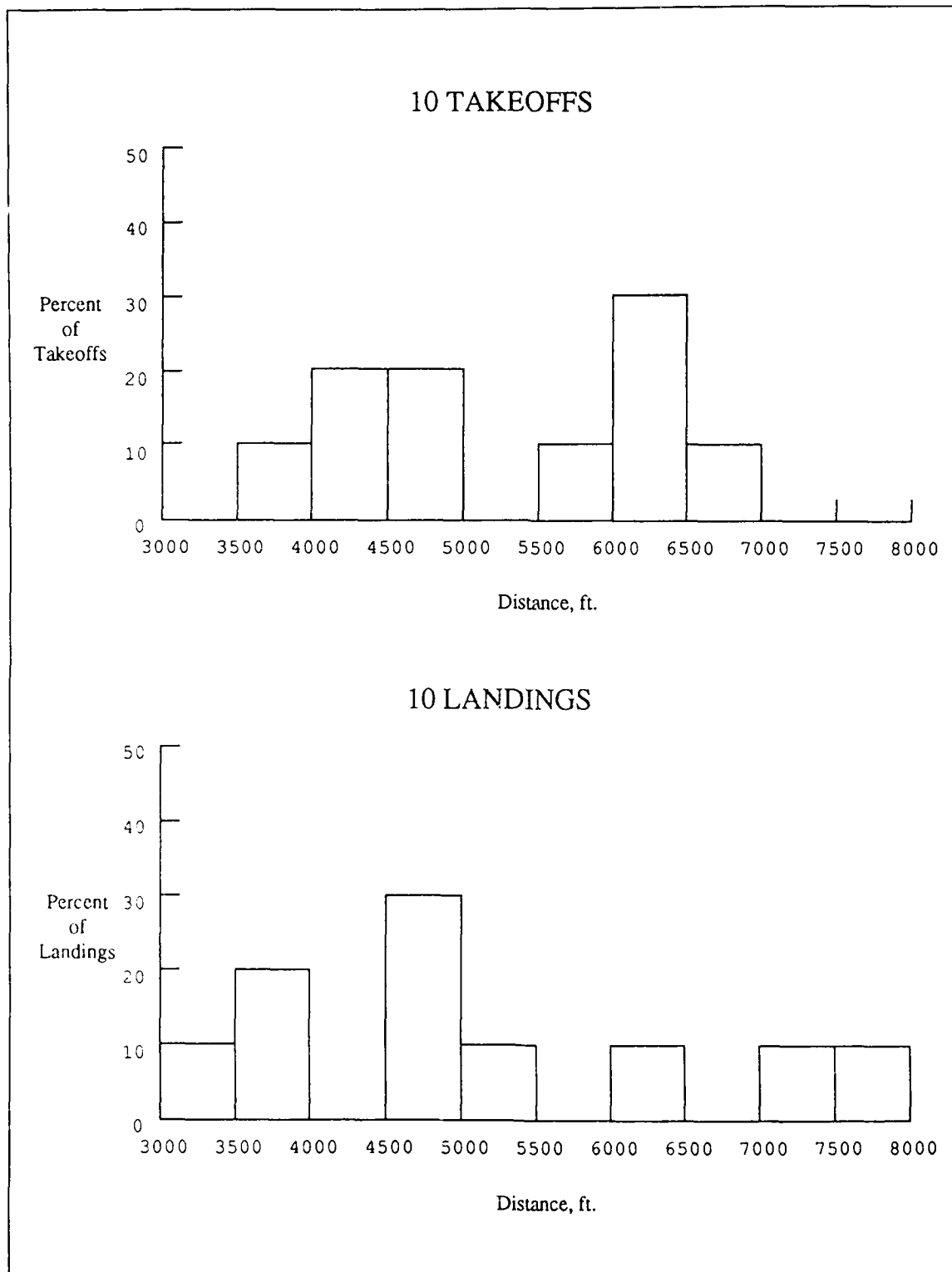


Figure 12 — DVGH Phase 1.5 Ground Parameter Results

Norman L. Crabill

- Objective
 - To demonstrate automated data acquisition and reduction systems
- Approach
 - Process data in near real time on board aircraft and store desired statistical types
 - Minimum ground processing
- Development
 - Contracted to RTI through NASA Wallops
 - Completed brass board
 - Obtained 200 hours in King Air, 1984-1985
 - Reported in CR 168353, March 1988
- Conclusion — Practical way to go

Figure 13 — DVGH Phase 2.0 Smart Recorder

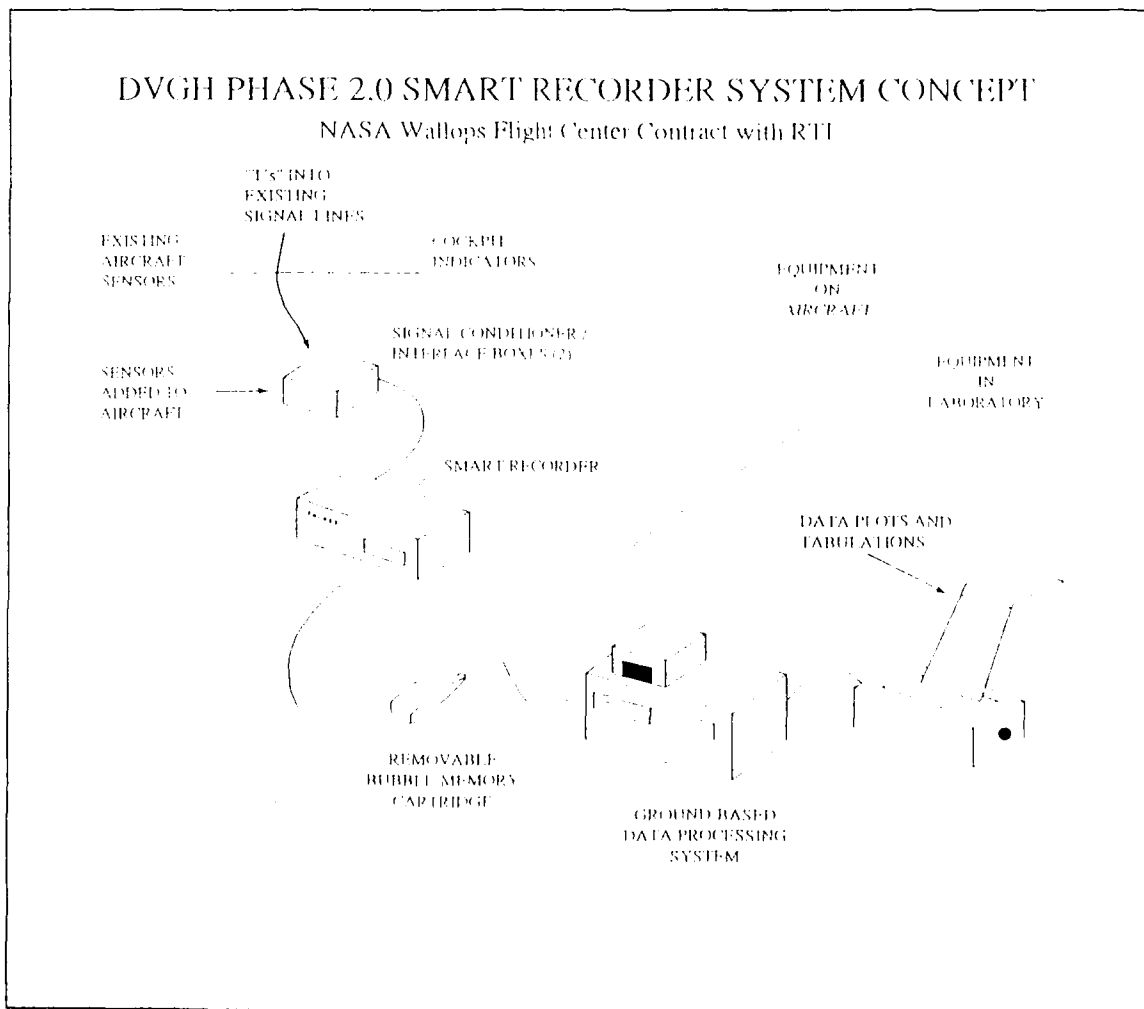


Figure 14 — DVGH Phase 2.0 Smart Recorder System Concept

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Percent time of indicated airspeed versus altitude bins for all flight conditions derived from onboard processing

IAS (Kts)	Altitude Bins (ft)					
	-500	4,500	9,500	14,500	19,500	-500
	to 4,500	to 9,500	to 14,500	to 19,500	to 24,500	to 24,500
100 to 120	10.91	.38	.11	.91	1.53	2.92
120 to 140	23.51	11.66	8.89	13.68	25.46	15.06
140 to 160	26.47	21.37	14.00	62.64	71.85	34.48
160 to 180	18.51	18.51	41.83	20.34	1.16	23.36
180 to 200	16.31	35.73	32.27	2.40	.00	19.77
200 to 220	4.25	12.29	2.87	.03	.00	4.37
220 to 240	.04	.06	.02	.00	.00	.03
240 to 260	.00	.01	.00	.00	.00	.00
260 to 280	.00	.00	.00	.00	.00	.00
280 to 300	.00	.00	.00	.00	.00	.02
Percent all modes vs. Altitude	22.80	22.23	23.20	25.81	5.95	100.00
Flight Time in All Modes (hours)	41.90	40.83	42.63	47.42	10.93	183.72
Total Flight Time per Bin (hours)	41.90	40.83	42.63	47.42	10.93	183.72
Percent Time in Altitude Bin	100.00	100.00	100.00	100.00	100.00	100.00
Number of flights					252	
Average flying time					0.82	

**Figure 15 — DVGH Phase 2.0 Smart Recorder Results
(from NASA CR 168353)**

Norman L. Crabill

Level crossing counts per hour versus
altitude bins for vertical acceleration (gravity removed)

Vertical Acceleration (G)	On the ground	Altitudes Bins (ft)					
		-500 to 4,500	4,500 to 9,500	9,500 to 14,500	14,500 to 19,500	19,500 to 24,500	-500 to 24,500
0.75 to 1.00	.0	.0	.0	.0	.0	.0	.0
0.50 to 0.75	.3	1.4	.4	.2	.1	.0	.5
0.40 to 0.50	.9	5.0	1.2	.7	.3	.0	1.6
0.30 to 0.40	3.7	21.9	4.1	1.9	1.0	.1	6.6
0.25 to 0.30	8.3	45.2	8.3	3.4	1.8	.4	13.4
0.20 to 0.25	23.1	100.8	17.9	6.8	4.0	1.6	29.7
0.15 to 0.20	69.9	225.9	42.1	16.2	10.8	7.6	67.9
0.10 to 0.15	232.2	489.3	108.9	53.4	34.2	34.6	159.1
0.05 to 0.10	970.6	1114.2	438.2	336.8	241.0	316.8	510.7
0.00 to 0.05	3951.0	2244.6	2655.2	2871.7	3346.3	3298.7	2828.5
-0.05 to 0.00	3955.5	2245.4	2655.4	2871.2	3346.1	3299.0	2828.6
-0.10 to -0.05	590.5	811.5	358.9	272.4	165.8	162.7	380.5
-0.15 to -0.10	141.2	312.7	83.1	44.8	26.4	25.7	108.5
-0.20 to -0.15	39.9	134.2	31.6	14.4	8.9	6.4	43.7
-0.25 to -0.20	11.9	56.4	14.0	6.2	3.5	1.6	18.4
-0.30 to -0.25	3.8	25.1	6.9	2.8	1.7	.6	8.4
-0.40 to -0.30	1.9	12.7	3.4	1.7	.8	.1	4.3
-0.50 to -0.40	.2	2.9	1.1	.6	.3	.0	1.1
-0.75 to -0.50	.1	.9	.5	.3	.1	.0	.4
-1.00 to -0.75	.0	.2	.2	.1	.0	.0	.1
Average cts/hr	500.3	392.5	321.6	325.3	359.7	357.8	413.7
Flight time/bin	23.16	41.90	40.83	42.63	47.42	10.93	183.72

Figure 16 — DVGH Phase 2.0 Smart Recorder Results
(from NASA CR 168353)

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- NACA/NASA has had a long involvement in Airworthiness programs
 - Discrete Gust Analysis
 - Continuous Turbulence Response of Flexible Aircraft
- NASA State of the Art Measurement Programs
 - VG 1933
 - VGH 1946
 - DVGH 1977
 - Smart Recorder 1982 — appears to have a lot of advantages for fleet use
- NASA currently embarking on Cooperative Program with FAA to continue to provide Airworthiness data on airliner operations
 - Publication of DVGH Results in NASA CR 181909 in five volumes
 - Support of FAA measurements program involving Smart Recorder technology

Figure 17 — Summary

Flight Loads



J. BEN DE JONGE

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Ladies and gentlemen, it's my pleasure to give you a review of program on the acquisition and usage of loads data for the KSSU-747 aircraft from the Aircraft Condition Monitoring System (ACMS) recordings. KSSU stands for KLM, Swiss Air, SAS Scandinavian, and UTA, the French airline.

This program has been active from 1974 until 1989 and we at NLR acquired this data under contract with KLM Dutch Airlines with the moral support, I would say, of the Dutch Civil Airworthiness Authorities, who also paid for part of the data analysis programs.

In my brief review I will give you a short description of the data acquisition procedures — the type of data acquired. I will give a brief review of the total data base that is now available, but I will concentrate on an example of the application of the data that were acquired in this program.

The program objectives were twofold. The first is the monitoring of aircraft usage and load experience in relation to fatigue for these aircraft involved. This information is operator-oriented.

The second is gathering of gust statistics. Acceleration data were converted to derive gust velocities, and that is comparable to the VGH programs.

That part of the objective is outside the scope of my present presentation. I will not give you information about that part. However, the total data base at this moment includes nearly 122,000 flight hours and more than 24,000 flights. That is considerably more than the NASA VGH data base on that subject.

In this program we had a number of limitations. In the first place, we were only allowed to make use of the existing ACMS that was on board the aircraft. No changes to this system were allowed. No impairment of the aircraft operation was allowed. It was also a requirement that the cost should be kept down to a bare minimum. The total cost for KLM has never been more than \$25,000 a year in this project.

The data acquisition procedure is as shown in Figure 1. You have to keep in mind that these 747 aircraft have been equipped with ACMS

Data Acquisition Procedure

- KSSU Boeing 747 aircraft have been equipped with ACMS recorders
- A large number of parameters are continuously scanned and are recorded if specific criteria are met
- A limited number of data, relevant for describing usage and load experience, are extracted from ACMS data tape and stored in;

ACMS Fatigue Data Base

Data are stored on a flight-by-flight basis

Stored data include:

- General flight data, such as type of flight, date, tow, departure and destination airport
- Flight profile data, such as speed, altitude, A/C weight and cabin pressure during flight
- C.G. acceleration data
Values of recorded acceleration peaks/troughs with time of occurrence

Figure 1

recorders. In these recording systems a large number of parameters — and I mean a few hundred parameters — are continuously scanned and they are recorded if specific criteria are met. For example, in periods of severe turbulence, during takeoff, landing, and now and then at intervals during the flight.

That's the standard equipment in these aircraft. The recorder data are put on a magnetic tape. The magnetic tape is brought to the computer facility of the airline and all the data are subjected to analysis for purposes largely

associated with the maintenance of the aircraft. But in this case they were run through a specific program that was called the AIDS fatigue data program, and a limited number of the recorded data that were relevant for describing the aircraft usage and relevant to the load experience were extracted from this general batch of ACMS data and stored in the ACMS fatigue data base.

In this data base all the data are stored on a flight-by-flight basis. There are three types of data. The first is general data describing the type of flight, the date of the flight, takeoff date, the departure airport, destination airport, and things like that. The second is flight profile data. Every flight is split up in a number of segments. For example, when the altitude changes 2,000 feet, you start a new segment. During cruise, a new segment is started every hour. At the end of each flight segment the speed, altitude, the aircraft weight, were recorded. So, from this flight profile data you have a picture of the mission profile. The third is CG acceleration data. The peaks and troughs values were scanned and stored in the data base together with the instantaneous time of occurrence. Having the mission profile data, the change of the weight, speed and things like that, you can then derive gust velocities. You can reduce acceleration data to gust velocities. But, as I said, that is outside the scope of this presentation.

Figure 2 gives a brief review of the type of standard output that was produced as an overall summary of all flights. There are about 24,000 flights. It is distributed by flight duration intervals with a concentration in the area of seven to eight hours, that's the trans Atlantic flight time of the 747. The general review includes the average flight duration, average block time, and average takeoff rate.

The other type of information is usage statistics for various altitude bands. Figure 3 shows the altitude band of 10,000 to 15,000 feet. You see the average time spent in that flight interval, the speed within that interval.

Figure 4 shows the 35,000 feet to 40,000 feet interval that is, on the average, the cruise altitude for the longer flights.

Figure 5 is an overall summary of the recorded CG accelerations according to altitude

J. Ben de Jonge

FLIGHT TYPE LEGEND		FLIGHT DURATION INTERVALS (HRS)														ALL FLIGHT DURATIONS
		.0- .5	.5- 1	1-1.5	1.5- 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 -10	>10		
NUMBER OF	A	1591	1739	1110	1577	1347	1607	765	1651	4849	4696	1936	490	399	23757	
FLIGHTS OF	B	9	43	28	55	90	43	26	4	17	15	22	10	0	362	
INDICATED	C	0	1	2	0	0	0	0	0	0	0	0	0	0	3	
FLIGHT TYPE	D	1	4	3	10	7	10	0	0	1	0	0	0	0	36	
	X	23	37	6	11	22	8	4	4	39	24	17	5	0	200	
	ALL	1624	1824	1149	1653	1466	1668	795	1659	4906	4735	1975	505	399	24358	
AVERAGE FLIGHT DURATION (HRS)		.44	.76	1.26	1.72	2.57	3.47	4.51	5.56	6.52	7.52	8.37	9.54	10.58	5.01	
AVERAGE BLOCK TIME (HRS)		.78	1.14	1.67	2.15	3.05	3.95	5.04	6.02	7.04	8.03	8.84	9.96	10.99	5.47	
AVERAGE TON (X 1000 KG)		222.60	225.36	233.51	230.34	250.78	267.20	284.64	293.53	302.26	318.94	326.42	339.53	347.84	283.12	
STAND. DEV. TON (X 1000 KG)		13.89	21.49	24.97	20.22	20.27	24.50	21.80	19.16	15.95	18.71	17.05	17.70	14.04	43.13	
AVERAGE FUEL CONSUMPTION (X 1000 KG)		6.43	9.92	15.06	18.64	28.33	38.52	51.82	62.70	74.37	87.82	97.87	111.19	124.27	57.78	
STAND. DEV. FUEL CONSUMPTION (X 1000 KG)		4.84	5.83	6.60	5.18	5.95	5.69	7.44	5.58	6.10	6.89	6.66	7.77	7.14	33.90	

Figure 2 — Summary Review of Recorded Flights

----- U S A G E - S T A T I S T I C S RESULTS, FLIGHT PROFILE DATA -----																
***** ALTITUDE INTERVAL 10000 - 15000 FEET *****																
AVERAGE VALUES WITHIN ALTITUDE SEGMENT	FLIGHT DURATION INTERVALS (HRS)														ALL FLIGHT DURATIONS	
	.0- .5	.5- 1	1-1.5	1.5- 2	2- 3	3- 4	4- 5	5- 6	6- 7	7- 8	8- 9	9-10	>10			
TIME SPENT (HRS)	.166	.101	.089	.100	.099	.099	.107	.102	.104	.118	.131	.125	.115	.11		
WEIGHT (X 1000 KG)	216.37	220.41	227.14	220.54	234.81	247.69	258.84	262.39	267.06	273.44	271.55	280.37	286.66	253.51		
VELOCITY (M/SEC)	189.36	180.28	176.62	168.48	176.06	179.82	182.44	184.44	182.23	181.21	177.25	181.59	186.93	180.80		
MACH NUMBER	.58	.55	.53	.51	.53	.54	.55	.56	.56	.55	.54	.55	.57	.55		
ALTITUDE (X 1000 FT)	12.96	12.60	12.43	12.31	12.47	12.43	12.42	12.43	12.42	12.43	12.44	12.42	12.40	12.49		
***** ALTITUDE INTERVAL 15000 - 20000 FEET *****																
AVERAGE VALUES WITHIN ALTITUDE SEGMENT	FLIGHT DURATION INTERVALS (HRS)														ALL FLIGHT DURATIONS	
	.0- .5	.5- 1	1-1.5	1.5- 2	2- 3	3- 4	4- 5	5- 6	6- 7	7- 8	8- 9	9-10	>10			
TIME SPENT (HRS)	.034	.080	.083	.082	.093	.093	.103	.098	.099	.118	.132	.117	.110	.10		
WEIGHT (X 1000 KG)	220.90	221.74	227.56	221.70	236.05	249.59	260.50	264.49	269.31	275.38	274.32	287.16	297.21	259.99		
VELOCITY (M/SEC)	203.81	202.80	200.94	198.87	200.39	205.48	207.35	208.01	206.98	206.73	203.32	207.76	212.14	205.21		
MACH NUMBER	.63	.63	.62	.61	.62	.63	.64	.64	.64	.64	.63	.64	.66	.64		
ALTITUDE (X 1000 FT)	16.03	17.46	17.53	17.51	17.50	17.52	17.54	17.54	17.55	17.58	17.56	17.54	17.55	17.51		

Figure 3 — Example of Flight Profile Data

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----- USAGE - STATISTICS RESULTS, FLIGHT PROFILE DATA -----														
***** ALTITUDE INTERVAL 30000 - 35000 FEET *****														
AVERAGE VALUES WITHIN ALTITUDE SEGMENT	FLIGHT DURATION INTERVALS (HRS)													ALL FLIGHT DURATIONS
	.0- .5	.5- 1	1-1.5	1.5- 2	2- 3	3- 4	4- 5	5- 6	6- 7	7- 8	8- 9	9-10	>10	
TIME SPENT (HRS)	.002	.003	.292	.304	.520	1.036	1.807	2.077	2.804	3.821	4.402	4.855	5.289	2.20
WEIGHT (X 1000 KG)	260.71	213.31	226.37	221.90	241.54	259.54	263.09	267.58	269.57	279.59	281.67	290.85	289.09	274.63
VELOCITY (M/SEC)	250.67	246.20	246.55	240.76	249.06	252.01	253.27	252.11	251.15	251.54	251.10	251.90	251.06	251.39
MACH NUMBER	.84	.82	.81	.82	.82	.83	.83	.83	.84	.84	.84	.84	.84	.84
ALTITUDE (X 1000 FT)	32.79	32.17	32.81	33.07	33.08	33.15	33.09	33.22	33.25	33.15	32.98	33.04	32.99	33.13
***** ALTITUDE INTERVAL 35000 - 40000 FEET *****														
AVERAGE VALUES WITHIN ALTITUDE SEGMENT	FLIGHT DURATION INTERVALS (HRS)													ALL FLIGHT DURATIONS
	.0- .5	.5- 1	1-1.5	1.5- 2	2- 3	3- 4	4- 5	5- 6	6- 7	7- 8	8- 9	9-10	>10	
TIME SPENT (HRS)	.001	.009	.269	.620	1.106	1.549	1.561	2.428	2.773	2.504	2.625	3.357	3.591	1.83
WEIGHT (X 1000 KG)	236.06	216.32	216.88	215.08	231.11	234.74	244.19	246.65	249.16	251.81	250.90	251.40	247.89	247.22
VELOCITY (M/SEC)	251.30	246.89	247.99	248.37	249.14	250.08	250.77	250.53	249.81	250.53	249.97	250.64	250.20	250.10
MACH NUMBER	.85	.84	.83	.83	.83	.84	.84	.84	.84	.84	.84	.84	.84	.84
ALTITUDE (X 1000 FT)	37.98	35.05	36.71	37.12	37.15	37.14	36.73	36.62	36.46	36.29	36.20	36.56	36.65	36.51

Figure 4 — Example of Flight Profile Data

ALTITUDE INTERVAL (FT)	TOTAL DISTANCE FLOWN (NM)	TOTAL TIME SPENT (HRS)	NUMBER OF PEAK OCCURRENCES IN INDICATED DELTA-G. INTERVALS U P W A R D									
			.15-.20	.20-.25	.25-.30	.30-.40	.40-.50	.50-.60	.60-.75	.75-.90	.90-1.10	>1.10
< 1500	197652	1228.20	19072 x	6275	1839	717	89	21	3	1		4
1500- 3000	257594	1367.30	14689 x	5332	1672	612	80	6	6			5
3000- 5000	353521	1574.52	11164 x	4489	1516	651	92	12	1			2
5000- 10000	878411	3156.67	11361 x	4796	1783	936	173	38	10	5		2
10000- 15000	956828	2722.50	4086 x	1963	815	479	113	32	16	4		
15000- 20000	949962	2381.51	2019 x	861	350	231	53	17	13	3	1	
20000- 25000	1295227	2952.09	1639 x	700	286	154	54	21	8	3		
25000- 30000	3829993	7993.12	2947 x	1237	441	293	58	22	10	1		2
30000- 35000	26199429	53613.85	12275 x	4717	1611	974	170	58	26	2	2	5
35000- 40000	21687962	44611.17	9083 x	3666	1327	710	140	47	18	1		2
> 40000	141655	293.45	115 x	49	24	10	2					
ALL ALTITUDES	56748235	121894.38	88450 x	34085	11664	5767	1024	274	111	20	3	22
ALTITUDE INTERVAL (FT)	TOTAL DISTANCE FLOWN (NM)	TOTAL TIME SPENT (HRS)	NUMBER OF PEAK OCCURRENCES IN INDICATED DELTA-G. INTERVALS D O W N W A R D									
			.15-.20	.20-.25	.25-.30	.30-.40	.40-.50	.50-.60	.60-.75	.75-.90	.90-1.10	>1.10
< 1500	197652	1228.20	8942 x	1819	399	185	21	10	7	1		
1500- 3000	257594	1367.30	7870 x	1786	436	124	30	25	13	11	1	
3000- 5000	353521	1574.52	5778 x	1669	517	202	29	15	3	4		
5000- 10000	878411	3156.67	6755 x	2473	871	491	94	20	8	3	1	
10000- 15000	956828	2722.50	3310 x	1232	449	318	77	29	12	3		
15000- 20000	949962	2381.51	1817 x	641	285	156	33	9	6	3	1	
20000- 25000	1295227	2952.09	1476 x	491	190	118	17	9	6	2		
25000- 30000	3829993	7993.12	2666 x	939	373	220	56	19	4	1	1	
30000- 35000	26199429	53613.85	11217 x	3899	1454	735	158	51	25	2		
35000- 40000	21687962	44611.17	8214 x	2997	1034	594	129	43	12	5		
> 40000	141655	293.45	117 x	37	14	12	1					
ALL ALTITUDES	56748235	121894.38	58162 x	17983	6022	3155	644	231	96	35	4	

x STATISTICALLY UNRELIABLE DATA DUE TO A FLOATING LIMIT SETTING OF 0.18 G

Figure 5 — Recorded C.G. Acceleration Peaks

interval and number of peaks within the various intervals.

The application of the usage data is, in the first place, to compare the design usage with the actual surface experience of the aircraft for a particular operator with regard to, let's say, the mission profile assumptions, flight length distribution weights and cabin pressure differentials. (See Figure 6)

You may also study the variation of usage with time for a particular operator. The changes in the network of an operator, for example, may result in changes of its operation and changes of its load experience.

That is, in the first place, the comparison of the design usage and, in the second place, you may compare the design loads with service experience, and finally get some idea about the conservatism of the design data with regard to turbulence that is currently used.

Figure 7 for the 747, gives a review of the design mission mixture for the aircraft. This is a specific mission mixture, with a concentration for the seven-hour transatlantic type of flight. The average mission mixture resulted in an average flight duration, design flight duration, of three hours. You may recall that the design life of the aircraft was 20,000 flights or 60,000 flight hours. These figures then match.

Figure 8 shows the observed flight duration distribution from our data base. The Swiss

Air and KLM — and for KLM there is a combination version and a full passenger version — average flight duration is in the order of five hours.

The first observation, is that this flight duration is considerably longer than the design assumption of three hours. But looking then to the flight length distributions for Swiss Air compared to the KLM, you'll notice that for Swiss Air there is a pronounced peak at the very short duration flight lengths.

The reason for this is that Switzerland is a small country and there are two airports, Zurich and Geneva. They flew from Zurich to John F. Kennedy with an intermediate stop, a half-hour flight, at Geneva. That was a very short duration flight and it had a very pronounced influence on the average flight duration.

Figure 9 looks at the average cabin pressures that were reached. The first observation is that in all KLM and Swiss Air flights the cabin pressure remained well below the design value of 9 psi. There is a concentration at the 8.7 to 8.8 psi. That's a considerable difference in terms of fatigue from the 9 psi design value.

But for Swiss Air that is because of that very short flight from Geneva to Zurich. In 30 percent of the flights the cabin pressure remained below 8.2 psi. You can imagine that this has a considerable effect on the fatigue life consumption -- if you assume a pressure of 9 psi for every flight and in actual fact, in 30 percent of your flight cycles the pressure remains below 8.2, you have a considerable saving in fatigue life consumption. This is the type of information that is very useful for an aircraft operator and also for the airworthiness authority.

Figure 10 looks at the mission profiles, the usage. The other subject, of course, is comparing the design loads with actual measured loads. Shown here is the CG acceleration spectra, the dotted curve is the measured curve, and the other curve is the flight condition spectra.

We calculated the loads spectra that you would find for the actual mission profile if you used the NACA TN4332 data that were used for the 747 in calculating the design loads spectra. You see here that the TN4332 data are conservative compared to what is actually measured. That is a comforting feeling for the

- Comparison of design usage with service experience
 - Flight length distributions
 - Weights
 - Cabin pressure differentials
 - Variation of usage with time
- Comparison of design loads with service experience
 - Conservatism of design
- Gust load data

Figure 6 — Examples of Application

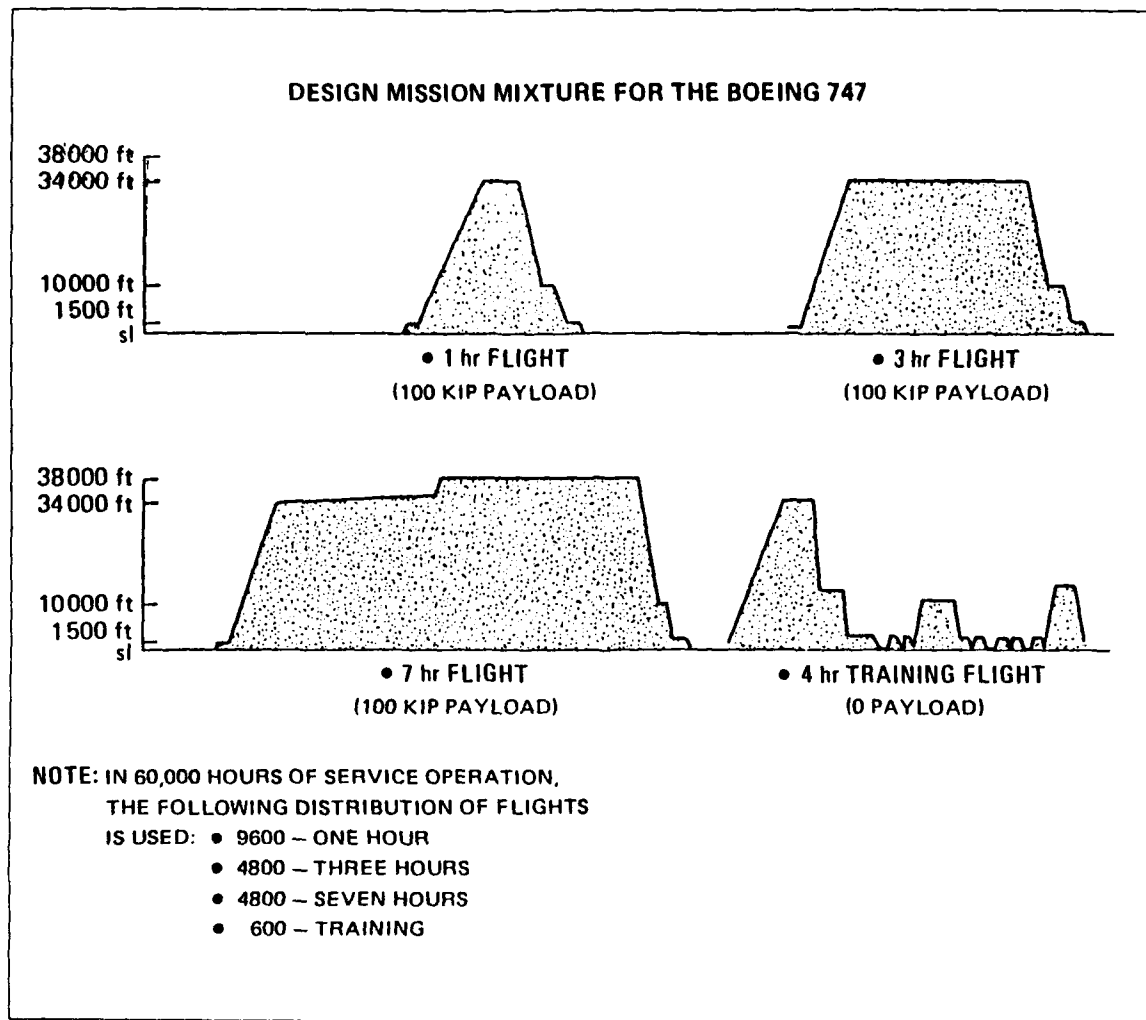


Figure 7 — Design Mission Mixture for the Boeing 747

airline and for the airworthiness authority and in actual fact also for the passengers flying in these aircraft.

We should keep in mind that we have measured here our data that include maneuvers and gusts. We were not able, because we just got acceleration peaks, to distinguish between maneuvers and gusts in the first instance. We were not able to apply a filter. We just received reduced data from the ACMS system and we could not change them.

There is another conservatism in that. We tried to correct our CG data for maneuvers by subtracting a part of the load factor that we thought was due to a turning maneuver. If you

have the bank angle of the aircraft, you can calculate the associated maneuver load factor with the bank angle. We measured the bank angle and subtracted that from the total measured incremental acceleration and got the correction. That way you have then subtracted the parts of the load factors due to the maneuver. In many cases, especially at low altitude, the airplane is making turns, or is in a holding pattern, and you have a certain bank angle and you are meeting the turbulence. So, you have a situation that the turbulence loading is superimposed on the long duration type of maneuver.

Looking at the results in Figure 11, you have to consider that it is a logarithmic scale.

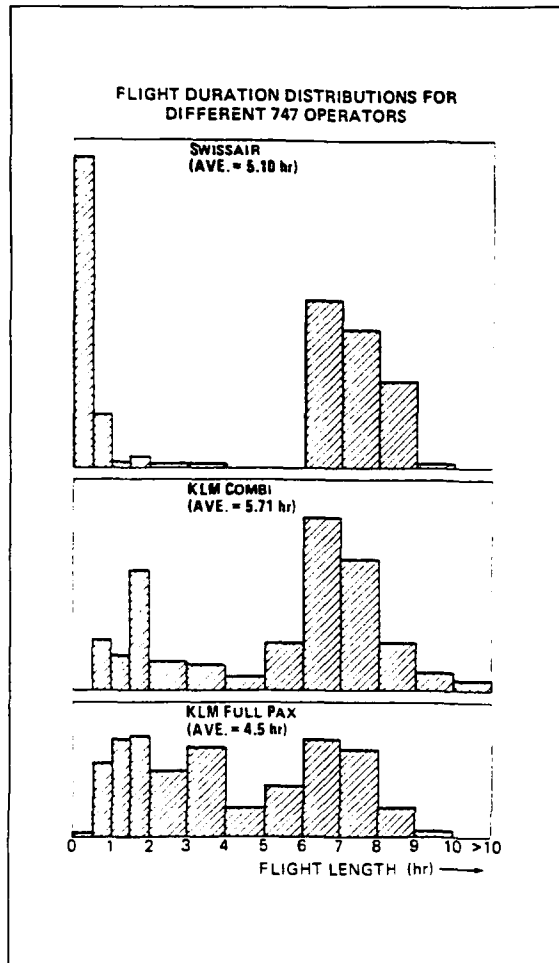


Figure 8 — Flight Duration Distributions

This might be a relatively simple way of splitting maneuver loads and gust loads.

Figure 12 is just a picture of the variation in usage. You see three periods. The small triangles on the right side are variations over the periods of the average flight time for the KLM Combination. Perhaps not very drastic here, but the average flight duration changed in the period of two years for this aircraft from nearly six hours to a little bit more than five hours, just because of a change in the network, an operational change, or perhaps the introduction of another aircraft in the fleet. These variations may be important, and it is interesting for the airline to be aware of such changes.

This program shows that it is possible to obtain very relevant information at very little cost and without very much difficulty.

Very few airlines apply systematic usage or loads monitoring in their aircraft. KLM stopped their activity just last year for the sake of saving the \$25,000 a year.

The reason there is very little application so far is that service loads monitoring only becomes effective if there is close cooperation and agreement between the three parties involved. These three parties are the airline, the aircraft manufacturer and the airworthiness authority.

The airlines say they know what they have at the moment with regard to inspection and maintenance burden. Those measurements can result in two findings. Either our load experience is more severe than expected, and then we will get a more severe maintenance burden. Or, on the other hand, if it turns out that our load experience is less severe, we are not sure that we get the benefit for that. Will the authorities really allow a reduction of the maintenance burden?

The airworthiness authorities are very reluctant to say *beforehand* that they are willing to give a reduction. One of the reasons is that the civil airworthiness authorities are understaffed, people are very busy and they do not wish to commit themselves in this area.

Finally, you have the aircraft manufacturer. The aircraft manufacturer is interested in this type of activity but not really enthusiastic. It turns out that they can do that but it would mean a lot of extra work.

Although the means are there to apply usage monitoring for operators at low cost, people don't do it or you find very low application of systematic monitoring. We continue to apply relatively large safety factors or scatter factors to cover the uncertainty, the actual uncertainty, about our service loads experience.

Monitoring usage and loads experience offers the possibility to take away a certain amount of uncertainty in our fatigue assessment. Taking away a part of uncertainty means an increase in the overall accuracy and in the overall safety of aviation.

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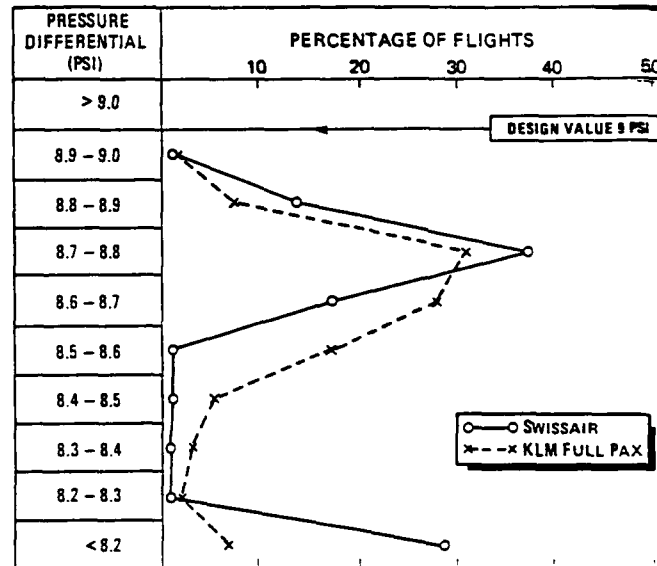


Figure 9 — Distribution of Maximum Cabin Pressure Differential for Two 747 Operators

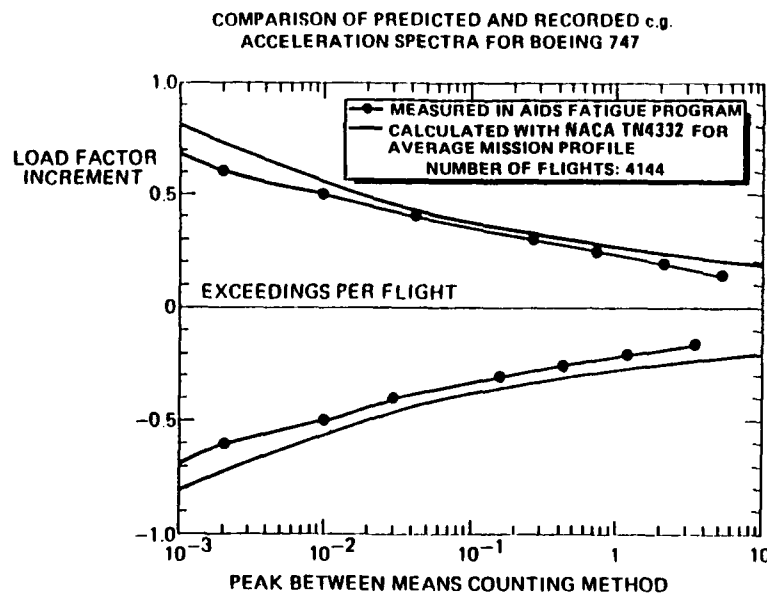


Figure 10 — Airframe Structural Integrity Program

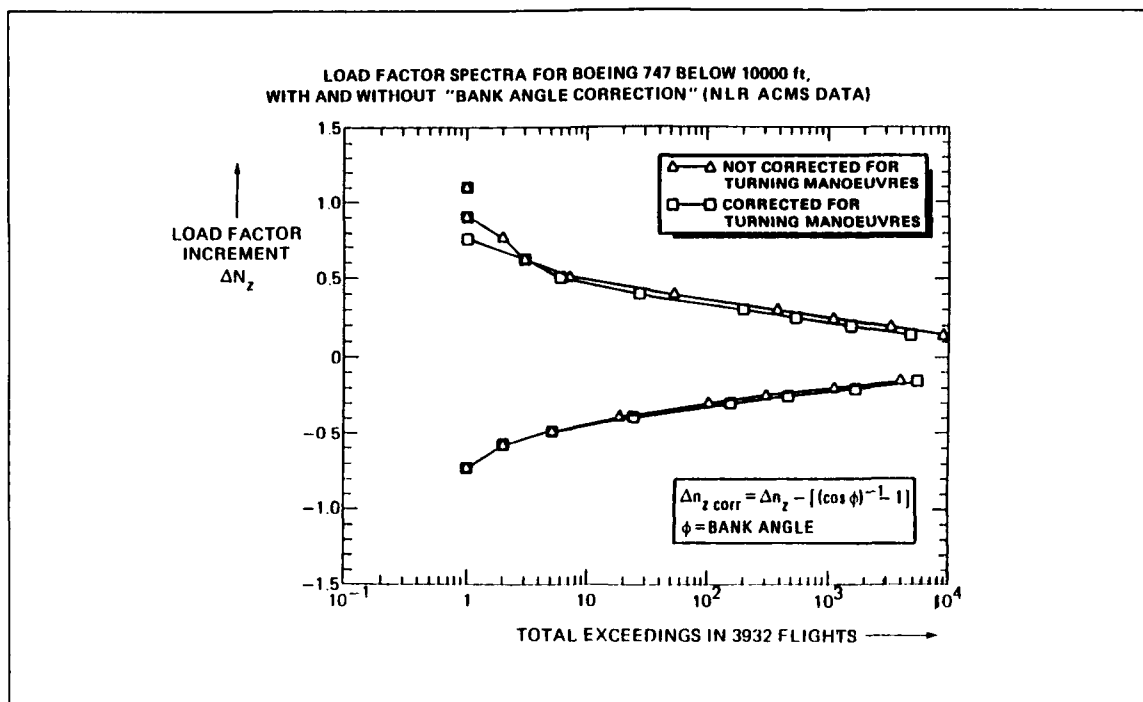


Figure 11 — Load Factor Spectra for Boeing 747 Below 10,000 ft, with and without "Bank Angle Correction" (NLR ACMS data)

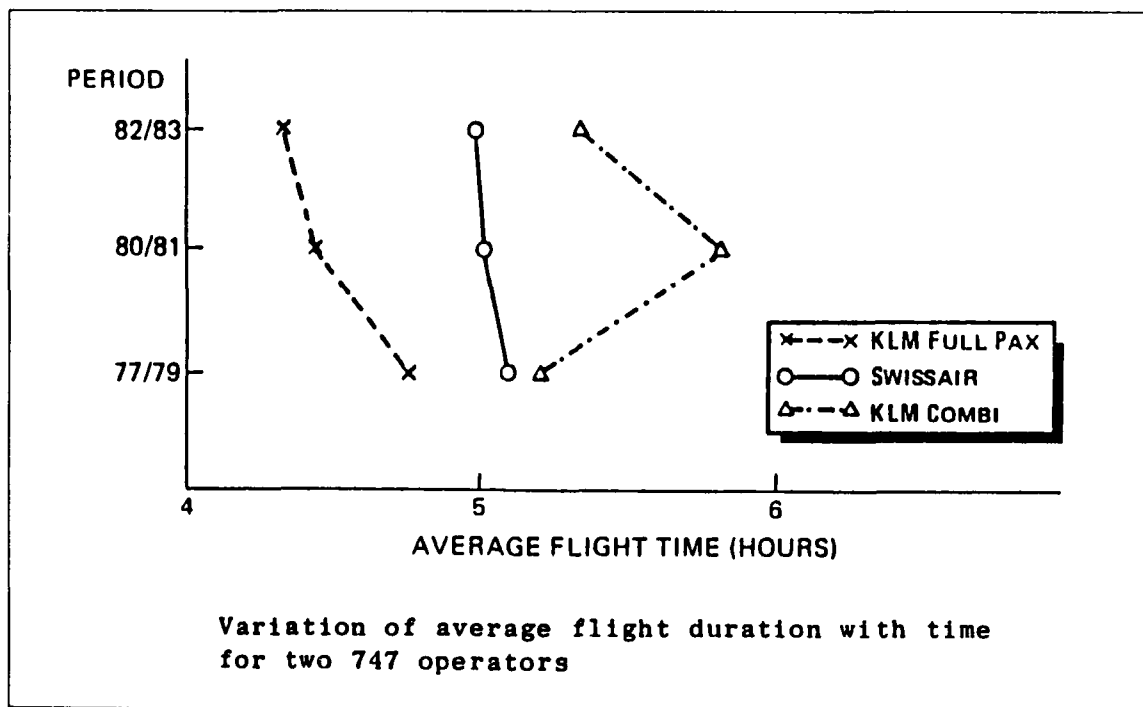


Figure 12 — Variation of Average Flight Duration with Time for Two 747 Operators

The Responsibilities of FAA, the Manufacturers and the Airlines for the Continuing Safety of Aging Aircraft



WILLIAM R. HENDRICKS

FAA Director of Accident Investigations

I'm very honored to present my paper to this distinguished group and I realize that I'm in with the heavyweights of the industry and the top structural and maintenance experts in the world in the subject of aging aircraft. Your knowledge on this subject far exceeds mine.

My perspective is from the window of accident investigation and I hope to focus on the Aloha Airlines accident which occurred in the Hawaiian Islands on April 28th, 1988. I'd like to show the factors that were developed during that investigation and how they spotlighted the issues concerned with aging aircraft.

While the Aloha accident wouldn't be classified as a catastrophic event in terms of the classic high fatality major aircraft accident, I believe that it will be looked on as a landmark accident in terms of the intense industry interest and expedited efforts for corrective actions that have evolved.

In these terms, I would place it in the same category as the Eastern Flight 66 accident, which occurred at JFK in June of 1975, killing 113 passengers and crew. This was a thunderstorm accident which precipitated the first full-scale efforts by the FAA and the industry to develop wind shear detection and training programs.

I would also place it in the same category as the PSA, the midair collision accident that occurred in San Diego in September of 1978. This accident killed 144 people and it resulted in massive changes to the National Air Space System. TCAs and other major airspace changes have evolved from that accident.

The Aloha accident, which involves an in-flight structural failure to a high-time airplane, may well be remembered as the springboard for higher standards in new technology and procedures for maintaining the world's aging aircraft.

William R. Hendricks

Activity associated with the Aloha accident by no means overshadows the long-term efforts both by the FAA and industry with regard to aging aircraft. There has been considerable progress made over the years resulting in comprehensive programs to monitor and repair transport airplanes throughout their operational life. The Aloha accident has served to accelerate and to magnify these efforts.

I would like to first look at the in-service structural history of the Boeing 737 and the interrelationships between the FAA, the manufacturer, and the operator as they pertain to the causal factors involved in the accident. I will then briefly discuss some of the specific activities and recommendations for corrective action that have been initiated since this occurrence.

I think it might be a good idea to review first the accident scenario. As I mentioned before, the accident occurred on April 28, 1988. Aloha Airlines Flight 243, a Boeing 737-200, was on a regularly scheduled passenger flight from the Island of Hilo to Honolulu, Hawaii.

Shortly after leveling the airplane at flight level 240, with the first officer at the controls, the crew heard a loud clap and a whooshing sound behind them, followed by the sound of rushing air. They observed almost immediately that the cockpit door was gone and that there was blue sky where the ceiling of the airplane had been in the first-class section.

The captain immediately took control of the airplane and began a 4,000 foot per minute emergency descent using speed brakes and maintaining an air speed of about 280 to 290 knots during the initial portion of the descent. Air traffic control was advised of the emergency and approved a diversion to Maui.

The captain stated that during this time they were experiencing severe vibrations and the airplane was handling very rough. He slowed the airplane to about 200 knots as the flight descended through 10,000 feet. The flaps were set to five degrees. Then the crew tried to extend the flaps to 15 degrees, the airplane became less controllable so the crew returned the flaps to the five degree position.

The captain then attempted to slow the aircraft in preparation for the landing, but as it

decelerated below 170 knots, the airplane again became less controllable. The captain elected to maintain the speed at 170 knots throughout the landing approach.

At that time it was also noticed that the plane had lost power on the number one engine. The flight landed on runway 2 at the Kahului Airport at 1358 hours. A normal touchdown and landing was accomplished using the brakes and reverse thrust on the number 2 engine.

The entire episode from the time of the structural failure at flight level 240 to touchdown was approximately 11 minutes. There were 95 persons on board; 89 passengers, two flight crew, three flight attendants and an FAA air traffic controller in the jumpseat.

The senior flight attendant in the first-class cabin was lost during the decompression; 59 passengers were taken to the hospital with injuries from minor to serious.

I think, all factors considered, it was a miraculous escape for those on board except for the tragic loss of the flight attendant. Indeed, the flight is a testimony to the skill of the flight crew and to the residual strength of the Boeing 737.

If you recall, the fuselage structure from above the floor level on the left side to about the top of the window belt on the right side and extending from just aft of the passenger entry door to just forward of the wing were missing completely, from body station 360 through fuselage station 540. All fractures associated with that break-away were typical of overload, static overload separations.

The NTSB in their report determined that the failure initiated along the number 10 stringer on the left side near fuselage station 440. The top skin ripped from that point down and to the left on the left side and up and over the airplane and rearward on the right side. More like an egg shell breaking apart. The floor on the left side in the area of fuselage station 440 was the most severely deformed. The oxygen system lines were torn out below the decks and there was no oxygen available.

There were about four or five floor beams broken through, primarily on the left side of the airplane where the most severe damage oc-

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cured in the area of fuselage station 440 — that was in the area where the NTSB surmised that the peak loads occurred.

After the accident a witness was located — a passenger actually — who boarded the airplane at its origination point. The lady was about four-foot ten inches tall and as she was getting on the airplane, she noticed a crack in the fuselage at about her eye level. She described it in later conversations as about a six-inch crack with the skin actually protruding from beyond the rivet heads. The area she describes was along the 10-L stringer in the area that the NTSB figures that the separation occurred.

This was a high-time, high-use airplane and it was manufactured in 1969. At the time of the accident, it had accumulated 45,493 flight hours. More significantly, it had 89,090 cycles, which equates to about 13 flights a day for 19 years. This was the second highest number of flight cycles in the worldwide 737 fleet.

A sister ship, also owned by Aloha Airlines, had accumulated over 90,000 cycles, which was the highest for any 737 at the time. That aircraft was in the Aloha hangar for maintenance at the time of the accident.

As I mentioned before, this accident has spawned many questions concerning aging aircraft, not only the 737, but all categories of the so-called senior aircraft fleet. It has also focused attention on the individual responsibilities of the FAA, the manufacturer and the airlines in maintaining the safety and integrity of the system.

By that I mean the manufacturer's responsibility in the design, production and tracking of their aircraft, the FAA in their role of certification and surveillance, and the operator's responsibilities in their compliance with the prescribed and approved maintenance practices.

These responsibilities, when properly applied, should overlap and tie together to form a buffer or a margin of safety to preclude an accident like this. These joint responsibilities form the premise on which safety of our system is based.

Notwithstanding the facts of this accident, it's my contention that the system almost worked and I say it for these reasons. Very early on in

the service history of the 737, the manufacturer issued several service bulletins pertaining to disbonding corrosion and fatigue cracking around the fuselage lap joint.

The fuselage is divided into sections, with sections 41, 43 and 46 comprising the majority of the pressure vessel. (See Figure 1) These sections, along with section 48, are butt joined together at circumferential frames to form the entire fuselage. Section 43 forms the forward cabin area, which was the area of the missing upper section.

The sections are constructed of circumferential frames and longitudinal stringers that are covered by formed skins which are rivetted to the underlying structure of the stringers. (See Figure 2)

Each skin panel in the upper lobe of section 43 is the length of the entire section, which is 18 feet long. I think it is interesting how these panels are constructed. Two sheets of .036 inch aluminum are hot-bonded together. The tear straps are formed by an acid milling process which takes away one of the layers of skin in the prepared places, and leaves a waffle-like appearance with the tear straps spaced about ten inches apart. The panels are joined longitudinally by overlapping the edges of the individual panels and fastening them with rivets and a bonding process. One row of rivets secures the lap joint to the underlying stringer which in turn is attached to the frames by riveted clips.

Through aircraft line number 291, single thickness sheets at the lap joints are joined together with a cold bonding process. The three-inch overlap or lap joint area was single thickness sheets for the two panels being joined. The single thickness areas for the lap joint were also formed by the acid etch process. (See Figure 3)

The cold-bonding process used an epoxy-impregnated glass cloth, which was about the width of the joint, to join together these longitudinal edges of the skin panels. Then, the bonded joint was fastened together with three longitudinal rows of countersunk rivets, the middle row of which attached the skin to the stringer. This formed the lap joint. This bond — this cold bond — cured at room temperature after assembly.

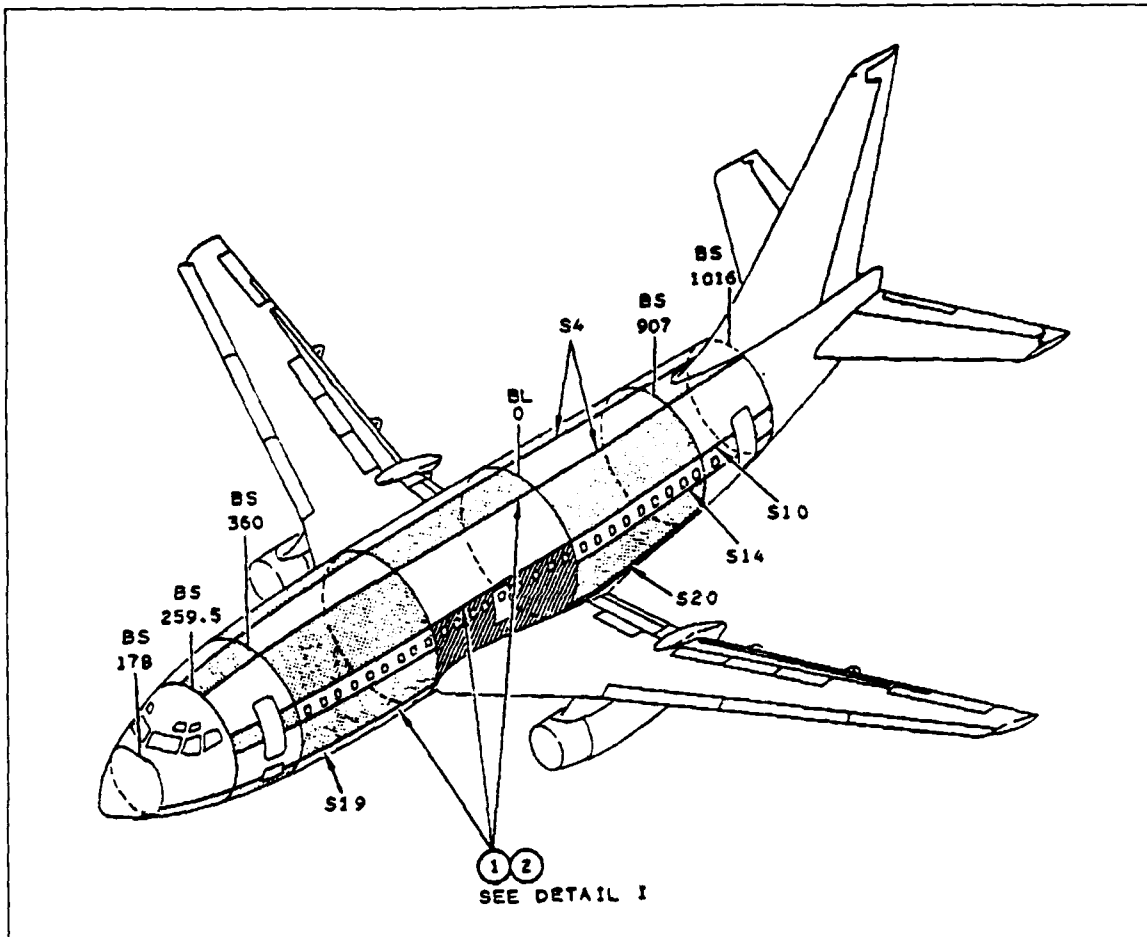


Figure 1 — Lap Joint Inspection
(See Figure 2 for Detail 1; Figure 3 for Detail 2)

After aircraft number 291, Boeing discontinued the cold-bonding process and used a smooth close-fitting surface-sealed lap joint with increased joint thickness. The overlapping piece of skin was retained at the double thickness and attached to a single thickness underneath. This redesigned joint became necessary as problems of delamination of the cold-bonded joint were encountered.

The first service bulletin which concerned the lap joint delamination corrosion repair was issued in 1972. Boeing revised this service bulletin three times, elevating it to alert status with the third revision on August 20, 1987. This upgraded state followed several reports from operators of fatigue cracking along the fastener

locations of the fuselage lap joints. An inspection and repair procedure was included in the service bulletin.

Following the third revision of the service bulletin by Boeing, and in view of confirming reports of multiple site fatigue cracking along upper row fasteners, the FAA acted by issuing an airworthiness directive in October 1987, which required a visual inspection of the fasteners along the number 4 stringer — 4 left and right — from fuselage station 360 to 1016 on all 737s with 30,000 or more cycles.

It specified that any cracks detected would have to be repaired in accordance with the instructions contained therein and it also specified that if any cracks were found on the visual

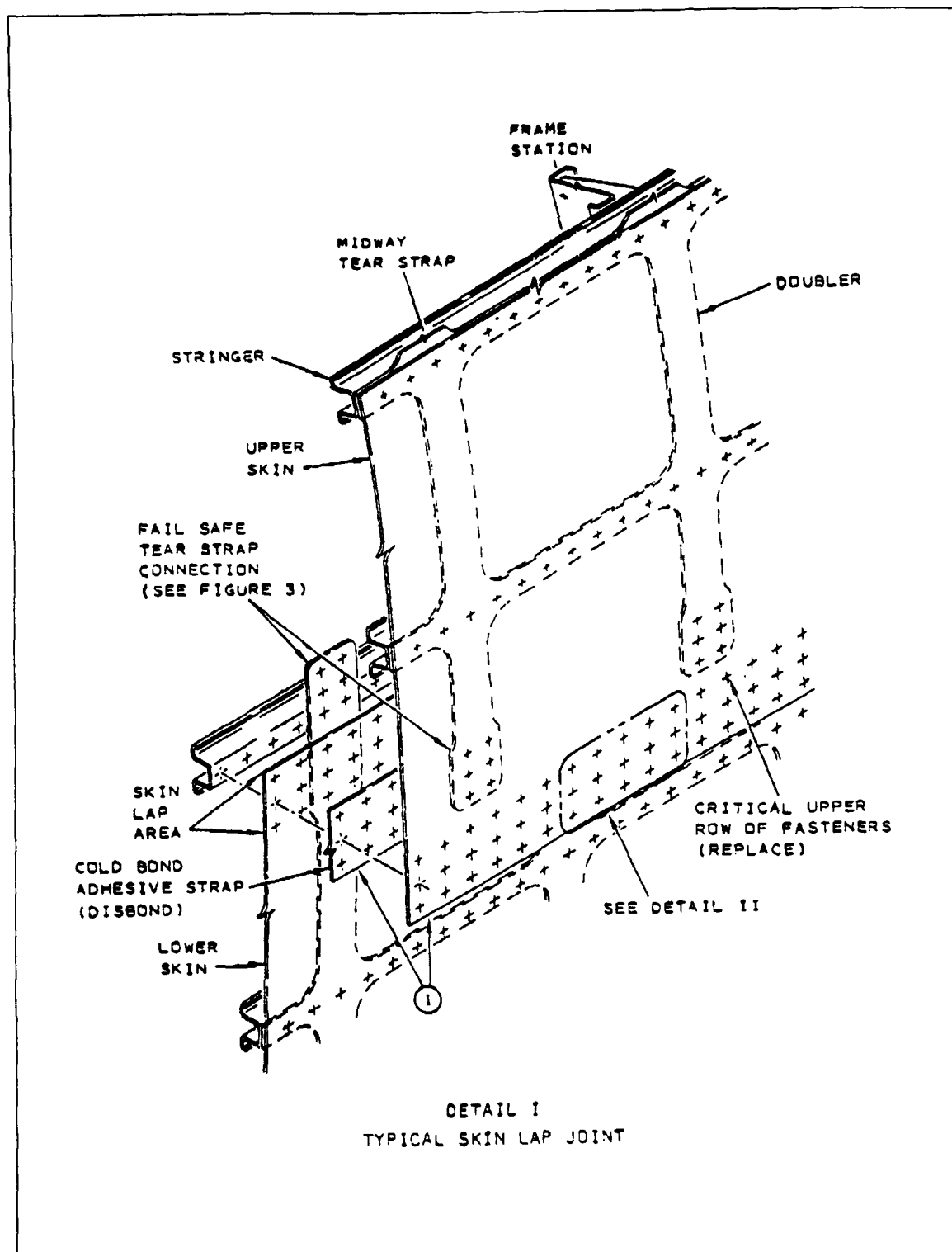


Figure 2 — Lap Joint Inspection (Detail 1, Typical Skin Lap Joint)

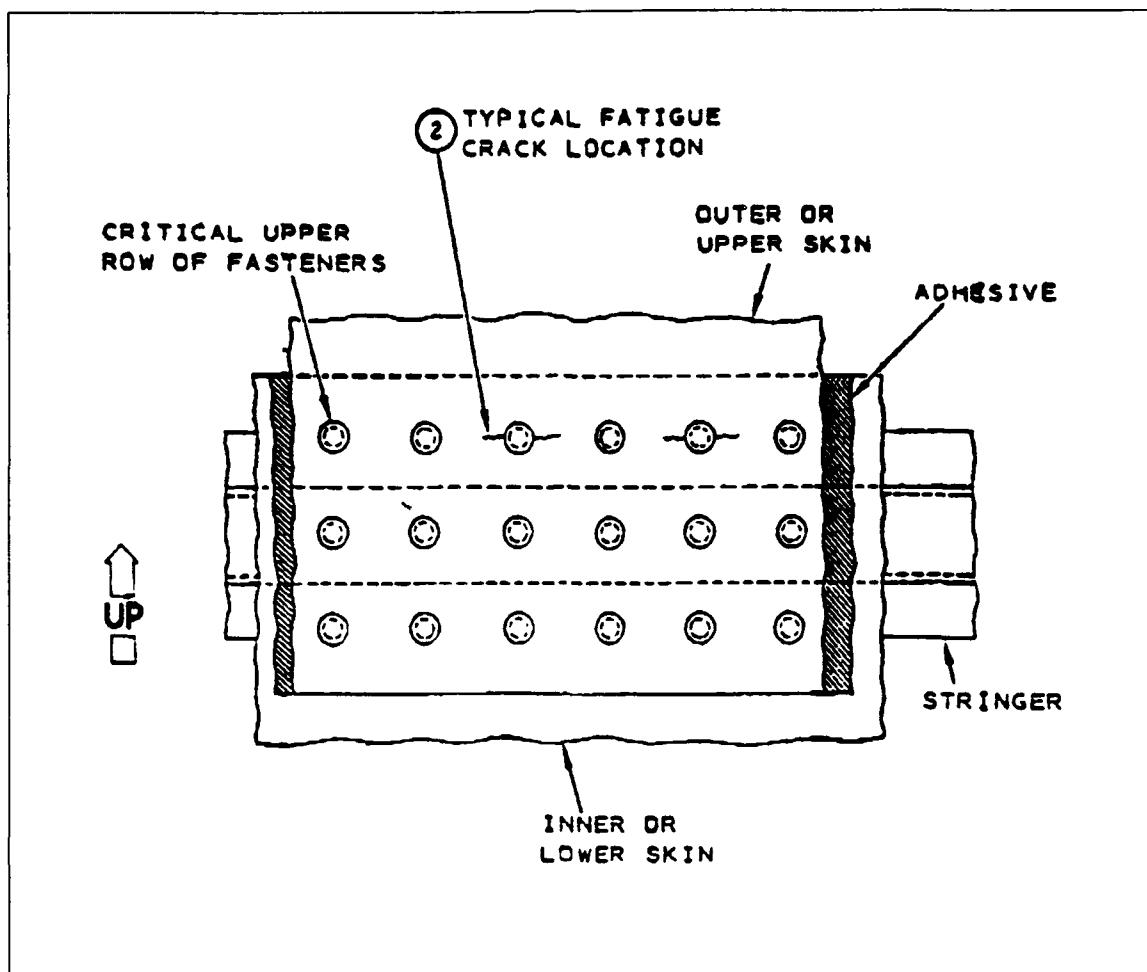


Figure 3 — Lap Joint Inspection (Detail 2)

inspection, an eddy current inspection would be required along the entire length of that stringer.

In accordance with the requirements of the AD issued by the FAA in November 1, 1987, Aloha inspected its entire 737 fleet, and on the visual examination of the accident airplane at least two areas of corrosion were found along the number 4 stringer. These areas were properly repaired and, according to Aloha, the eddy current inspection along the entire stringer, as required by the AD, was also performed. According to the maintenance records, no other defects were found.

However, after the accident the airplane was inspected by NTSB and many other areas

of detectable multi-site cracking were found along the number 4 stringer as well as in many other areas along the fuselage lap joints.

In the fall of 1987, prior to the FAA's issuance of the AD, the manufacturer, as part of its aging fleet research program, had sent a team of engineers to Aloha to collect data and to look at some of these high-time 737s. Although this accident airplane was one of the four Aloha 737s with over 65,000 cycles, it was not one of the airplanes examined during this visit.

In the general discussions with Aloha following the team inspection, and in its report delivered to the operator on April 14, 1988, which was two weeks before the accident, the Boeing team did express concern about the

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condition of the higher-time airplanes as well as about the adequacy of the maintenance program to cope with the existing corrosion problems in the corrosive environment that Aloha operates in.

So, in theory the system was working. All of the responsible parties were attuned to the lap joint problem and had in fact taken some form of action to correct this deficiency. These actions were not sufficient and in this case the system failed and an accident occurred.

The obvious questions are how and why the system broke down and what are we doing about it. Congressman Oberstar said it best at the June 1988 aging aircraft conference. He said then that what concerns us all is not that there isn't a tracking system for aging aircraft. There is. It's not that the system wasn't used because it was. What concerns us is that most of the right steps were taken but the system still failed.

Boeing should have issued a service bulletin to inspect cracks along the number 4 and 10 stringers, and they did. The FAA should have issued an AD requiring an inspection of the stringer on number 4 lap joints, and they did about six months before the accident. Aloha should have acted on these warnings, and they did, but they didn't find the problem.

A number of other people, including Congressman Oberstar and NTSB members, also asked these questions. Were the service bulletins issued by Boeing explicit enough or early enough. The Board said no, that Boeing should have issued an alert service bulletin in 1984 after the first evidence of cracking along these stringers were found. The regular service bulletin was issued and upgraded to alert status in 1987.

Was the airworthiness directive issued by the FAA as complete, comprehensive or timely as it should have been? The Board said no, the FAA should have mandated the inspection of all lap joints instead of limiting inspections to the number 4 lap joints.

Were Aloha's inspection personnel sufficiently trained for the task? Were they skilled and experienced enough to recognize the problem when they encountered it? Was the inspection as vigorous and meticulous as it should

have been to discover cracks? The Board said no to all these questions. A proper eddy current inspection should have detected those cracks that were found along the number 4 lap joint after the accident. They indicated that either an eddy current inspection was not conducted or, if it was, it was ineffective.

Was the FAA's surveillance of Aloha's maintenance program adequate? The Board said no, the FAA failed to evaluate properly the Aloha maintenance program and to assure that the airline's inspection and quality control deficiencies were corrected.

As I said before, this accident precipitated a lot of questions. Many of them were raised at the last conference and are still under consideration here today.

Do the current certification criteria and maintenance practices adequately account for the present use of high-time, high-cycle airplanes?

Is aviation technology adequate to detect early signs of impending failures of aircraft structure or do we need more advanced detection technology?

Are the corrosion control techniques used today adequate for high-time airplanes?

Are the human factors and realities of repetitive, visual and NDI inspections properly accounted for in the design and expectations of inspections programs?

Is there a limit to the lifespan of an airplane? And, if so, shouldn't it be taken out of service before it reaches that threshold?

I know that a good many actions have already been completed and many more are actively underway as a result of your efforts. With regard to the Boeing 737, as you know, the FAA last year issued an AD that required the replacement of all upper row rivets for aircraft 291 and below, depending on the number of cycles. That equates to about 7,200 rivets per airplane and about \$800,000 in expenses. So, it's a big job.

Also, the FAA issued some NPRMs, one of which is applicable to the 737, which will require mandatory structural modifications to those aircraft when they reach their economical design goal. As I understand the meaning of that, it's the point in service where the maintenance costs necessary to assure continued

William R. Hendricks

operational safety of an airplane would be expected to increase significantly due to age-related factors. Perhaps differently interpreted, it is the point where it becomes economically unfeasible to operate these airplanes.

For the Boeing 737 that goal was set for 75,000 cycles or 20 years. Considering the original cost of a 737 which was about \$6 million, and the cost of a new 737 today, which is at least \$30 million, I would think that that economic design goal will be pushed out even further.

The requirements of the new NPRMs represent a significant change in the philosophy regarding the maintenance and safety of aging airplanes in that it sets a life limit on individual parts considered to be critical structure. This differs from the long-standing philosophy and practice of repetitive inspections and appropriate repairs to assure safety throughout the lifetime of that airplane.

I think these actions are a positive step in the right direction and we all look forward to more recommendations from the participants of this conference which will address the continuing aging aircraft problems.

Although in the Aloha case, we did have an accident, and indeed an example of how the system didn't quite work, I would like to conclude on a positive note by saying that I believe

this is an isolated exception to the proven record of safety by all of our transport aircraft. I base this conclusion on the thousands of air carrier hours that are successfully flown each day all over the world.

All one has to do is go to one of the major airports and look at the scope and the tempo of the operations and the complexity of the technology involved to realize how extraordinarily safe our system is.

The magnitude of this accomplishment is not only a tribute to the improved technology, but also to the constant attention to safety that is deeply imbued in this industry and by the organizations that comprise our system. However, any failure, no matter how small or insignificant, must be recognized and corrected before an accident occurs.

Thus, while we did have a breakdown in the system in this case, we now have a tremendous effort underway to look at these deficiencies and make whatever corrections are necessary. This, after all, is the purpose of this conference, to effect corrective action so that we don't have another similar accident.

I think it's a great benefit to aviation to have the experts in this field meet together to resolve these most challenging issues, and we all look forward to the results of your discussions.

Session III: Corrosion



CHAIRMAN JOHN J. DE LUCCIA

Manager, Aerospace Materials Division
Naval Air Development Center

This is the second international conference on the topic of aircraft aging, but since the first international conference did not have corrosion as a specific session, this will be the first time we're addressing this topic in regard to aircraft aging.

Our laboratory is concerned about Naval aviation materials and specifically about their protection. We have the most severe natural environment known to man, one in which we routinely fly our airplanes.

The fact is that some mechanical failures have their origin in corrosion and its electrochemistry so we want to look at that aspect in great detail.

I also want to bring out now the fact that we have been flying some Navy airplanes — for example, the A-3 — for upwards of 35 years. Bear in mind that we fly in the world's worst environment and we have been able to do this with the same airplane for 35 years.

You might say then, that the answers are all there. Yes, the answers are there. We do know

how to protect airplanes and we do know how to treat corrosion. However, you have to realize that in order to maintain our airplanes, we expend a lot of manhours and we in the military are not concerned with profit. We're concerned with mission. Thus, for our F-14 airplanes it takes, and we give, about 10 maintenance manhours per flight hour specifically devoted to corrosion. So, it takes a very labor-intensive effort to make sure that those planes are properly maintained.

Figure 1 shows the triad relationship we discussed before. How could we, the Navy, fit into the triad?

The FAA, asked us to share some of our products, procedures, techniques and knowledge with them with regard to corrosion. So, our little bubble at the upper right-hand portion of the triad is essentially us giving the information to the FAA.

Before we go on to the formal topic, I again want to say a few words about the topic of aging and corrosion. It's important to look at

AGING AIRCRAFT PROGRAM CORROSION CONTROL & PREVENTION

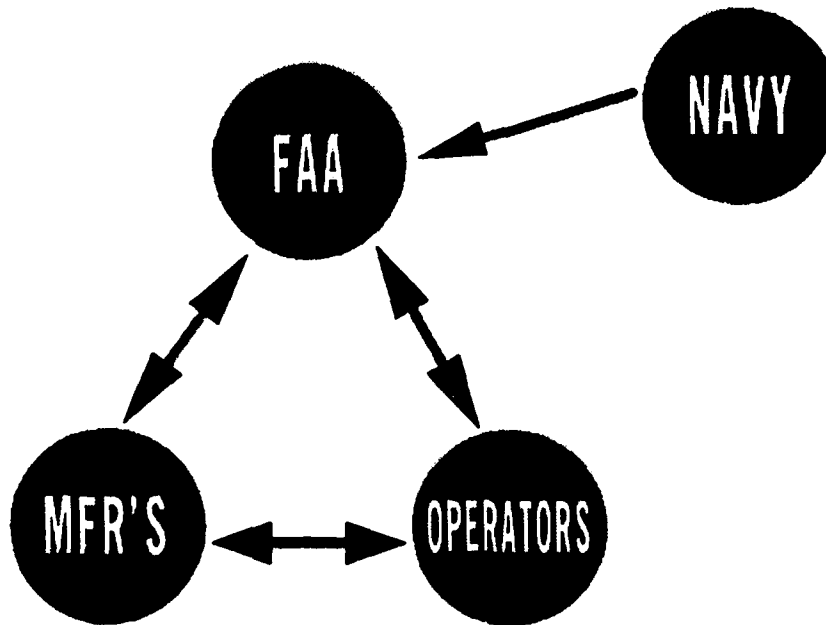


Figure 1

that word "aging." The word aging, implies time. We find that the phenomena of time has different effects as you look at corrosion.

The left-hand portion of Figure 2 is the time-dependent phenomena that we see on airplanes. The corrosion that we see on airplanes that is time-dependent — general attack, pitting, exfoliation, crevice corrosion and filiform corrosion — all take time. What do they do? They give us slow failure.

There are other phenomena that are time independent. Those phenomena are, stress corrosion cracking and environmental embrittlement. These things happen without warning. These are catastrophic.

In the middle of the figure we have time-related corrosion phenomena, and primary

among them is corrosion fatigue and intergranular corrosion. Corrosion fatigue is a topic of extreme importance and of extreme interest.

People very frequently talk about fatigue, fatigue life, endurance limits and design loads and so forth and they're not taking into consideration the environment. I was gratified to hear Clyde Kizer make the statement that you throw everything away when you have corrosion with regard to fatigue because when you have corrosion you don't have an endurance limit, you don't have a design stress that you measured in the laboratory under dry conditions.

Our speakers will talk about these topics and hopefully we'll all go away smarter so that we can preclude some catastrophic and long- and short-term failures on our aircraft.

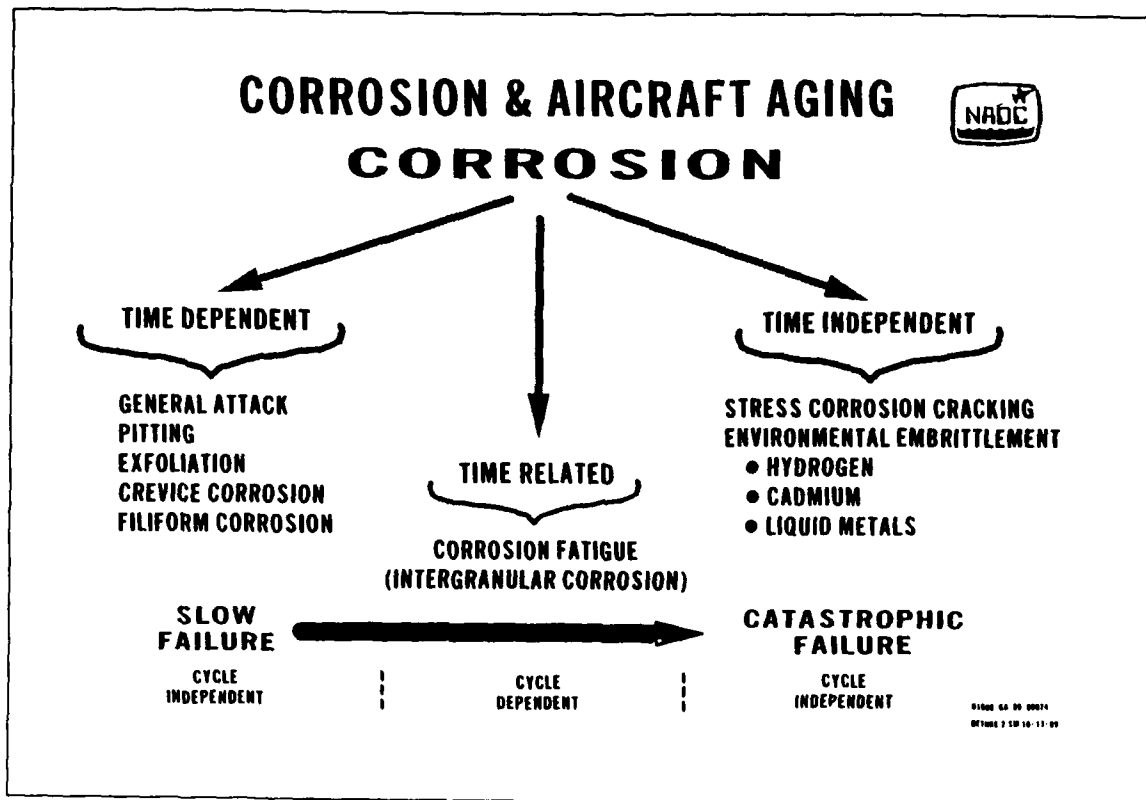
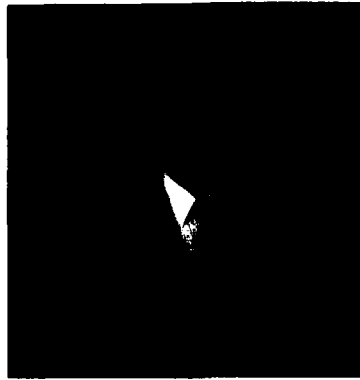


Figure 2

Corrosion



J. A. MARCEAU

Principal Engineer
Boeing Commercial Airplanes

I would like to thank you for inviting me to this conference. It's a pleasure to stand here and talk to this group of people involved in the aircraft industry.

I've spent a fair amount of time in recent years with the aging fleet problems. What I want to share with you today are some of the highlights of what I've seen as a manufacturer over the years as a result of the aging fleet survey that Boeing conducted in the last two or three years. I'm going to talk about the basic corrosion control practices that we have been using on aircraft over the last 20 years. When I'm finished you will have an understanding of what we've done in the past and what we're doing today.

Normal signs of age are usually wear and fatigue. These are somewhat predictable and can be accounted for by the airline maintenance program to preclude major structural problems. But corrosion is a very insidious problem. The only thing you can be sure about with corrosion is that you're going to have it. But you cannot predict how severe it's going to be.

Boeing conducted the aging fleet survey

and there were a number of survey findings that came out of the investigation. The most significant was corrosion. It varied significantly between operators and within an operator's fleet.

Airplanes that were in corrosion prevention programs from the very beginning of service had very few corrosion problems as they aged. Repairs may be required more frequently if the corrosion program was implemented later in the life of the aircraft — then the operator could expect to continue to have corrosion but at a lower level than if they did not do anything.

In a few cases corrosion had progressed to the point where extensive repairs were required. Also, we found that washing, if done properly, removes corrosion-inhibiting compounds that then have to be replaced.

There are a number of causes of corrosion and these start right from the very beginning of airplane design. (See Figure 1) For example, you could design good drainage into the airplane, which will help, or you could not, which can create problems in the life of the aircraft.

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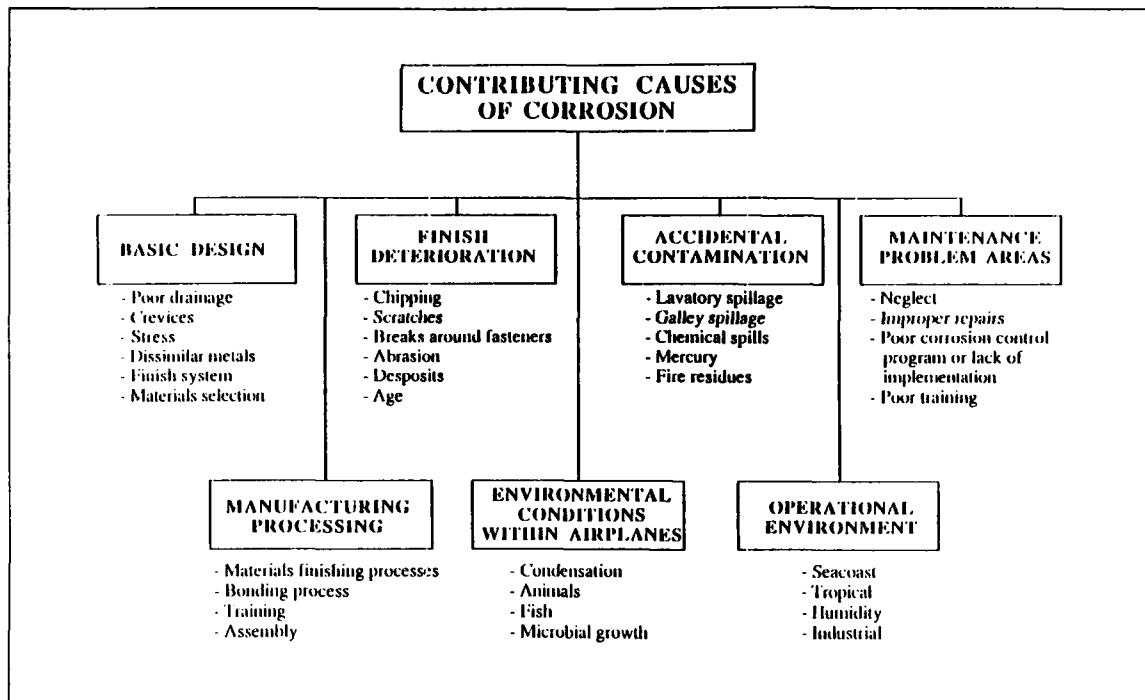


Figure 1

Stress corrosion cracking problems result from the use of materials that are stress-corrosion sensitive.

Next you have the manufacturing processing situation. What's on the design drawing has to be done in manufacturing, but if there are any manufacturing deficiencies, they can also affect corrosion. Additionally, you have material finishing processes that are very, very critical. Once the aircraft is delivered, it's in the hands of the operators and there are a number of factors that influence corrosion. You can have finish deterioration, chipping, scratching, breaks in the paint, abrasion, or deposits. Just general age of the finish can enter into the problem. You also have environmental conditions within the airplane.

For corrosion to occur, there is one element that you need, and that's water. However, water cannot be eliminated from the airplane since there is always condensation.

Condensation provides the carrier for the electrolyte that's going to cause corrosion. That can be compounded if the airline carries animals. There is a lot of water given off by ani-

mals and a tremendous amount of condensation. A lot of air carriers carry seafood in the cargo holds. These containers leak quite often and the essential ingredient for severe corrosion, plain common salt, is there. That can be a big problem. You can also have microbial effects, particularly in fuel tanks. The fuel can support microbes and the byproducts create corrosion.

Then you have accidental contamination such as lavatory spillage and galley spillage. These provide good electrolytes for corrosion.

I'd like to share an incident that I observed back in the late 1970s. We had delivered a brand new 727 to an operator. It was only a few months old and was down in Miami when it had a fire on board while sitting on the runway. It burned through the crown of the 43 section.

The plane was ferried back to Seattle and it was repaired. I looked at the structure several weeks after the fire and the smoke residue that had condensed on the stringers, frames and throughout the entire fuselage was already causing corrosion.

We had to wash it out, spray it down with

a neutralizer, and then we sprayed it with a corrosion inhibiting compound. Even with a small fire, the smoke residue can be very, very harmful.

Last but not least, is the maintenance area. How the operator conducts his maintenance program, how he trains his people, and his awareness of corrosion problems plays a tremendous role in how badly corrosion will occur.

In the aging fleet survey we found that the most significant factor in the corrosion problem of airplanes was the operator's maintenance program. His corrosion control program and how well he carried it out, not the geographic location or the flight profiles or whether or not there are sea coast or industrial environments involved was the most significant factor.

I'd like to touch briefly on various types of corrosion. Perhaps the most common form of corrosion in an airplane is just simple crevice corrosion where water and the electrolyte get in between two parts.

Perhaps one of the most serious forms of corrosion is intergranular corrosion (exfoliation), where a lot of the structure is rendered useless with minimal amounts of consumption of the metal itself. Most of this corrosion takes place in the grain boundaries, in the grain structure itself. The grain itself is not being corroded substantially.

Another very detrimental form of corrosion is stress corrosion cracking. You can't always see the crack, but it's there. When you have stress corrosion cracking, there is very little consumption of metal involved but the structure itself is rendered almost useless because of the loss of structural integrity.

Pitting corrosion can create fatigue cracks or stress risers which result in fatigue cracks. You can have that in the bore of a hole or perhaps even on the skin where you have enough pits occurring that could result in fatigue cracking.

Another initiator of corrosion is dissimilar metals, such as having an aluminum nickel bronze bushing in an aluminum housing.

There are other forms of corrosion that aren't as destructive such as general corrosion, filiform corrosion and so forth.

As a result of our general experience with corrosion reports and the aging fleet survey, we have a number of areas of concern where we have most of the corrosion problems, and rather severe problems at times.

Areas of concern include the galley, under the lavatory, at pressure bulkheads, near entryways and cargo doors, in bilge areas, belly skins, stringers and lap splices.

When the lap splice delaminates, if the hot bond is a marginal bond, you can have delamination of the bond material in the chem mill pocket and that's a perfect site for crevice corrosion.

The lap is exposed to the exterior environment, which is a rather aggressive environment. There are industrial pollutants, salt and so forth in the environment that ingress through the lap splice, causing that particular area to be quite vulnerable on the 737.

Another problem area is in the wings. The spar buildup areas have a lot of crevices where water and electrolytes would get in and we had a lot of corrosion of spar cords, webs and wing skin planks against the spars and on the empennage.

The 747 has a very large sump area at the rear spar of the wing center section and we have a lot of drains incorporated there to remove the water. Now, if that area is not properly maintained and water sits in what we call the guppy pond, you can have rather severe corrosion in that area. Someone found a dead frog in a 747 in that area.

Another common corrosion area is pin joints where bushings are pressed in a bore of a hole. Water gets in around the bushings if they are too loose and not sealed properly and you get corrosion inside those bores. That's pretty common whether it's aluminum or steel.

Over the years we've learned a lot about what causes corrosion and we've done a lot over the years to improve the corrosion-prone areas of our airplanes.

The basic design philosophy today is quite a bit different than 20 years ago, from the corrosion standpoint. Some of the significant changes deal with materials selection. (See Figure 2) The two materials on an airplane that are

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- Materials selection
- Effective drainage
- Finish **system** selection
System = Surface treatment process
+ primer/enamel
- Elimination of crevices by faying
surface sealing
- Use of corrosion inhibiting compound

**Figure 2 — Design Philosophy
Significant Factors**

really prone to corrosion are aluminum and steel. I'm concentrating mainly on aluminum because that comprises about 80 percent of the aircraft structure, although steel has basically the same problem.

If you build an airplane that's not going to corrode, you probably couldn't fly it because it would either cost too much or it would be too heavy. But we make a lot of material compromises based on weight, cost, function, and reliability to build an efficient structure.

The significant factors beyond that become effective drainage, finish system selection, and elimination of crevices. The way we do it is this: we surface seal — and use corrosion-inhibiting compounds.

We have made corrosion improvements on the 737, and today we have a tremendous number of improvements on the current production 737s as well as 747s. The newly designed 767s and 757s have these improvements incorporated.

- Personnel training
- Continual use of corrosion inhibitors
- Planning for corrosion and factoring in the time to clean up corrosion early during "C" and HNV checks
- Accessibility to the structure

**Figure 3 — Preventive Maintenance
Significant Factors**

From the preventive maintenance end, what the airline has to do is have good personnel training, use corrosion-inhibitors on a continuous basis and plan for corrosion in their maintenance programs. Plan for it because it's going to exist. (See Figure 3)

Accessibility to structure is also very important, as is cleaning. However, if you do too much cleaning, you have to reapply inhibitors and regrease the structure, otherwise you run into problems.

In summary, corrosion of airplanes is a combined effect of materials selection, design details, processing, finishes, maintenance programs and the operational environment. (See Figure 4) The thing I want to stress here is that the airplanes we build today are totally different than the ones that are in the aging fleet today. Their corrosion performance should be tremendously better.

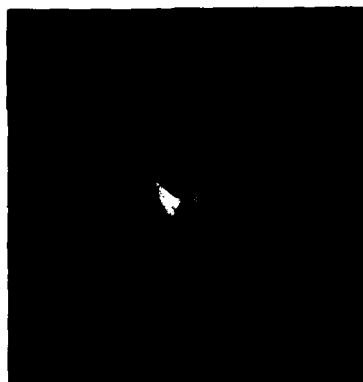
However, one must keep in mind that corrosion is still going to occur and you have to keep looking for it. You cannot slack off on your corrosion prevention programs until we build up a base, a history on these newer airplanes.

J. A. Marceau

- Corrosion of airplanes is the combined effect of:
 - Materials selection
 - Design
 - Detail processing/finishing
 - Maintenance programs
 - Operational environments
- Airplanes manufactured today will have fewer corrosion problems than those in the current aged fleet because of:
 - Significant design and corrosion protection improvement
 - Operators increased awareness of their role in preventive maintenance
- Maintenance and corrosion control programs will still play a major role in the control of corrosion as airplanes age
- Most significant factors in controlling corrosion:
 - Drainage
 - Sealing faying surfaces in corrosion prone areas
 - Finish system
 - Liberal use of corrosion preventive compounds
 - A good corrosion control maintenance program

Figure 4 — Summary

Corrosion Control



CHARLES HEGEDUS

Team Leader, Organic Coatings, Aerospace Materials Division
Naval Air Development Center

Figure 1 indicates the relative corrosivity of several environments. We show an industrial location and a couple of sea coast locations. The aircraft carrier is two or three times more corrosive an environment than these other areas, indicating that this is truly one of the most corrosive natural environments known to man.

One example of a severe location is the Indian Ocean (see Figure 2). Through the months of May and August there are continuous overcast skies, high winds and temperatures ranging from 80 to 90 degrees Fahrenheit. Relative humidity is 80 percent or higher during the day and close to 100 percent at night. There is a continuous mist of salt particulates in the air.

What I'm showing here is that the Navy performs in an inherently corrosive environment. Dr. DeLuccia's depiction of corrosion damage illustrates that corrosion is a thermodynamically and kinetically preferred process, which means that corrosion prevention and control need to be a continuous process.

My objective today is to describe how the Navy approaches its efforts in preventing cor-

rosion and to try and illustrate how that technology could be transferred to the commercial arena.

Obviously, the first place to start is with design. When the Navy is going to build aircraft it builds design requirements into the contract. We specify design documents and guidelines. We very heavily depend on design evaluations and reviews where we go out and observe how they're building aircraft or aircraft components. Some documents address what the Navy is looking for in corrosion prevention and control.

There are three levels of maintenance within the Navy. The first is the organizational level. This is the squadron, the people who are actually hands-on, day-to-day, every hour. Essentially they are performing maintenance for equipment that is still on the aircraft. When they spot some corrosion, they try to remove it to some extent and apply corrosion-preventive compound. It's a very quick but effective means of a continuous day-to-day type of maintenance.

If there is a major piece of equipment that's

Charles Hegedus

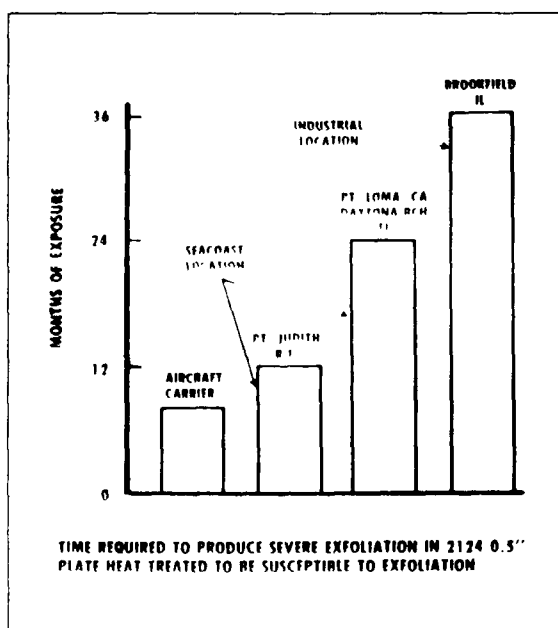


Figure 1 — Corrosivity Simulation of Aircraft Environment

damaged, or something that needs to be replaced or repaired, it can be taken off the plane. The part goes to an intermediate maintenance activity. The extent of the repair effort is at a much higher degree and level of sophistication.

Finally, there is the depot level. This is where the entire aircraft is brought into a depot and is put through a major overhaul. Navy aircraft are, in many cases, originally designed to go for a depot overhaul approximately every four years.

We have a good handle on what is causing corrosion and the fleet is doing a good job on a day-to-day basis. Because of this, depot intervals have been increased to five, six, and possibly seven years. When an aircraft's depot cycle is due, engineers from the depot go out and inspect the aircraft, and if they feel it can go for another year without any problems, they extend the depot cycle a year. That will continue until the plane essentially needs to be rebuilt.

To emphasize the importance that the Navy puts on corrosion control, let's listen to this policy statement. "Each command shall place special emphasis on the importance of the corrosion control program and lend its full

The continuous southwest monsoon during the months of May through August produces extremely high humidity and low ceilings. The weather during this period is unchanging.

Overcast — 1000 to 1500 feet

Winds — Southwest at 10-20 knots

Temperature — 80-90° F

R.H. — 70-89% Day
95-100% Night

Continuous salt/particulate mist in the air up to 3000 feet

Figure 2 — Environmental Conditions in Indian Ocean

support to ensure that corrosion prevention/control receives a priority for timely accomplishment." Greater than 90 percent of the sailors who work in the aviation branch of the Navy receive some form of corrosion control training. It doesn't matter what their job is; they receive corrosion control training. That is Navy policy. To state it briefly, corrosion is everybody's business in the Navy.

Corrosion documentation forms are used by the organizational and intermediate level people to keep very fine records of when and where they work on an aircraft. They document exactly what is done to the aircraft. This gives engineers a good handle on what is occurring, which might indicate why it is occurring, and eventually how it can be stopped. There is now a huge data base on this type of information.

There are 89 intermediate maintenance activities. Most of these are on shore, but there is an IMA on each aircraft carrier. 127,000 repairable items are processed per month; 94,000 are ready for issue, and 64,000 are repaired per month. But the Navy still has its corrosion problems. It's a continuing battle.

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Figure 3 shows our newest aircraft, an F/A-18, which obviously doesn't relate to a commuter aircraft, but it illustrates that even though we have a good handle on what is going on, we still have problems.

One area that I'd like to point out is the dorsal longeron where there is extensive pitting. It's really amazing. This corrosion probably starts soon after the aircraft is built, to tell you the truth. Essentially, this area consists of aluminum and some graphite epoxy composite. There is also some copper and silver. You see the disadvantages. I guess one of the advantages is that it probably could act as a second battery, if the aircraft ever needed it.

There have been about four fixes to this so far, and we always end up with a corrosion problem. There must be other reasons why it keeps occurring. But this is an example of something that could really have been prevented during design, and now the sailors have to deal with it on a day-to-day basis.

There are obviously quite a number of corrosion-prone areas on this P-3 aircraft. (See Figure 4)

I'll mention a little story about one of the areas. It's an antenna, which is located on the underbelly of the aircraft. The antenna door has some bonding strips which are copper, and they attach to aluminum. Obviously, there's a corrosion problem there. That really was the obvious problem. As it turns out, right above the door there is a battery which has a tendency to leak onto the antenna.

It's hard to understand how people design things like this, but it happens.

As Dr. DeLuccia mentioned, we are in the Aerospace Materials Division at the Naval Air Development Center, and what I'd like to do is describe how we help the Navy in addressing its corrosion problem.

We provide the research and development and fleet support to assist everything from design to what goes on on a daily basis. I guess it's in my job description to say that we are the best in the world at what we do. That sounds like boasting, but in a sense it's true, because we're forced to be. If you think about it, no airline or no other "air force," performs or operates in an environment anywhere close to

what we operate in on a continuous basis. In the Navy we address this issue from a full-spectrum approach of fundamental research and development, design and procurement, and maintenance activities.

In our laboratory, we simulate, to some extent, the aircraft carrier environment. We have a fairly extensive program where we mount exposure racks onto aircraft. This allows us to expose specimens and study how they corrode; the mechanisms and the time to failure; et cetera. We also try and simulate that in the lab.

One particular chamber we use is a salt spray/SO₂ chamber that we quite frequently use in investigating corrosion phenomena. Of course, we also do a battery of electrochemical and other types of exposure studies.

Figure 5 is a schematic of a stress corrosion cracking experiment. Obviously, if you have a crack, there is always a possibility of stress corrosion cracking. It is possible to analyze this situation, and this is what we're doing, evaluating this phenomenon from a fracture mechanics standpoint. Our objective is to develop inhibitors to prolong or stop initiation or prolong propagation of any stress corrosion cracking.

Another phenomenon that is receiving a lot of attention at this conference is fatigue. The upper curve of Figure 6 is a fatigue graph (stress versus number of cycles) for a specimen that is exposed in "normal" air. Note that most materials have an endurance limit. This endurance limit tells the design engineer that he can design to that endurance limit and feel fairly secure that the part won't fail.

Unfortunately, when you expose that same material to a corrosive environment, the fatigue curve drops down. This figure says two things: One, not only does the number of stress-to-cycles curve drop dramatically, but it also says that there is no "design limit." So no matter what you do, you can't design the fatigue failure out of the system, unless you maintain and consider this on a daily basis.

One approach we are working on is to develop instrumentation to test for the presence of hydrogen in high-strength materials. What we're worried about is hydrogen embrittlement.

F/A-18 AIRCRAFT CORROSION

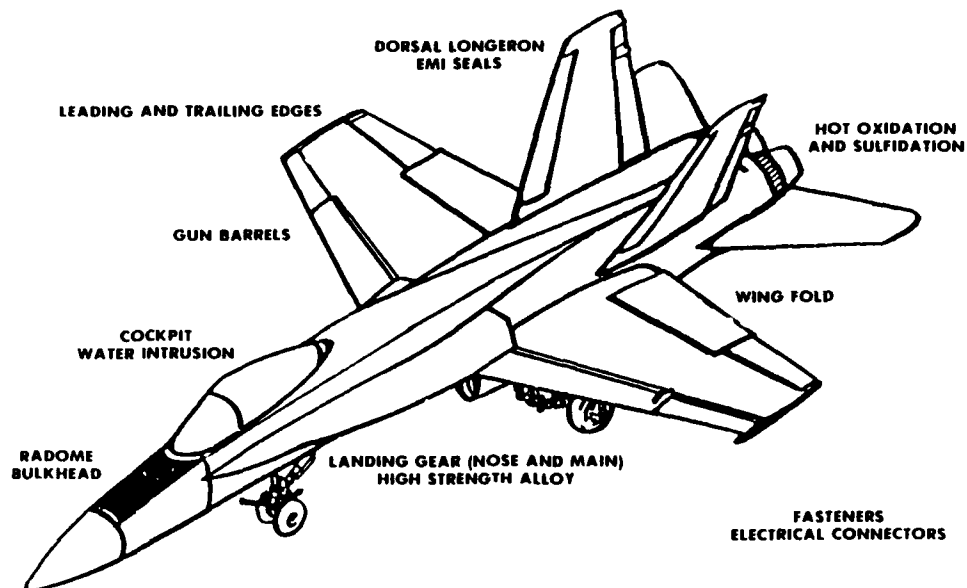


Figure 3

P-3 AIRCRAFT CORROSION

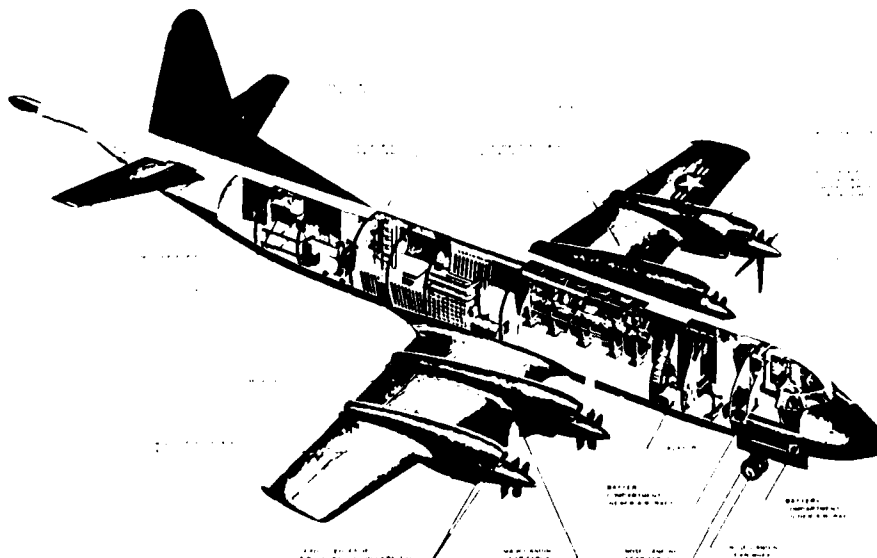


Figure 4

STRESS CORROSION CRACKING

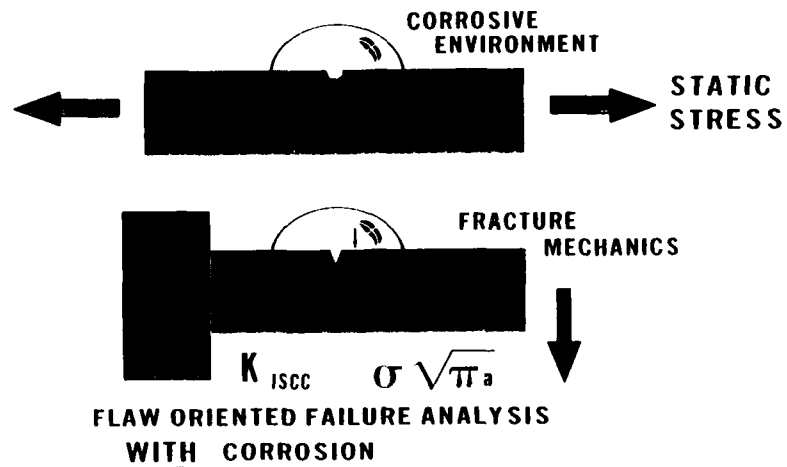


Figure 5

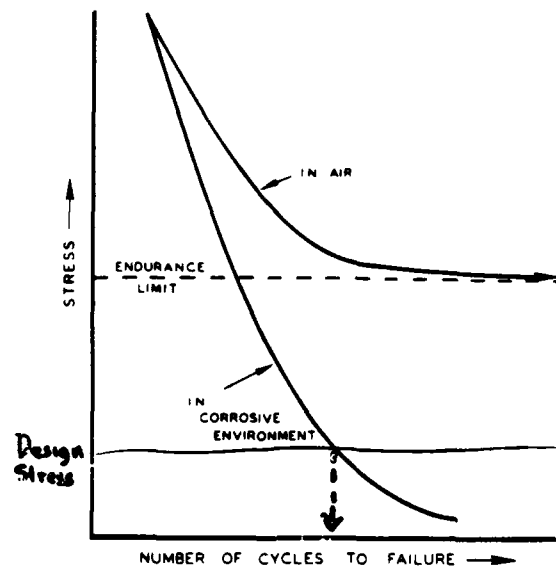


Figure 6

Charles Hegedus

This instrumentation is not being used on a continuous basis, but we have several prototypes and we're checking them out in the fleet.

Figure 7 addresses some of the materials that we're working on. We have developed a mixture or a cocktail, if you will, of inhibitor materials. We call it DNBM; that's short for a number of inhibiting compounds we mix together. When they're together they address a number of corrosion mechanisms, and there are probably some synergistic effects when they're mixed.

The figure shows that the treatment with DNBM on a continuous basis shifts the crack velocity versus K_{ISCC} (stress corrosion cracking) over to the right fairly dramatically.

On the other graph, we have corrosion fatigue, and again, we see a shift in the curve when DNBM is applied on a continuous basis.

I guess I should mention that this particular inhibitor mixture, is still in the research phase. It has been developed, but now we are trying to apply it by putting it into corrosion preventive compounds, paints, greases, lubricating fluids, et cetera.

Corrosion preventive materials such as AML-350, AMLGUARD, and WDP are some of the materials that are used in the fleet on a daily basis. Essentially, they are corrosion preventive compounds that displace water. They are designed to be touch-up materials. And of course, when you're taking care of an aircraft on an aircraft carrier, even on a nice day there's a lot of humidity, there's a lot of condensation. Even if you prepare the surface before applying a paint or a corrosion preventive compound, there's still a good possibility that there's some water left on the surface.

So these materials were designed specifically to address some surface chemistry issues. When you apply the material, if there happens to be water on the surface that's being coated, the compound will displace the water and form a barrier between the environment and the substrate. This type material ranges from soft, greasy-like materials, to actual paints, and they are being used on a continuous basis out in the field.

We recently developed what we call a self-priming top coat. Our name for it is "Unicoat."

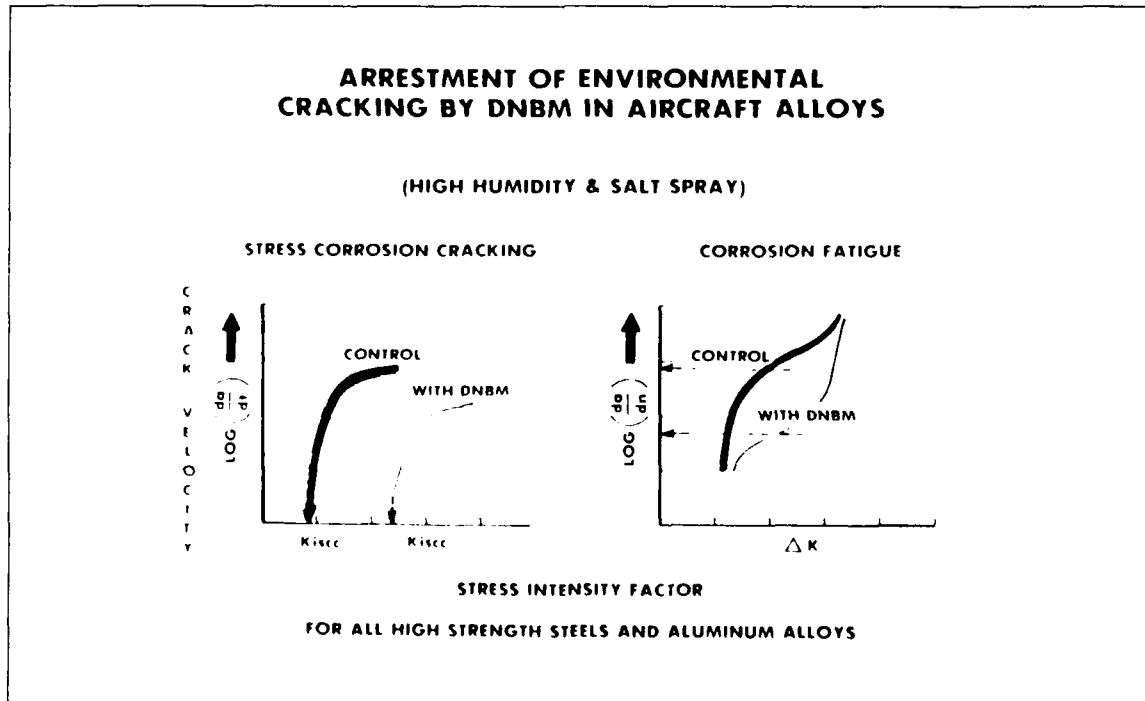


Figure 7

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Normally, when aircraft are painted (commercial aircraft or military aircraft) a corrosion-preventive primer is applied first. It's an epoxy material with some corrosion inhibitors and then a polyurethane top coat is applied. The primer is there to promote adhesion and enhance the corrosion inhibition properties of the paint system. The top coat is primarily there for aesthetics, but also for chemical resistance and weather resistance.

Unicoat was designed to replace those two coatings with just one coat. It contains some corrosion inhibitors, but it also can be tailored to a number of different colors. And it has obvious implications as far as weight savings, application, manpower, time and material savings. Also, it contains no chromate materials, and has lower volatile emissions, which has huge environmental implications. This is an enormous issue in reworking aircraft these days.

This particular coating is not in a full-scale production phase yet. However, we have painted 11 aircraft, four of which were painted approximately two years ago. Some aircraft that have seen nine months of sea duty, look as good or better than those that used the standard paint system. So the Navy definitely sees the potential of saving a lot of money with this particular coating, without sacrificing corrosion inhibition properties.

Figure 8 is a list of manuals that we control. The manuals address a number of issues: aircraft cleaning and corrosion control, avionics cleaning and corrosion prevention, preservation of aircraft and ground support equipment. These manuals are used on a daily basis by the fleet. They also provide a direct and official means of transferring our technology from an R&D center to the person who is touching and working on the aircraft every single day.

This technology, the manuals, the materials and the specifications are available for transition. As a technologist, I feel that what I do just isn't worth it unless someone is actually using the technology, whether it's in the military or in the commercial area.

As far as naval aviation corrosion control is concerned, there are three major issues that need to be continuously addressed; and that is design, preventive and corrective actions on a continuous basis, and a continuous research and development program to address state-of-the-art issues. If a new alloy comes out, we need to address it. New inhibitors are being introduced every day that could be appropriate for paints and corrosion preventive compounds.

The technology that we are developing is definitely available for transition to the commercial community. (See Figure 9)

Contain technical information detailing corrosion prevention/control procedures and required corrective actions.

- I - NAVAIR 01-1A-509 - Aircraft cleaning and corrosion control
- II- NAVAIR 16-1-540 - Avionics cleaning corrosion/prevention control
- III - NAVAIR 15-01-500 - Preservation of naval aircraft
- IV - NAVAIR 15-02-5 - Preservation of aircraft engines
- V - NAVAIR 17-1-125 - Ground support equipment cleaning and corrosion control
- VI - NAVAIR maintenance publications peculiar to specific aircraft models and related equipment

Figure 8 — Technical Manuals

AGING AIRCRAFT PROGRAM



TRANSFER OF CORROSION TECHNOLOGY

FROM DOD (NAVY)  DOT (FAA)

TRANSFER OF:

- (1) KNOWLEDGE (CORROSION WORKSHOPS / COURSES)
- (2) PRODUCTS (COATINGS, CORROSION PREVENTIVES)
- (3) PROCEDURES (ADV. CIRC., MANUALS)
- (4) TECHNIQUES (LEVELS AND FREQ. OF MAINT.)

MAINT. INTERVALS AND PERFORMERS
UPDATE ADVISORY CIRC.; START MANUAL
AMLGUARD, UNICOAT ETC.
NAESU CORROSION COURSE ADAPTED FOR FAA INSPECTORS

} PAYOFFS

Figure 9

Corrosion Control



ROBERT DEROSA

Standards and Systems Division, United Airlines

Good afternoon. I've worked for United for 23 years, so we've had plenty of time to develop corrosion programs. We've had Boeing 727 airplanes from the start, and B-737s from the start.

United has a fleet of well over 400 airplanes. We operate throughout the United States, North America and the Far East. These airplanes vary in age from brand new — we're getting deliveries every week — to well over 25 years old. So consequently, the degree of corrosion protection incorporated into design of the airplane varies from virtually non-existent with some of the early airplanes, to fairly extensive on the later airplanes.

Because of this, our corrosion control programs are tailored to individual fleets, depending on age, prior experience, flight environment and degree of corrosion protection incorporated into the airplane prior to delivery.

In addition to maintaining all the protective finishes, we apply corrosion-preventive compounds, such as LPS-3 or Dynol, to all areas on periodic visits. Our periodic maintenance visits are established on the basis of maintaining the structural integrity of the

airframe by minimizing the amount of structural corrosion repairs required.

The optimum program would be one where the only repairs necessary would be restoration of protective finishes. This of course is not achievable. However, it is possible to maintain the integrity of the airframe indefinitely by an effective treatment and prevention program.

Treatment of corrosion depends primarily on the amount and severity of the corrosion found. In most cases, the corrosion is fairly localized and easily repaired. Where corrosion blend-out exceeds structural repair manual limits, localized repairs or replacement of parts is used to restore structural integrity.

The exception is adhesive bond corrosion, which I believe everybody here is well aware of. This type of corrosion is generally widespread and difficult to contain. In most cases, skin panel replacements and extensive skinlap repairs are the only effective method of repair.

When this occurs, we take advantage of the opportunity to upgrade the corrosion protection of the underlying structure. Stringers and frames are repaired or replaced as necessary,

Robert DeRosa

and protective finishes are reapplied. Single-thickness, non-bonded skin panels are installed with faying surface sealant, and corrosion preventive compound is reapplied to all areas. This procedure in effect restores the reworked area of the fuselage to an as-new condition as far as corrosion protection is concerned.

Prevention consists mostly of restoring the protective finishes on the airplane that the airplane came with, or in some cases applying it for the first time. After the protective finish is restored, we then apply corrosion preventive compounds.

At approximately four-year intervals, we open up all internal areas where spillage accumulates below the galleys, the doorways, the lavatories, the cargo compartment sub-floors, and external fairings. We do a complete inspection and restore the protective finish, and then reapply the corrosion preventive compound.

In areas where the moisture accumulation is not significant, such as internal areas in the cabin or the stabilized internal structure, we go into that area at approximately eight-year intervals. In those areas that are subject to a severe external environment, such as wheel wells and wing spars, corrosion preventive compounds are applied annually.

The indicated figures show typical examples of corrosion found on in-service airplanes. The repairs range from relatively simple, to complex.

Figure 1 is a 737 airplane, and one that's been reworked. The upper row of the fasteners are universal head fasteners that were put in.



Figure 1

This airplane is over 20 years old. As you can see, there are still a lot of airplanes in service that have the bond intact, and no delamination and no corrosion.

In this case, we have removed the fasteners, done an eddy current nondestructive inspection, oversized the hole and put in universal head rivets in the skin lap. On the inside, we have applied corrosion preventive compound to the seam between the joints.

Now this in effect eliminates the fatigue problem. However, it does not end the corrosion control problem. This airplane will still receive an annual inspection for corrosion at all the skin laps, even after the modification has been completed.

Figure 2 shows an airplane where we are replacing a skin panel. The underlying structure is what I'm really trying to show here, and you can see it's almost as if it's a new structure. Once you eliminate the bonded panel and get rid of it you are starting out, as far as the corrosion protection is concerned, just as you would as if the airplane was new.

What we do is install the new panel with universal head rivets to eliminate the counter sinks in all of the original fastener locations on the old panel. The new skin is put in with faying surface sealant. Again, wherever possible, we do not go back in with bonded skin panels.

Figure 3 shows the opposite extreme. On the left you have extensive light to moderate surface corrosion. You can see all the white



Figure 2



Figure 3

powder residue built up on the joint. The actual corrosion on this lap, however, in most cases does not exceed the 10 percent limit. In fact, what we found is that once you clean the corrosion products off the airplane, the actual loss of material is minimal. However, getting the corrosion products out of there usually means that we exceed the 10 percent limit because we cannot control the methods of removal.

Figure 4 shows a skin lap repair. What we have found is that if you are going to repair the skin lap, it's better to just cut the full length of the panel and install a full-length repair doubler on the lap. This eliminates the entire bonded joint.

Again, you can see above where we are replacing the remaining fasteners with button head fasteners in the lap.

Figure 5 shows another skin lap repair, and

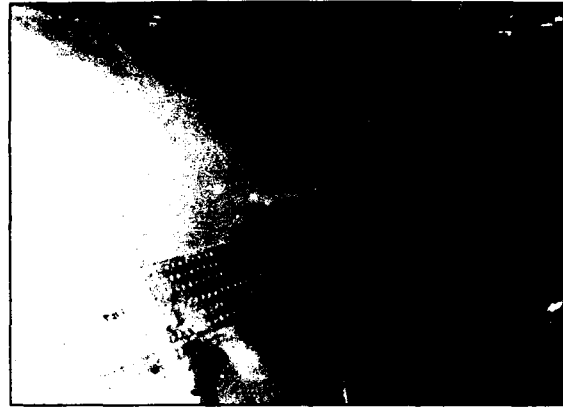


Figure 5

it's a fairly extensive one. This one is only on the upper skin. But again, it's almost a full panel-length repair.

Figure 6 shows another 737 panel replacement. You can see the rework going on, where we are putting in universal head rivets. The next panel down, you can see the skin cut out for a corrosion repair. Then we replace the entire panel.

I'd like to point out that you can see the condition of the stringers and the frames under the skin and their relatively good condition. When the panel goes back on, we would first put faying surface sealant back on those frames and stringers.

Figure 7 is a better shot of the area. You can see where the primer has been reapplied to the stringers and the frames. You can see the condition of the bonded straps, where all the adhe-



Figure 4



Figure 6



Figure 7

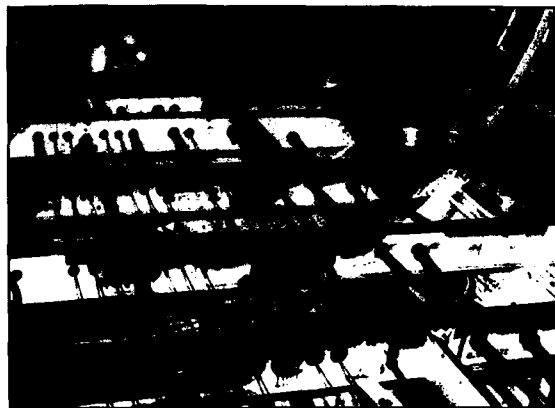


Figure 9

sive remains have been cleaned off. The structure is alodined and primed prior to putting on the new panel. The intention is to go back with a panel that is non-bonded wherever possible.

Figure 8 is showing you the condition of the panels now. The deep dark purple or plasticized color shows you the delamination. The red light spotty areas where you see the white powder residue, which are the oxides, is the actual corrosion. Up in the upper corner is an indication of where the bond is still good. And it's very descriptive of showing the three stages of bonded panels here. You have delamination, corrosion and good material.

Figure 9 is showing a galley area. You can see the pressure dome bulkhead and the area under the doorway, which is essentially where the galley and lavatories sit, and where you get the spillage. The corrosion has been cleaned

out on these frames and reinforcements have been applied per the SRM.

Incidentally, all repairs that we install, whether they are skin repairs or extruded angle repairs, are installed with faying surface sealant between the repair and the primary structure.

Figure 10 is some typical cut-out doubler repairs. The reworked areas have been done by reinstalling the universal head rivets.

Figure 11 is another door doubler, and it shows how extensive the damage can get when you have corrosion and fatigue cracks building up that extend through all the layers of the external skin and throughout the doublers. It also shows you another area that's very critical—make sure you pull up scuff plates on a routine basis and make sure that you check the area in the entryways of all the doorways.

Figure 12 is a shot that shows the cabin



Figure 8



Figure 10

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Figure 11

interior of an airplane, just generally to show the condition. The general condition in the cabin area is very good.

After any work that has to be done is accomplished, the primer would be touched up, and then prior to installing insulation blankets the corrosion preventive oils or compounds will be reapplied to the entire structure.

Figure 13 shows the horizontal stabilizer on a 727. This one in particular is an area where we have problems. We found that in a majority of early airplanes, dissimilar metal bushings were installed without primer, paint or anything. The holes were bored and the bushings just shoved in there dry. Luckily, the design was such that there was plenty of material, so that we could oversize the holes and then reinstall



Figure 13

the bushings wet with primer, or with sealant.

Figure 13A is another shot showing the rework of some clevis joints, where we were getting corrosion between the tension tie fitting on the 727. We had fretting corrosion on the clevis lugs where they mate.

Figure 14 is a main wheel well of a 727. You can see the general condition of the 950 forging and the start of the outer spar cord.

We clean the wheel well so that the inspections could be accomplished, and after the inspections are completed we reapply the corrosion preventive compounds.

Figure 15 is another shot of the main landing gear beam attach link on a 727. It's just showing the general condition.

Figure 16 is a 727. What we're doing here is



Figure 12

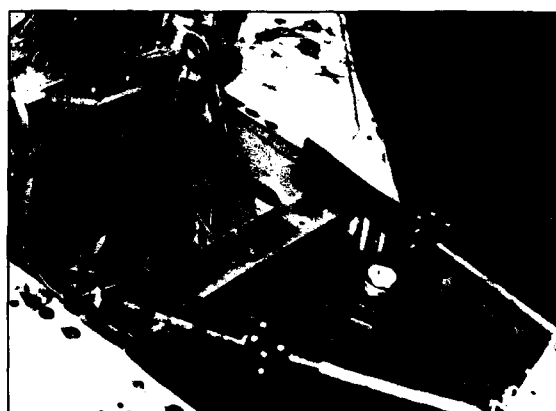


Figure 13A

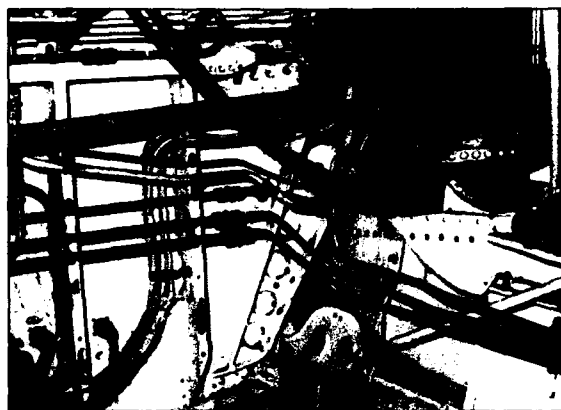


Figure 14

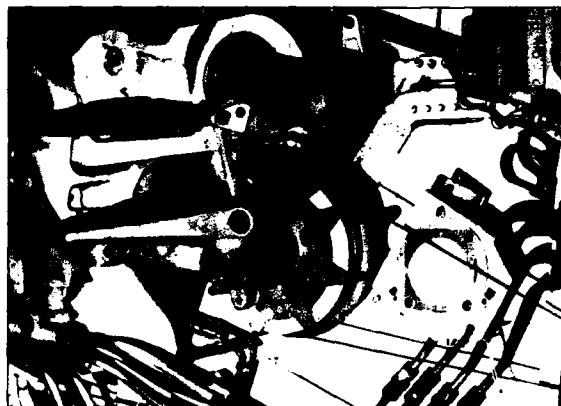


Figure 15

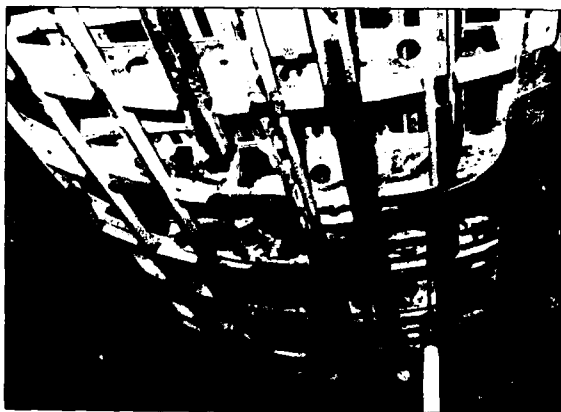


Figure 16

replacing the two aft-belly skin panels. These run from body station 950 to body station 1183, from stringer 26-left to 26-right.

We have a somewhat unique problem on the 727, in that the bonded panels, unlike the 737 where the panels were bonded and then chemically milled, were not chem milled. So corrosion preventive compounds do not help you very much on a 727. Once the panel is delaminated and you have corrosion starting, the oils cannot penetrate, because in some cases it would have to travel 12 to 18 inches, and we know that the range that the preventive compounds can penetrate is not that great.

Rather than continue patching the airplanes, we elected to replace these panels. We started in about 1972, and went through all of our dash-100 airplanes. We had 90 of them and we replaced the panels. In some of the early ones, where we couldn't get the single thickness panel, we had to go back in with the bonded panels. In some cases we replaced those panels twice.

Figure 17 shows the corrosion repair around an outflow valve. This is one of the areas where it is virtually impossible to prevent corrosion. When you get spillage out of the service tanks for the lavatories, all you can really do is make sure you have a very effective corrosion protection program and do periodic inspections to ensure the integrity of the area.

Figure 18 is the center engine inlet duct area of the 727.

Figure 19 is related to the stress corrosion



Figure 17



Figure 18



Figure 20

problem that we have on the 727s and early 737s, which is the 7079 T-6 forgings. We have replaced quite a few of these forgings. This particular one is the 950 bulkhead forging and is a fairly large-sized one to replace. However, the reason for showing this is to indicate that you can do fairly extensive parts replacements when necessary.

Figure 20 shows another part that is frequently replaced. It's the drag brace support beam in the nose landing gear wheel well. It was one of the problems associated with the bushings being installed dry. In a lot of cases, the corrosion is so extensive that we had to replace the fittings.

Figure 21 shows the nose landing gear

trunion support fittings. The bearing bores are a fairly corrosion-prone area. In this case, after the corrosion is cleaned out and the bore oversized, we contact anodize the surfaces and re-install the bushings.

Figure 22 is another repair and skin lap on a 727 airplane.

Figure 23 shows a lower wing skin corrosion repair under the flap track fitting. Probably what happened here was that the fretting strip between the fitting and the structure disintegrated, and the eventual corrosion occurred.

The basis for any effective corrosion control program must start at the pre-production phase of the airplane. If the corrosion protection is not emphasized right from the start, it is impos-



Figure 19



Figure 21



Figure 22

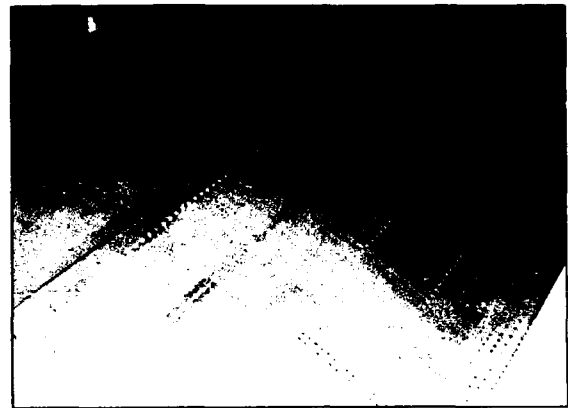


Figure 23

sible to ensure a corrosion-free airplane through its life.

With that point in mind, we stress corrosion prevention in all new airplane design reviews. In general, our goal is to ensure that all structure below the floor line be assembled with faying surface sealant, and all detail parts be top coated with polyurethane paint before assembly.

In addition, we try to limit, as much as possible, the use of bonded fuselage skin panels below the floor line and areas that are subject to severe corrosion environments, such as galleys and lavatories.

We also require that all basic fuselage structures be treated with corrosion preventive compounds. Since bonded structures are our most significant concern, we are attempting to convince the airframe manufacturers that 100

percent inspection of bonded skin panels for delamination is necessary prior to airplane delivery.

The program I have outlined is a brief summary of United's approach to corrosion control programs. With some minor differences, I believe the majority of airlines have developed similar programs. Our program adheres closely to the baseline corrosion prevention and control program recommended by the Aging Fleet Task Force.

This baseline program should alleviate some of the concerns associated with operating airplanes beyond their original design life goals. Although it is true that protective finishes deteriorate and break down, periodic repair or replacement of parts and restoration of protective finishes can ensure the structural integrity of the airframe.

Session IV: NDE/NDI



CHAIRMAN STEPHEN N. BOBO

NDI Specialist, Transportation Systems Center
U.S. Department of Transportation

Introduction

Since the Aloha aircraft accident, all components of the aircraft industry have made a massive effort to ensure the continued airworthiness of the air carrier fleet under the purview of the FAA.

In an effort to coordinate these activities the FAA hosted an International Conference on Aging Aircraft in June, 1988.

One problem which became apparent was that the need exists for improved NDI particularly in the following areas:

- Detection of crack growth as an element of fatigue damage to fuselage structures.
- Development of improved methodologies for characterizing integrity in bonded lap joints.
- Identification and isolation of corrosion damage in aircraft structures.

Perhaps the major problem, however, is the huge scale of the task. Current plans call for the

individual inspection of thousands of fasteners and bonded joints on each aircraft; and with current technology, the inspections of the existing fleet of some 1,600 aircraft will require millions of dollars. Clearly, a major need exists for improved, more cost effective inspection methods.

As a result of the recommendations from the conference, a research plan was completed in May 1989, one component of which was a far reaching NDI initiative aimed at developing improved inspection methodologies for the air carrier fleet. The work includes an assessment of existing methods, a search for relevant methods not now being fully utilized, and an evaluation of emerging technology that might be brought to bear on the problem. Oversight of the projects related to the initiative is obtained through an NDI Working Group (AANWG) consisting of representatives from the air carrier industry, aircraft manufacturers, academia, DOD and NASA.

Figure 1 is a flow diagram containing the major elements related to NDI.

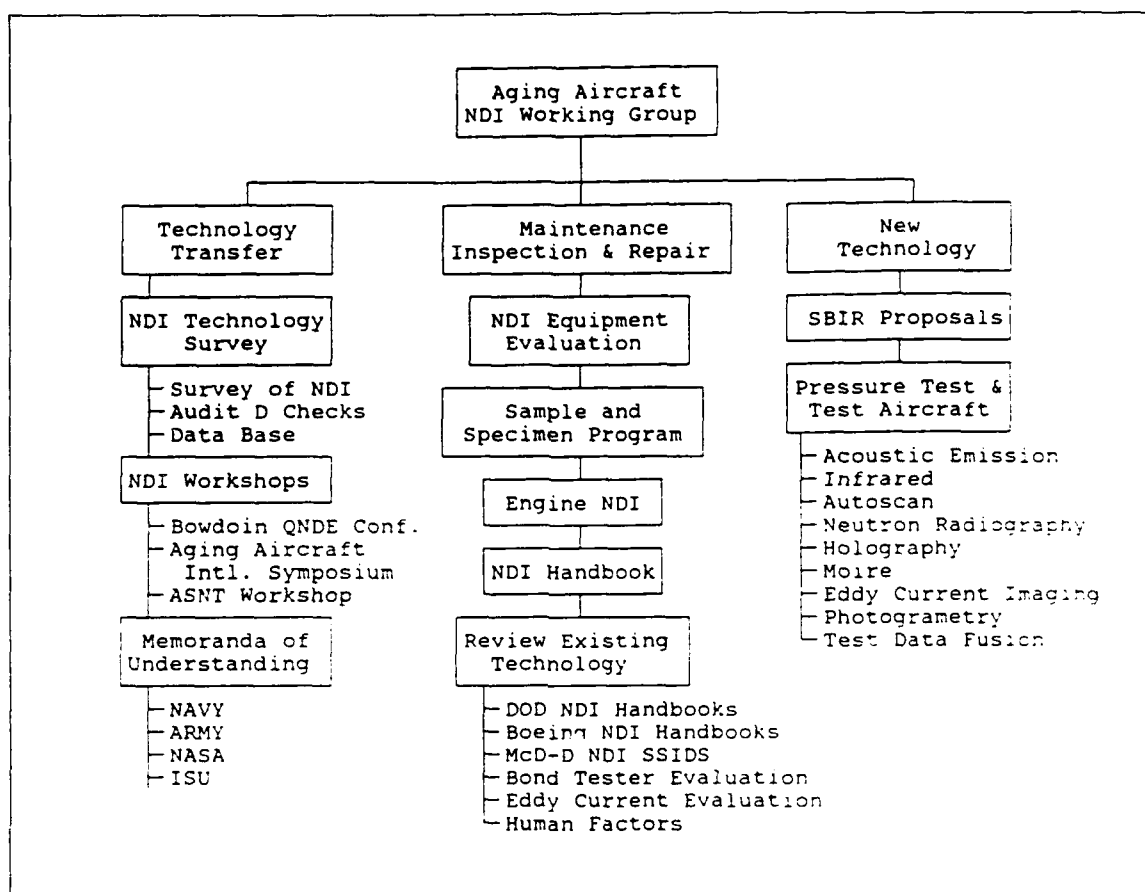


Figure 1 — NDI Flow Diagram

Technology Transfer

The first task under the NDI portion of the Aging Aircraft Program has been to assess the effect of baseline aircraft NDI activity, now being accomplished in two projects: an ongoing audit of heavy maintenance checks or "D" checks, the major periodic inspection carried out by most commercial carriers to fulfill the FAA requirements for continuing airworthiness; and a broad based survey of NDI practice, both in the aircraft industry and in other industries which may have relevant technology.

D-checks

Up to 60 heavy maintenance inspections are now being monitored by representatives of

FAA engineering and inspection elements for uniformity of practice and effectiveness of procedures. The framework for this audit is provided by a massive checklist in which all elements of the inspection are covered; from documentation to training and human factors. The NDI portion of the audit checklist seeks to determine types of inspections, procedures, instrumentation, training, qualification of inspectors and storage and handling of specimens and samples. Data from the checklists are being collected, organized and condensed with a view to preparation of a report late in 1990. Meanwhile, NDI data is being reviewed to determine uniformity and level of quality of the NDI practice, and to serve as a baseline for potential improvements to the system.

Survey of NDI Practice

The Nondestructive Testing Information Analysis Center is currently under contract to conduct a state-of-the-art survey of NDI as related to its use in commercial aircraft over seven years old. The purpose of the survey is to determine whether existing technology in other areas of the industry may be effective in improving the effectiveness of the inspection procedures now in use in the industry. The survey will contain but not be limited to the following elements:

1. Physical principles used, i.e. ultrasonics, eddy current and aided visual.
2. Generalized description of the instrumentation. A listing of each instrument considered qualified for use, its specifications, approximate cost and an estimate of the level of its acceptance by the industry, classified by physical principle from No. 1 above.
3. A generalized description of the inspection procedure used for each instrument cited in No. 2.
4. An assessment of the cost of use of the instrument, either on the basis of cost per hour of use, or cost per inspectable unit or unit of area being inspected.
5. An assessment of the future development potential of the physical principle from No. 1, and some kind of estimate of the ultimate limitation of the technique.
6. A summary evaluation of other promising techniques from other areas, either DOD, nuclear, utilities or others. This summary is heavily biased by considerations of the economic pressures found in the commercial aircraft industry.
7. A listing of sites on the aircraft where the bulk of the NDI is carried out, and the preferred instrumentation for these inspections.

A preliminary document is available now, and a final report is scheduled for August, 1990.

Workshops and Symposia

An important means of obtaining a continuing technology transfer between the NDI

users and industry in general is through symposia and workshops. A series of workshops is being scheduled in 1990, beginning with one in April on Structures and Fracture Mechanics. Others are planned on Human Factors and Corrosion.

Other Activities

In addition to the above activities, a data base is being maintained of potential bidders in technical areas likely to become fruitful as new NDI initiatives. Those wishing to be on the bidders list will be requested to provide information about their capability and will be considered for projects in their areas of expertise. Also, a library of articles and up-to-date documents from current literature is being maintained and circulated. In addition to work with industry, Memoranda of Understanding are in effect or are being negotiated with elements of DOD and NASA.

Maintenance Inspection and Repair

The FAA has several major tasks in connection with its NDI responsibilities in the area of maintenance and repair. The first task is evaluation of NDI equipment and procedures; supplementary work under this task is the organization and implementation of a comprehensive library of flaw samples. The second is to assess the NDI needs of the industry in engine NDI. The third task is to create guidelines for utilization of NDI practice by preparation of an FAA NDI Handbook.

Equipment Evaluation

Two major short-term inspection problems exist within the aircraft fleet: the need to reliably inspect large numbers of rivets for the existence of multiple site damage (MSD), and the ability to inspect extensive areas of fuselage for adhesive bond integrity in the presence of corrosion and other contaminants. With indus-

try help, various inspection methods are being evaluated in an effort to find the most reliable and cost effective method for inspection of lap joints and other sites in which MSD is likely to occur. Figure 2, from the Boeing 737 NDT Manual, shows areas in a Boeing 737 that require emphasized inspection. Existing methods for detecting adhesive bonds are generally satisfactory in uncontaminated areas, but when corrosion, its byproducts, or other contamination exists in riveted lap joints and doubled butt joints, detection of adhesive bond integrity becomes unreliable. Accordingly, the FAA is diligently searching for a more effective method for inspecting the adhesive bonds in aircraft.

Criteria for Determining the Effectiveness of Inspection

The FAA is developing criteria for evaluating the effectiveness of NDI procedures. In general, these criteria are similar to those found in DOD and in airframe manufacturers' handbooks. They consist of utilizing a set of standard samples, some of which have characteristic flaws and some of which have no flaws. The samples are inspected by several inspectors, and the number of flaws detected are counted. The number of missed flaws are also counted (Class I errors) as well as the false positives (flaws averred to be present where no flaws exist are Class II errors). From the data obtained, statistics may be derived for a given technique and compared with other competing techniques. Probability of detection (POD) is calculated for a given confidence level, as well as error rate and incidence of Class II errors. Figure 3 is a typical family of POD curves for four commonly used NDI methods. (D. Hagemmaier, McDonnell Douglas, Maintenance Engineering Plan, May, 1988) Table 1 is a listing, from the same source, of the common NDI methods and their capabilities and limitations.

Sample and Specimen Program

Samples and specimens play a large part in calibration, training and development of pro-

cedures for utilizing NDI equipment on aircraft structures. Also, it is frequently necessary to evaluate fatigue by using complicated structures fully simulating the construction aspects and geometry of aircraft in which fatigue has been found. Accordingly, in order to meet the objectives of the aging airplane program, it is a vital requirement to collect and maintain a library of simple and complex examples representative of structures found on aircraft. Figures 4 and 5 are examples of the specimens that are being collected.

This library is now being assembled at the Department of Transportation's Transportation Systems Center in Cambridge, Massachusetts. The specimens will be used to validate new NDI techniques, compare the effectiveness of instrumentation, quantify the effectiveness of various procedures and evaluate operator training.

Engine NDI

Several initiatives aimed at on-board engine diagnostics are being investigated along with an assessment of current inspection practice.

NDI Handbook

Various elements of DOD have maintained a handbook on NDI for many years, as has each of the airframe manufacturers. In an effort to provide guidance for minimum requirements for such a handbook, to be used by those certified by the FAA and to promote commonality of handbook approach, it is appropriate for the FAA to prepare a standardized FAA NDI handbook.

The FAA already has an NDI Advisory Circular, but it requires updating to be relevant to the needs of inspectors in the field. The current AC will be reviewed, along with other handbooks available from industry and DOD. When the review is complete, the FAA staff will prepare an outline for the FAA handbook and develop a plan for orderly flow of information on relevant NDI procedures into the handbook format. The deliverable from this work

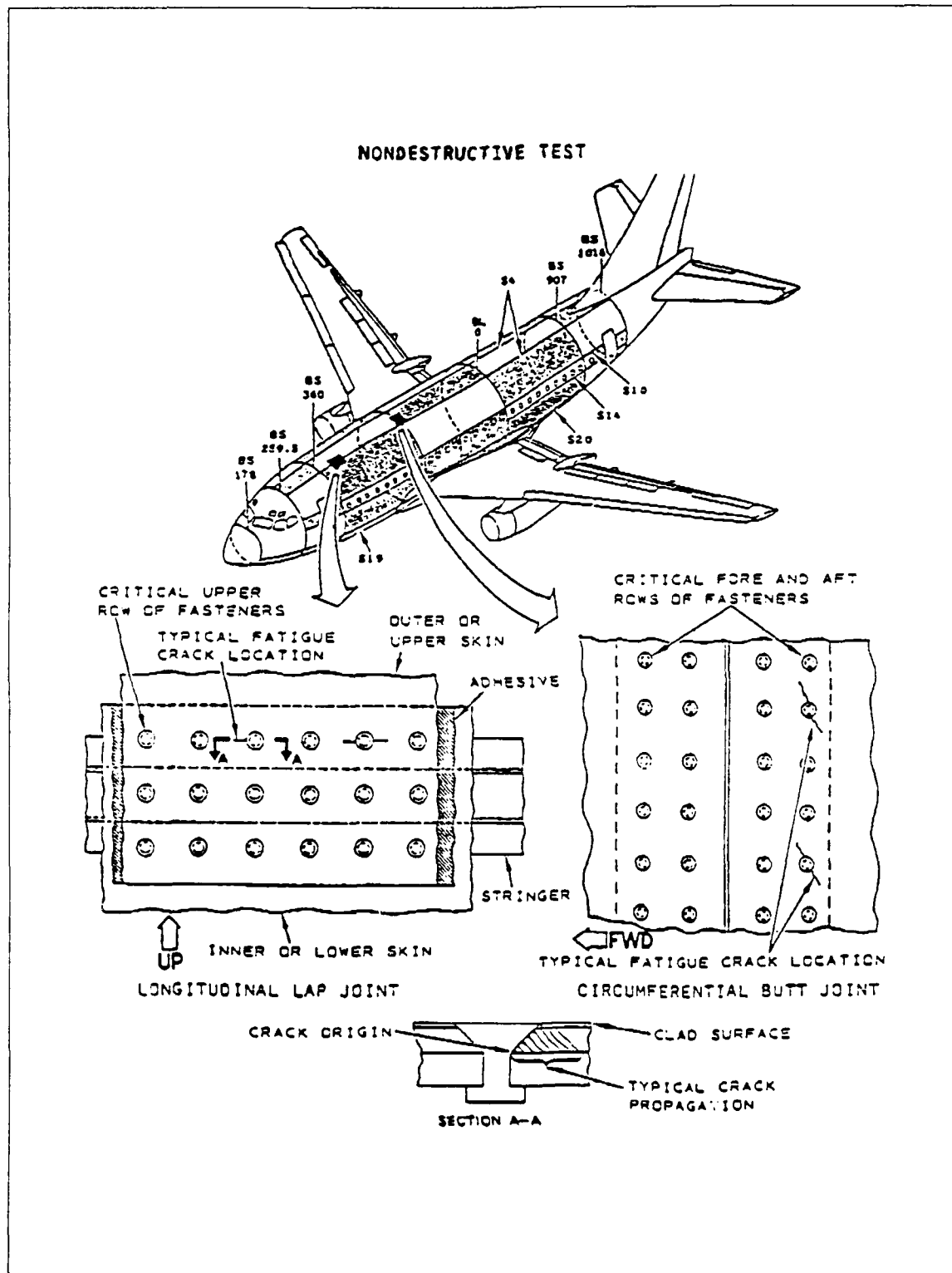


Figure 2 — Typical Fuselage Skin Joint Configuration and Crack Orientation

Stephen N. Bobo

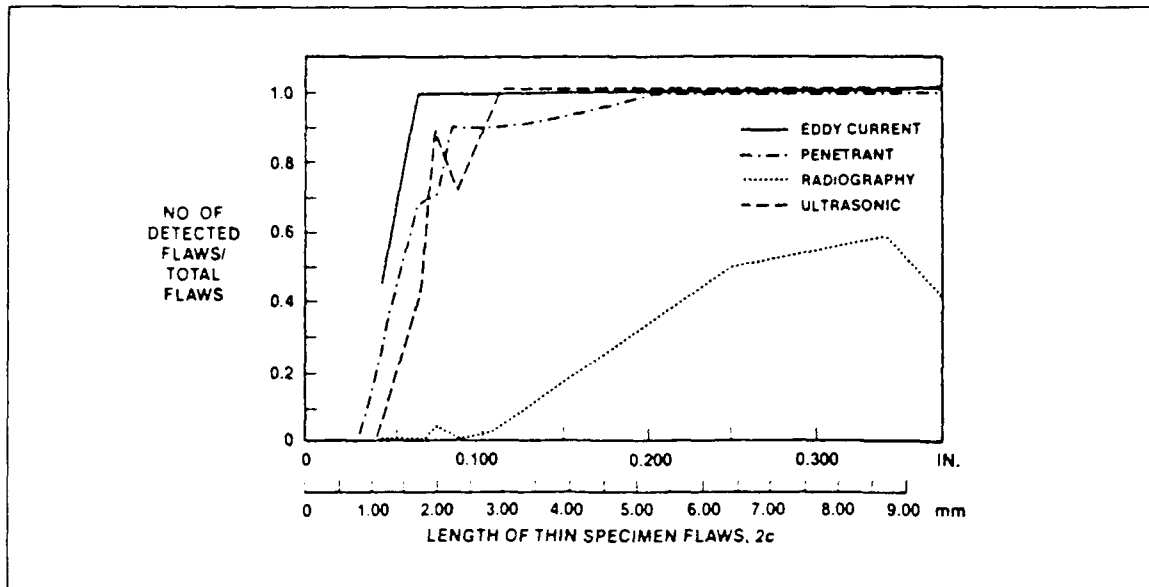


Figure 3 — Proportion as a Function of Length in Thin Aluminum Specimens, Combined Data

TYPE OF METHOD EMPLOYED	APPLICATION	ADVANTAGES	DISADVANTAGES
VISUAL OPTICAL 	DETECTION OF SURFACE DEFECTS OR STRUCTURAL DAMAGE IN ALL MATERIALS	SIMPLE TO USE IN AREAS WHERE OTHER METHODS ARE IMPRACTICAL. OPTICAL AIDS FURTHER ENHANCE THIS METHOD.	RELIABILITY DEPENDS UPON THE ABILITY AND EXPERIENCE OF THE USER. ACCESSIBILITY REQUIRED FOR DIRECT VISIBILITY OR BORESCOPE.
PENETRANT 	DETECTION OF SURFACE CRACKS IN ALL METALS, CASTINGS, FORGINGS, MACHINED PARTS, WELDMENTS	SIMPLE TO USE. ACCURATE, FAST, EASY TO INTERPRET.	DEFECT MUST BE OPEN TO SURFACE AND ACCESSIBLE TO OPERATOR. DEFECT MAY BE COVERED BY SMEARED METAL. PART MUST BE CLEANED BEFORE AND AFTER CHECK.
HIGH FREQUENCY EDDY CURRENT 	DETECTION OF SURFACE DEFECTS IN METALLIC SURFACES, CRACKS, PITS, INTERGRANULAR CORROSION, AND HEAT TREAT CONDITION. CONDUCTIVITY FOR MEASUREMENT FOR DETERMINING FIRE-DAMAGED AREA.	USEFUL FOR CHECKING ATTACHMENT HOLES FOR CRACKS NOT DETECTABLE BY VISUAL OR PENETRANT METHODS. FAST, SENSITIVE, PORTABLE.	TRAINED OPERATOR REQUIRED. SENSITIVE COMBINATIONS AND VARIATIONS IN MATERIAL. SPECIAL PROBES REQUIRED FOR EACH APPLICATION. REFERENCE STANDARDS REQUIRED.
LOW FREQUENCY EDDY CURRENT 	DETECTION OF SUBSURFACE DEFECTS IN METALLIC MATERIALS, CORROSION THINNING AND SPACING.	USEFUL FOR CHECKING FOR CRACKS WITHOUT REMOVAL OF FASTENERS OR DISASSEMBLY OF SUBSTRUCTURE.	TRAINED OPERATOR REQUIRED. LARGER PROBES NEEDED FOR LOWER FREQUENCY USAGE. SPECIAL PROBES REQUIRED FOR EACH APPLICATION. REFERENCE STANDARDS REQUIRED.
SONIC 	DETECTION OF DELAMINATIONS, DEBONDS, VOIDS, AND CRUSHED CORE IN COMPOSITE AND HONEYCOMB MATERIALS.	CAN BE ACCOMPLISHED FROM ONE SURFACE. DIRECT READING. DOES NOT REQUIRE PAINT REMOVAL OR SPECIAL SURFACE PREPARATION.	LOSES SENSITIVITY WITH INCREASING MATERIAL THICKNESS. ELECTRICAL SOURCE REQUIRED.
X-RAY 	DETECTION OF INTERNAL FLAWS AND DEFECTS SUCH AS CRACKS, CORROSION, INCLUSIONS, AND THICKNESS VARIATIONS.	ELIMINATES MANY DISASSEMBLY REQUIREMENTS. HAS HIGH SENSITIVITY, AND PROVIDES A PERMANENT RECORD ON FILM.	RADIATION HAZARD. TRAINED OPERATORS AND FILM PROCESSING EQUIPMENT REQUIRED. CRACK PLANE MUST BE NEARLY PARALLEL TO X-RAY BEAM TO BE DETECTED. ELECTRICAL SOURCE REQUIRED. SPECIAL EQUIPMENT REQUIRED TO POSITION X-RAY TUBE AND FILM.
MAGNETIC PARTICLE 	DETECTION OF SURFACE OR NEAR-SURFACE DEFECTS IN FERROMAGNETIC MATERIALS OF ANY SHAPE OR HEAT TREAT CONDITION.	SIMPLE IN PRINCIPLE. EASY, PORTABLE. FAST. METHOD IS POSITIVE.	TRAINED OPERATOR REQUIRED. PARTS MUST BE CLEANED BEFORE AND DEMAGNETIZED AFTER CHECK. MAGNETIC FLUX MUST BE NORMAL TO PLANE OF DEFECT TO YIELD INDICATIONS.
ULTRASONIC 	DETECTION OF SURFACE AND SUB-SURFACE DEFECTS, CRACKS, DEBONDS, LAMINAR FLAWS, AND THICKNESS GAGING IN MOST METALS BY PULSE ECHO TECHNIQUES.	FAST, DEPENDABLE. IS EASY TO OPERATE. RESULTS ARE IMMEDIATELY KNOWN. HIGHLY ACCURATE. HIGH SENSITIVITY AND PORTABLE.	TRAINED OPERATOR REQUIRED. ELECTRICAL SOURCE REQUIRED. CRACK PLANE ORIENTATION MUST BE KNOWN TO SELECT WAVE MODE TO BE USED. TEST STANDARDS REQUIRED TO ESTABLISH INSTRUMENT SENSITIVITY.

Table 1 — NDI Methods

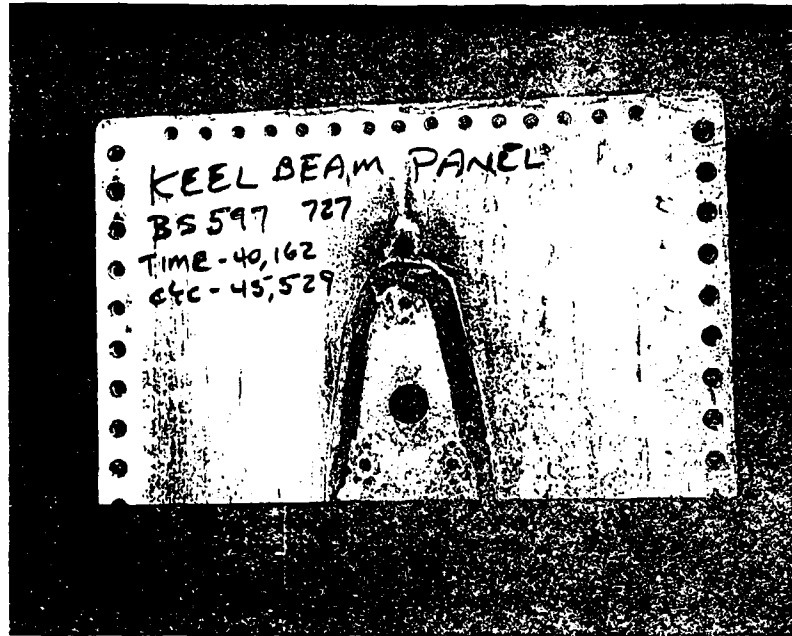


Figure 4 — Keel Beam Panel with Corrosion

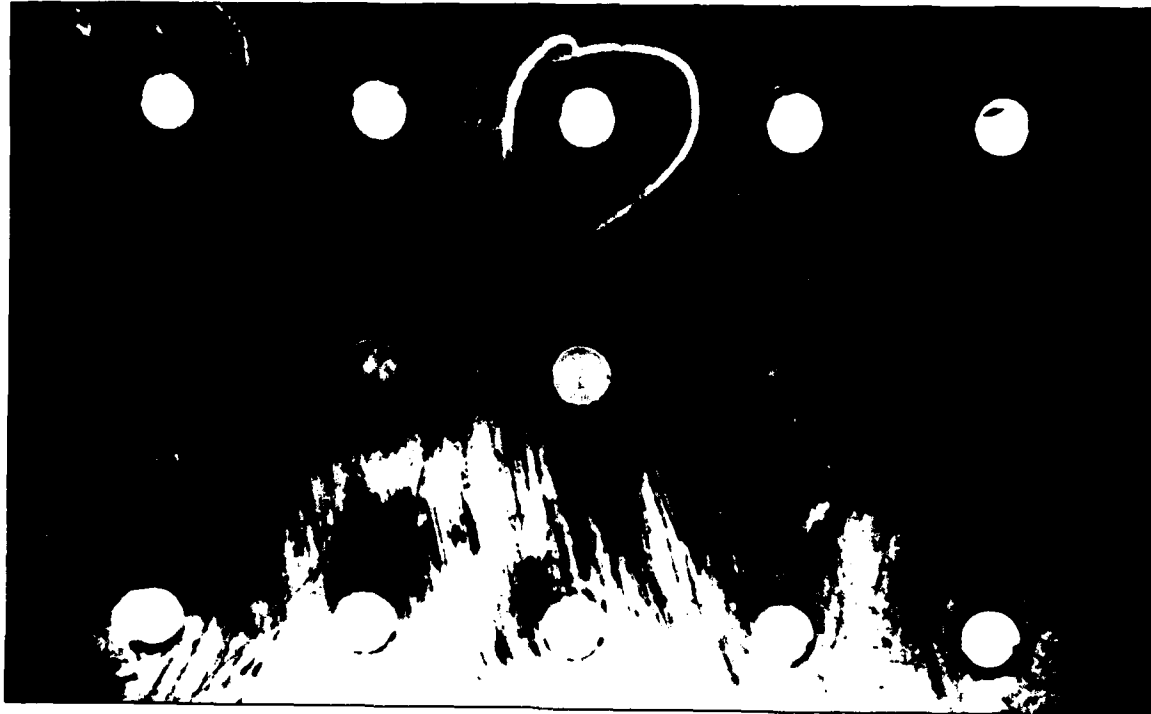


Figure 5 — MSD Crack Linkup Sample

will be a series of recommended actions by the certifying authority in the FAA on best NDI practice for inclusion in the NDI handbook format.

New Technology

It is necessary for the FAA to concern itself with emerging technologies to keep pace with inspection tasks prompted by the rapid expansion of the aging fleet.

As promising techniques are uncovered, they are validated using tests and statistical principles described earlier. Probabilities of detection, confidence levels and false positives are estimated. Human factors considerations are factored into the statistical plan, and agencies within the FAA responsible for human factors are consulted for inputs to the experimental design. The new techniques are added to a matrix containing the types of flaws known to exist in airframes and the various technologies for detecting them. The whole is then incorporated in the NDI Handbook.

Resources have been allocated to evaluate new technologies using a series of contract efforts as well as studies on actual aircraft. At present, several initiatives are being considered:

- Development of a standardized method of sizing, characterizing and reporting flaws in aircraft structures
- Development of improved image processing for X-ray photographs
- Evaluation of on-board engine probes
- Evaluation of the role of neutron radiography in detection of corrosion in aircraft structures
- Eddy current imaging
- Optical interference methods of large area microstrain measurement
- Thermal diffusion measurement using infrared imaging

Table 2 is a matrix showing some of the newer methods now being considered.

Pressure Test of 727 Aircraft

During manufacture, the fuselages of commercial airliners are pressure tested to the fed-

erally mandated 1.33 times the nominal pressure (P). Nominal is conventionally assumed to be between 8 and 9 psi, depending on the altitude at which the aircraft flies. A real concern exists, supported by some evidence, that pressurization to 1.33 P in older aircraft may either introduce damage or accelerate the rate at which fatigue occurs in the structure, particularly if the proof pressure test is to be carried out on a periodic basis.

To determine whether pressure testing is appropriate for older aircraft, the FAA will pressure test two 727 aircraft, one with relatively few operating cycles, and one very high cycle aircraft.

Serious concerns have been raised in the technical community about the safety of the proof test. Accordingly, another pressurization approach has been proposed, namely pressurization to 1.0 P with accompanying surveillance by relevant NDI methods to observe the progression of fatigue damage and identify its location.

Prior to pressurization, the aircraft will be subjected to an exhaustive and meticulous inspection, using the best of existing technology, including NDI. All damage or anomalous conditions will be rigorously and completely characterized and recorded.

Baseline Measurements

Existing proven inspection equipment will be used in evaluation of the aircraft to provide baseline data about the aircraft condition. Two basic conditions will be evaluated: adhesive bond in the lap joints of the structure and evidence of cracks around rivet heads.

New Technology

In addition to already validated technologies such as eddy current and bond testers, potentially valuable new technology will be utilized. Based on the hypothesis that any un-restored strains when the structure is relaxed after pressurization represent potential sites of stable crack growth, the NDI will focus on detection of crack growth during pressuriza-

Advanced Automated NDT Systems

System	Function	NDT Method	Operator
System for Inspection-Assisted by Microprocessor	Inspect Aircraft Fuselage in Region of Rivet Holes	Multicoil, Dual Frequency Impedance Plane Eddy Current	Airbus Industrie
Maneuverable X-Ray Radiography System	Inspect Aircraft Structural Elements for Cracking	Realtime Radiography	U.S. Air Force
Maneuverable Neutron Radiography System	Inspect Aircraft Structural Elements for Corrosion	Californium 252 Neutron Source and an Amplification Tube Realtime Imager	U.S. Air Force
Automated Realtime Imaging System (ARIS)	Inspect Aircraft Structural Elements for Disbonds and Delaminations	Ultrasonic Through Transmission or Pulse Echo with Color Scale Processing of Time, Depth, or Amplitude Data	U.S. Air Force
Robotic Deriveter System (RPS)	Machine Removal of Rivets and Inspection of Skin Around Rivet Hole	Multi-element Eddy Current	U.S. Navy
On Board Structural Computer (OBSC)	Collect and Process Strain Gauge Data from Aircraft Wings and Fuselage	Multiple Strain Gauges	Canadian Air Force

Table 2

Stephen N. Bobo

tion, evidence of nonlinear expansion of the fuselage, and evidence of unrestored growth after depressurization.

Some of the methods being investigated are:

1. Acoustic emission (AE) sensing may be able to detect the existence and location of all events of stable crack growth within the fuselage during pressurization.
2. Abnormal growth of sites on the fuselage as well as unrestored pressurization should be detectable, depending upon magnitude, by one of the methods below:

Photogrammetry
(Accuracy ± 0.010 inches)

Moire motion detection
(Accuracy ± 0.00010 inches)
Shearograph
(Accuracy ± 0.000001 inches)

Each of the above is an area detection method covering large areas of fuselage during the pressurization cycle.

After pressurization, the aircraft under test will be carefully inspected for evidence of damage, and the data compared with those obtained prior to pressurization. The older aircraft will then be available as a testbed for validation of promising NDI procedures and new NDI technology.

The FAA has done a good job of ensuring airworthiness in the short term. The need exists for superior NDI technology to meet the inspection challenge of the aging aircraft fleet.

Thermographic Inspection Techniques



WILLIAM WINFREE

Advanced Sensors Group, NASA Langley Research Center

What I'd like to talk about is some of the research that we're doing at NASA-Langley. In particular, I'd like to talk about some of the thermographic inspection techniques that we're developing.

This is basically an outline, an overview of the program at Langley. I'll talk about thermographic techniques and why one would use a thermographic technique. I'll also talk about delamination detection, crack detection and corrosion detection.

Most of the work done lately at Langley has been aimed at trying to increase the safety of a solid rocket motor. We've done a lot of NDE on a lot of different parts of the solid rocket motor (SRM) in order to increase its safety. What we are doing is taking some of the same technologies that we developed for the solid rocket motor and applying them to aging aircraft.

One of these technologies is thermography. Thermography has some advantages, it's a non-contacting technique. You don't have to use coupling, like in ultrasonics. We can use the computer to control both the application of heat and the data acquisition afterwards.

One of the biggest advantages of thermography is the ability to scan large areas at a time, including large, complex geometries. If there is a flaw, we are able to detect the variation in the heat flow around that flaw. And from that variation in heat flow, we're able to characterize the flaw.

We use some type of heat source. We can use a lamp, a hot air gun or other source. We heat up the sample. We then use an IR camera in order to monitor the temperature or the radiation on the surface of the sample.

One of the important things we found and that other groups have found, is to attach that IR camera to some type of image processor, where you take images in and average the images in order to increase the signal to noise and also to do some signal enhancement.

One of the things that we've embraced at Langley is the use of modeling to give some insight into what is happening in the thermographic process. We have some typical simulation results where we've modeled the SRM. We can use this in order to say what is the optimum heating time we should use and what

William Winfree

is the optimum time to look at the sample to acquire images. We can also use it to get an insight into the actual process that's going on, and use that insight in order to come up with a data reduction technique that helps us to draw out from those thermal images what we are really interested in seeing.

What you do is measure the temperature profile on the front surface. What you are interested in looking at is the flow, or the heat flux out the back surface, because that flow or heat flux out the back surface is what tells you where the delamination is.

One thing we see in some images is the fact that we weren't able to evenly apply heat to the sample. However, we process the data in such a way to pull that flow out the back surface. Then we can clearly see the delamination at the back surface of the sample.

With the lap joint, you're interested in putting heat in as evenly as possible. And then we try to see whether or not we could see those bonded doublers on the back side.

We can now take data and process it by

looking at it at different times. We're able to clearly pull out whether the doubler is bonded or not. We can see the region where it's bonded, and then we can see the region where it's obviously not bonded.

We have also done work looking at cracks and seeing whether or not we can detect cracks. We began this with some modeling of a crack that was in a lap joint. By looking at the variations of heat flow, we very clearly detect the crack. By processing the data, we're able to pull out features or see the presence of defects.

In summary, what I briefly have talked about today is looking at physical-based techniques for enhancing the data, that by modeling and using the physics of how the heat is flowing in the sample, we are able to draw out things that we couldn't see previously.

Also, we presented data showing the ability to detect different delaminations, as well as some of the research to do with looking for cracks in lap joints and for modeling that back surface and corrosion.

Nondestructive Testing of Aging Aircraft



DONALD HAGEMAIER

NDE Group Leader
Douglas Aircraft Company

Welcome, ladies and gentlemen. The one thing I have to explain is that airplanes are built differently by different manufacturers, and the problems we are confronted with are different, and the methods of inspection are somewhat different from company to company. So what I'm going to cover is the Douglas approach to the aging airplane inspection program and corrosion detection methods.

Douglas Aircraft Company has developed a supplemental inspection document (SID) program for fatigue crack detection and is presently developing a corrosion control program for aging aircraft. This paper describes the implementation of nondestructive testing in the SID program and various nondestructive test (NDT) methods useful for detection of corrosion and stress corrosion cracks in the aircraft structure.

Introduction

After an airplane enters service, ongoing inspection and maintenance of its structure are essential to ensure a continuing high level of safety. These maintenance programs are specified and approved by the certifying agencies. However, these aircraft will eventually reach an age where an increase in corrosion and fatigue cracking can be expected. Industry and airworthiness experts recognize that an additional structural inspection program, which would supplement the existing operator maintenance programs, is necessary for aging aircraft. Working with the aircraft operators, Douglas developed a SID for each of its aircraft models and is currently developing a corrosion control program for aging aircraft.

The SIDs identify the principal structural

elements (PSE) on each aircraft. (A PSE is defined as "a structural part or assembly of parts whose failure, if it remained undetected, could lead to loss of the aircraft.") SIDs also identify the inspection methods and procedures associated with each PSE. This is an inspection program to supplement or adjust existing structural inspection programs, as required, to ensure the continued safety of older aircraft.

This paper presents an overview of the Douglas SID program that was developed to detect fatigue cracks in high-time aircraft and various NDT methods that are useful for detecting corrosion and stress corrosion cracks.

Supplemental Structural Inspection Program

Douglas has developed a SID program based on fleet-leader-operator sampling (Figure 1). During the sampling, inspections are carried out on a PSE-by-PSE basis. Symmetrical structure results in two samples, left and right, per aircraft. For sampling purposes, one or both sides of the aircraft may be inspected. It is important to note that each PSE always stands by itself; i.e., inspection start points, inspection intervals, etc., are generally different for each PSE.

An industry steering committee (ISC) develops basic guidelines for use by the working

groups on each aircraft model. The guidelines include: (1) reviewing candidate PSEs and methods of inspection; (2) reviewing existing operator maintenance programs; (3) establishing a SID fleet-operator sampling inspection program; (4) establishing fatigue-life thresholds for the start of each PSE inspection; and (5) developing an adequate computerized reporting system between operators and Douglas.

The working groups for each model review their PSE list and methods of inspection. These reviews entail: (1) reviewing the basis of analysis and assessment of criticality and submitting the findings to the Federal Aviation Administration (FAA) and the Civil Airworthiness Authority (CAA); (2) reviewing proposed inspection methods and performing on-aircraft verification; (3) reviewing SID maintenance planning information; and (4) reviewing manpower requirements, special skill requirements, and special tooling/equipment requirements.

Inspection Procedures

Damage-tolerance analysis is performed for each PSE, and a marked-up engineering drawing of the component is submitted to the NDT engineer who determines the materials involved and the thickness of the various parts making up the component PSE. Potential non-destructive inspection (NDI) methods and techniques are then selected for inspecting the PSE.

For ultrasonic and eddy current inspections, simulated structure is fabricated with electrical discharge machining (EDM) notches of different sizes. These notched specimens are then used to work out preliminary procedures and determine the detectable flaw size (a_{det}) for each method as it applies to each PSE. Obviously, the a_{det} must be less than a_{inst} (instability flaw size) for each PSE. The procedures are finalized and then verified on operational aircraft. The verification procedure provides a means of detecting constraints that are not obvious from drawings or sketches and defines access and/or removals required to perform the desired inspection. Finally, the inspection procedures are reviewed by the operator and

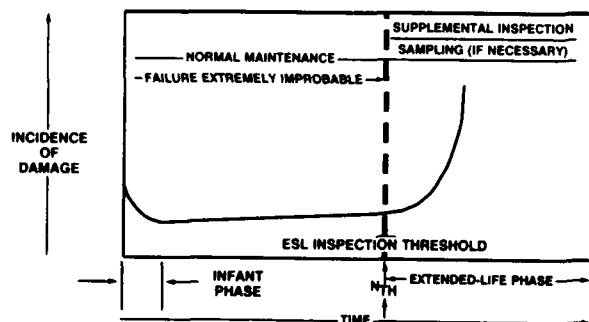


Figure 1 — Douglas Supplemental Structural Inspection Program

manufacturer working groups (for each model aircraft) prior to release to the FAA and CAA.

Detectable Flaw Size (a_{det})

In practical applications, an NDT limit, a_{det} , is usually specified; this is a crack length "a" corresponding to a high detection probability. The fracture mechanics residual life $N_{di}/2$, is the time required for a crack length a_{det} to propagate to unstable crack length a_{inst} at limit load (see Figure 2). The inspection interval is set as $N_{di}/2$, giving two opportunities to detect the crack before it reaches a_{inst} . Detectable crack size is defined for each inspection method and PSE. Although the detectable crack size is different for each method, the probability of detection (POD) in the SID program is considered to be 0.90 regardless of the method chosen. However, the method chosen will govern a_{det} and establish inspection start points and intervals.

Primary NDI method and at least one alternative method are developed for most PSEs. The primary method is the most sensitive method; i.e., it can detect the smallest crack, and it gives the largest crack growth interval, ΔN_{di} .

NDI demonstration programs consistently show that eddy current inspection is very reliable in detecting small, tight fatigue cracks.^{1,2} Eddy current testing became the primary crack detection method used in the Douglas SID inspection programs because of these findings.³

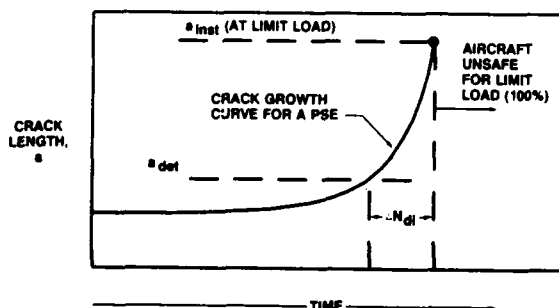


Figure 2 — Damage-Tolerance and Nondestructive Testing

A summary of DC-9-30 SID inspections for 45 PSEs clearly shows that high-frequency eddy current (for surface cracks) and low-frequency eddy current (for subsurface cracks) are the primary inspection methods:

Magnetic Particle	1
Visual	3
Ultrasonic	5
Radiographic	12
High-frequency Eddy Current	28
Low-frequency Eddy Current	65

The statistic of primary interest in the SID inspections is the capability of positive detection (see Figure 3). The probability of detection (POD) curve provides a convenient method for comparing inspection process performance. It graphically depicts discrimination capability. However, the POD curve does not provide an indication of the calibration performed to establish the baseline, the acceptance criteria imposed on the process, or the level of incorrect rejections (false calls) inherent in the application. The common denominators for both NDI performance and modeling of the performance of a specific technique are: (1) the signal and noise response distributions generated by application of the technique; and (2) the acceptance criteria applied to the decision process.

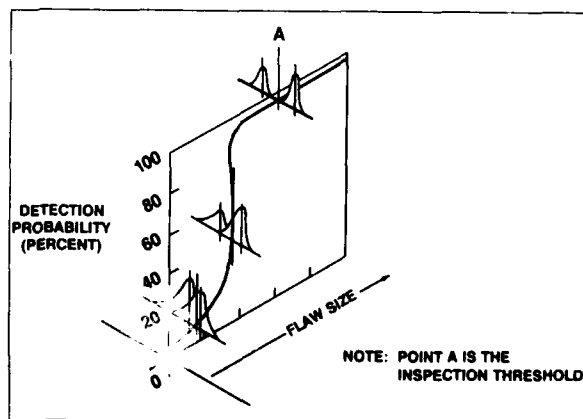


Figure 3 — Interaction of Signal/Noise Discrimination and the Probability of Detection (POD)

A POD curve typically reflects all the variations in signal-to-noise response and discrimination levels shown in Figure 3. A continuing variation in signal-to-noise response is reflected by variation in the discrimination level (threshold) along the POD. Where the NDI response (signal) distribution from a flaw is coincident with the process noise signals, there is no discrimination and the inspection is not valid.

In order to achieve successful detection, Douglas NDT engineers choose an a_{det} for each PSE. This a_{det} is obtained from the laboratory demonstration and is defined as detection threshold A in Figure 3. At this threshold, there is a good separation between flaw signals and noise, resulting in a reliable inspection. In addition, decision criteria (crack versus no crack) are clearly defined.

Inspection Program

The SID inspection program is established from statistical-probabilistic concepts of having and detecting a crack. These concepts are based on each PSE's fatigue-life estimate, its damage-tolerance characteristics, and the NDI method selected by the airline.⁴ The basic concepts are illustrated in Figure 4. In the sampling program, aircraft are to be inspected before they exceed the fatigue life threshold N_{TH} , with inspections starting at $N_{TH}/2$.

After a PSE exceeds N_{TH} , the intervals between inspections are a function of the NDI

method used and the crack growth and residual strength characteristics of the PSE. The interval is set to equal ΔN_{di} (Figure 4) divided by 2. ΔN_{di} is the time for a crack to grow from a_{det} to a_{inst} which is the crack length that would produce instability failure due to limit load. ΔN_{di} is divided by 2 in order to provide two opportunities to detect the crack before it reaches a_{inst} . Statistical-probabilistic considerations and the number of aircraft that must be inspected (sample size n) are used to calculate N_{TH} . Fatigue life to reach a specified crack length is a random variable represented by a log-normal distribution. The mean fatigue lives for a crack to reach a_{det} and a_{inst} are $\bar{N}(a_{det})$ and $\bar{N}(a_{inst})$ (Figure 4).

Because the inspection threshold, N_{TH} , varies from PSE to PSE, inspections will start at various times. Ten of the samples to be inspected must be the highest-time aircraft. The samples required in addition to the 10 highest-time aircraft ($n_i - 10$ samples) are allocated in proportion to the number of samples in the sampling population. Sample size n is a function of $\bar{N}(a_{inst})$ and $\Delta \bar{N}_{di}$ that reflects the NDI used; therefore, sample size may be different for different PSEs and NDI methods. For typical $\bar{N}(a_{inst})$ and $\Delta \bar{N}_{di}$ values, n may vary from 20 to 120. All samples n_i are to be inspected during a specified inspection interval.

Aircraft Corrosion

Severity of corrosion attack varies with aircraft types, design techniques, operating environment, and operator's maintenance programs. Common areas of corrosion problems are listed below:

- Floors in vicinity of, and structure under lavatory systems and galleys
- Structures surrounding doors, particularly landing gear doors
- Wing skin adjacent to countersunk fastener heads
- Aluminum-faced honeycomb panels used for exterior panels and floors
- Wing-to-body joint fittings
- Fuselage lower structure (bilge area)

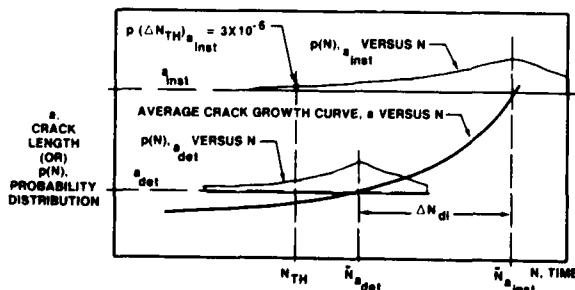


Figure 4 — Durability, Damage Tolerance and Statistics-Probability Concepts

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- Areas having environmentally unstable materials
- Structures susceptible to protective treatment damage during installation and repair, due to abrasion, fretting, and erosion.

Corrosion is a general term for the oxidation process of materials and can appear in many forms depending on the metals and the mechanism of damage. Corrosion on aluminum alloys and plated steel surfaces can often be recognized by dulling or pitting of the area, and sometimes by white or red powdery deposits. It may also be the origin for, or revealed by, delamination, cracking, metal thinning and fretting. The detection of each type of corrosion may require various NDT methods or techniques due to different characteristics that are involved.

Corrosion is the destruction of metals by chemical or electrochemical action, and is caused by a chemical reaction between metals (serving as electrodes) and an aqueous solution containing differentions or dissolved oxygen, acting as the electrolyte.

When the airplane, constructed of many metals, is exposed to a corrosive environment, such as exhaust gases, moisture, waste water and spillage, all factors necessary for chemical or galvanic action are present. Since some areas of the airplane are exposed to more corrosive contaminants than others, the necessary control measures vary accordingly. Corrosive attack starts on the surface of the metal; if allowed to continue, the corrosion penetrates into the core.

The most common types of corrosion found in one form or another on aircraft structures are illustrated in Figure 5 and are as follows:

- Pitting
- Intergranular
- Exfoliation
- Crevice/Galvanic or Dissimilar Metal
- Stress-Corrosion Cracking
- Microbial

Less common types of corrosion are:

- Filiform
- Thermogalvanic

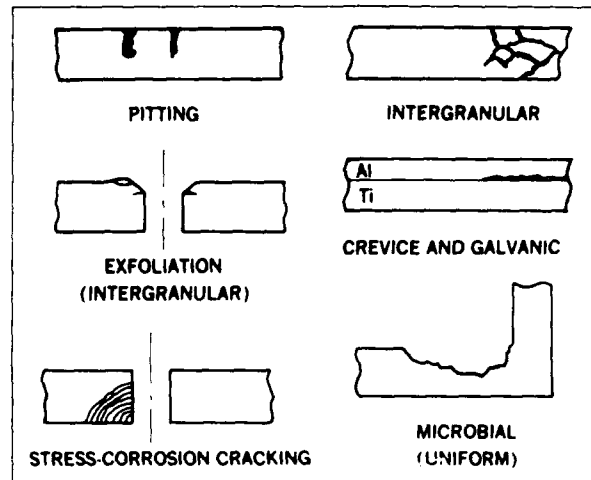


Figure 5 — Types of Corrosion

- Corrosion Fatigue
- Fretting
- Erosion Corrosion

Exposure to salt water, moisture condensate, chemicals, and soil and dust in the atmosphere affect the degree of corrosion. The geographical flight routes and bases of operation will expose some airplanes to more corrosive conditions than others. Corrosion prevention and control requirements will, therefore, vary somewhat from one area to another.

Inspection for Corrosion

All aircraft should be carefully inspected for signs of corrosion at each scheduled inspection period. Severe environmental conditions, such as salt spray, humidity and temperature, may require increased frequency of inspections. Areas most susceptible to corrosion should be inspected more often.

The first appearance of corrosion on unpainted surfaces is in the form of white powder or spots. Areas where sand, dirt and grime collect are particularly susceptible. In conducting inspections for corrosion, particular attention must be given to the lower interior of the fuselage, upper surfaces of wings, wing flaps, ailerons and actuating mechanisms. Areas subjected to battery electrolyte and exhaust

gases require close attention and frequent maintenance.

Naturally there will be less corrosion on painted, plated or aluminum clad surfaces than on unprotected surfaces. However, corrosion will also attack protected metal since moisture and contaminants may permeate the barrier coat when it has been damaged. In such cases, the affected areas are generally characterized by a scaly or blistered appearance, or sometimes by discoloration of the paint. Corrosion on aluminum alloys and plated steel surfaces can often be recognized as a dulling or pitting of the area, and sometimes as white or red powdery deposits.

Conventional NDT Techniques for Corrosion Detection

Several NDT techniques are commonly used for corrosion detection and evaluation. When the inspected area is physically accessible, visual tests are commonly used as periodic checks. Sometimes, tools such as magnifying glasses or borescopes are used for further evaluation or for less accessible areas. The inspection involves a visual search for cracks, change of color, texture or bulges.

Unprotected parts made from magnesium, aluminum, and steel are susceptible to pitting corrosion. Isolated pits may be difficult to detect before they penetrate the part. Fortunately, pitting corrosion generally occurs over a large enough area (frequency of attack) to allow detection by NDI techniques. Figure 6 shows pitting corrosion of the high-strength steel main landing gear truck beam. The corrosion can occur in the four lubrication holes if the lubrication (grease) is not replaced at periodic intervals as specified by the aircraft maintenance manual. The pitting, if undetected, can result in stress corrosion or corrosion fatigue cracking and possible failure of the part.

In-service inspection for these pits requires the removal of the lubrication fitting and grease from each hole. The internal surface of each hole is checked using a zero-degree (forward-looking) 2.8-mm (.101-inch)-diameter endoscope that is a high-quality medical borescope. If cor-

rosion products or pitting are revealed, the hole is checked a second time with a 70-or 90-degree (side-view) endoscope. When pits are detected, the beam is removed from the aircraft and the pits are removed by oversizing the affected holes. Beams showing slight corrosion may be left in service if periodic endoscope and ultrasonic shear wave inspections are made to detect possible stress-corrosion cracks that may originate at a pit.

Figure 7 illustrates typical stress-corrosion cracks that have occurred in 7079-T6 Al main landing gear attach forgings. Large cracks are detected by a careful visual inspection. As illustrated in Figure 8, smaller cracks, originating at fastener holes, are detected by removing the fasteners and performing an eddy current inspection using a surface plug probe.

Intergranular corrosion occurs along aluminum grain boundaries, which in sheet and plate, are oriented parallel to the surface of the material due to the rolling process. (Intergranular corrosion in its more severe form is exfoliation corrosion.) Exfoliation corrosion is basically intergranular delamination of thin layers of aluminum parallel to the surface, with white corrosion products between the layers. Where fasteners are involved, the corrosion extends outward from the fastener hole, either from the entire circumference of the hole, or in one direction from a segment of the hole. In advanced cases, the surface bulges upward (Figure 9), but in milder cases there may be no telltale bulging and the corrosion can be detected only by NDT methods.

Hidden Corrosion

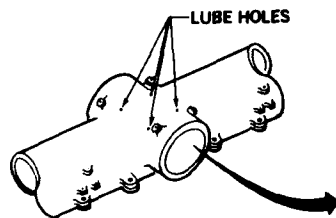
In the case of hidden corrosion, several NDT methods are being used:

- X-ray and Thermal Neutron Radiography
- Ultrasonic
- Eddy Current
- Acoustic Emission

Radiography

Radiography is used to facilitate inspection of complex structures and to provide an over-

INSPECTION METHOD:
VISUAL ENDOSCOPE



BEAM CORROSION CAUSED
BY FAILURE TO APPLY LUBRICANT

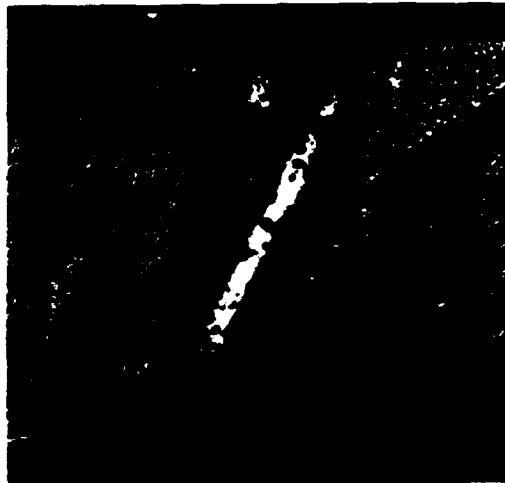


Figure 6 — Pitting Corrosion and Stress-Corrosion Crack in Steel Main Landing Gear

INSPECTION METHODS

VISUAL

EDDY CURRENT

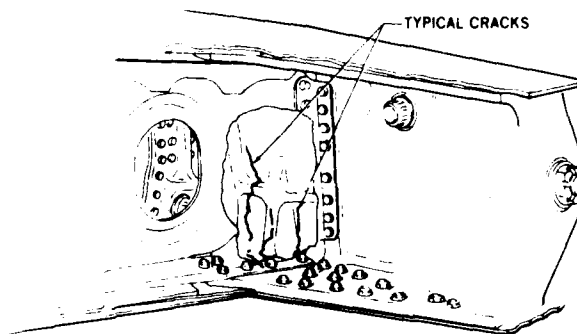


Figure 7 — Stress-Corrosion Cracking of 7079-T6 Main Landing Gear Attach Forging

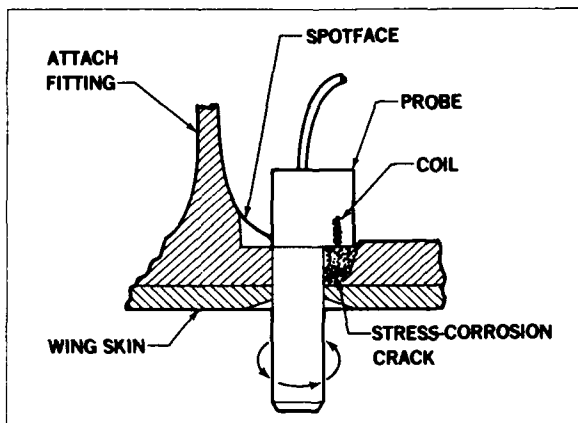


Figure 8 — Eddy Current Check for Stress-Corrosion Cracks in Main Landing Gear Attach Fitting

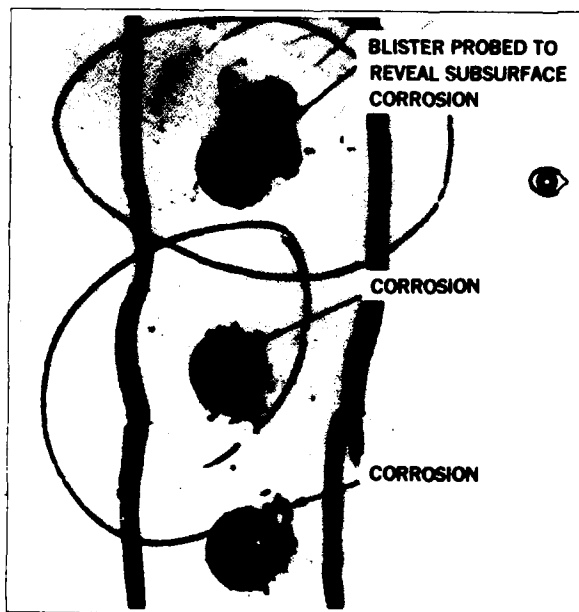


Figure 9 — Surface Manifestation of Subsurface Corrosion Around Installed Fasteners

view of the status of a complete assembly. It has also been used to detect pitting corrosion in tubular steel cylinders. Generally, X-ray radiography lacks sensitivity or produces low-contrast radiographs, unless beryllium-window X-ray tubes that produce soft (low-energy) radiation, are used. The changes in thickness, to be detectable, must be on the order of one-to two percent of the total thickness. Radiography may be used to detect stress-corrosion cracks when the radiation beam is parallel to the plane of the crack.

Figure 10 is a radiograph showing water-filled honeycomb cells and corrosion attack of the core. Moisture intrusion in to assemblies of this type has caused considerable damage to similar aircraft structures over the past decade. Low kilovoltage X-ray radiography, using a beryllium-window X-ray tube, is the major NDT method used to detect corrosion of adhesive-bonded honeycomb structures on the aircraft or in maintenance shops. Tap testing or ultrasonic bond testing instruments are sometimes used to detect delamination (unbonding) in these adhesive-bonded structures. Similar procedures are used to detect corrosion in adhesive-bonded metal-to-metal laminates.

A more sensitive radiographic method is thermal neutron radiography. It can detect corrosion products because oxygen has approximately an order-of-magnitude-higher mass-absorption coefficient than aluminum. This reveals the presence of corrosion products

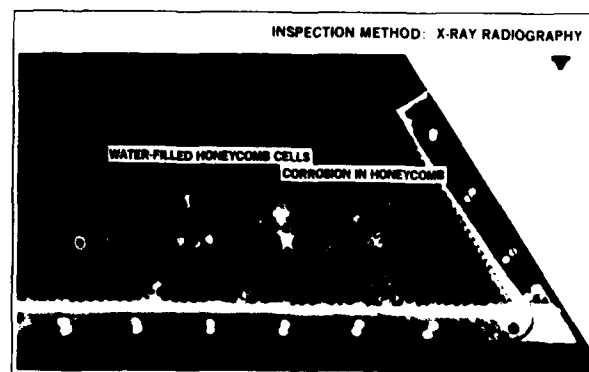


Figure 10 — Corrosion of Aluminum Honeycomb Core by Water Intrusion

as well as metal thinning. If moisture is present in the corrosion products, then the hydrogen atom adds additional absorption of the neutron bearer, which provides additional contrast to the neutron radiograph. Two major obstacles are encountered in applying this technique: the state-of-the-art practical thermal neutron sources are not portable and require long exposures because of the low flux; and the presence of hydrogen compounds such as trapped moisture, fuel, or sealing materials, can mask the corrosion products and reduce detectability.

Ultrasonic

Ultrasonic testing provides a sensitive detection capability for corrosion damage when access is available to a surface having a continuous bulk of material exposed to the corrosion. Stress-corrosion cracks or exfoliation are expressed by production of a new interface within the material that causes reflections in a shorter time period than reflections from the back surface.

As illustrated in Figure 11, ultrasonic testing has been successfully used to detect stress corrosion cracks in the 7075-T6 aluminum hori-

zontal stabilizer skin planks. The cracks run fore and aft from the attachment holes in the integrally machined plate stock. The cracks are detected by directing the ultrasonic beam normal to the crack plane. The inspection is performed from the external surface of the stabilizer center box.

Ultrasonic thickness gages are commonly used for detection of exfoliation, stress-corrosion cracks, and general material thinning. Pitting and intergranular corrosion cause scattering of the ultrasound and can be detected by the use of shear waves in an angular incidence. In addition, this scattering can result in attenuation of longitudinal waves (straight beam) commonly referred to as loss of back surface signal. This phenomenon serves as a means of corrosion detection in relatively thick structures. Its main limitation is that increased attenuation may also be caused by sealants or adhesives. Additionally, ultrasonics cannot provide any information about layers further than the probed one unless they are properly bonded.

The manual ultrasonic technique, for detection of exfoliation corrosion, requires the use of a liquid couplant on the surface of the

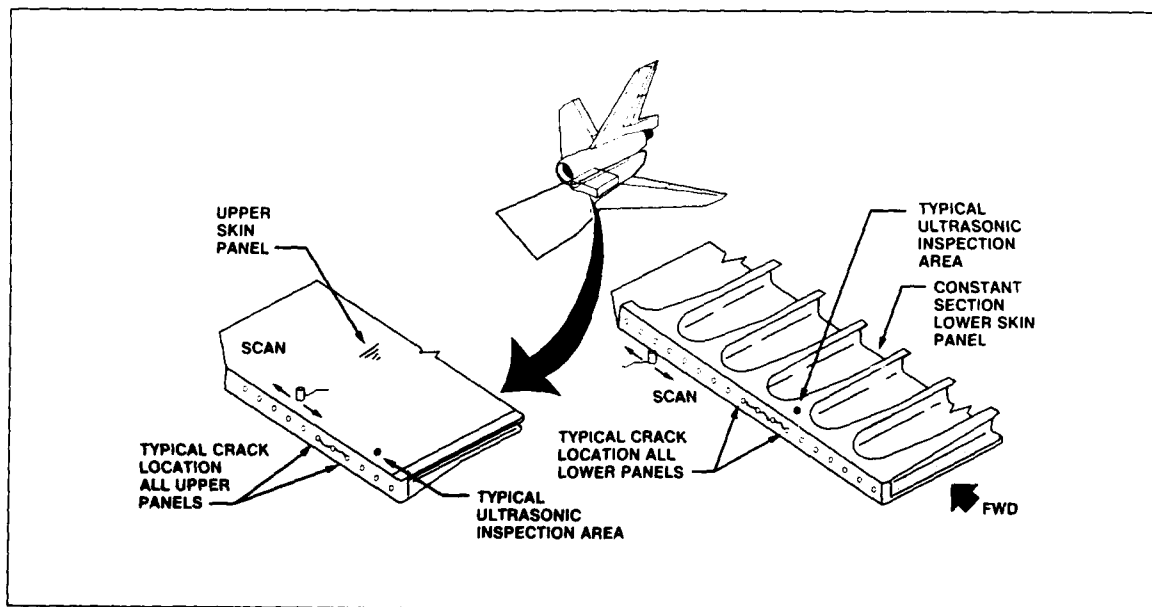


Figure 11 — Ultrasonic Detection of Stress Corrosion Cracks in Horizontal Stabilizer Skin Planks

test part. Small diameter [6.35-mm(.25-inch)] search units are employed to reveal small areas of corrosion. The circle template may also be used to guide the search unit around the periphery of the fastener head. Tests performed at both 5 and 10 MHz yielded equally good results. The ultrasonic detection of the exfoliation corrosion is based on the principle of both ultrasonic scattering and attenuation. When the search unit (probe) is placed over an uncorroded areas, multiple back reflections (thickness values) are obtained as depicted in Figure 12. However, when the probe is placed over an area of exfoliation corrosion, no back surface

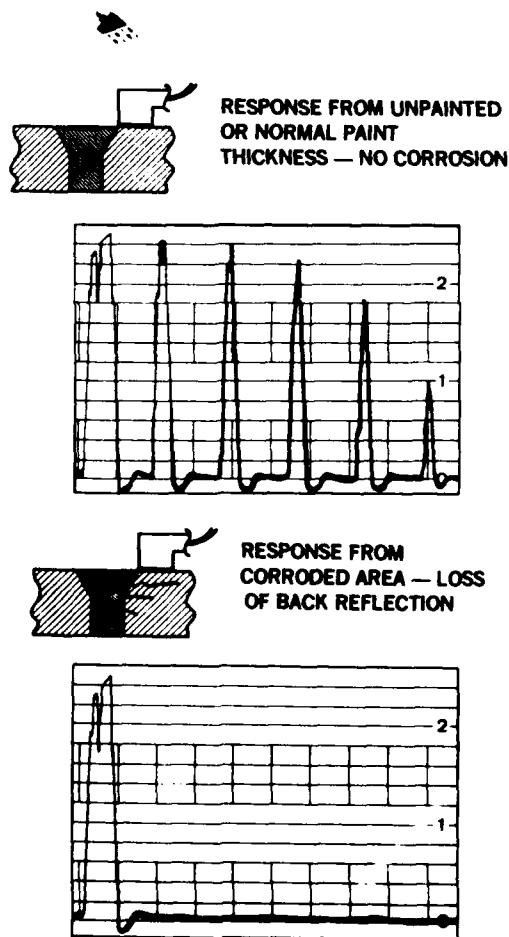


Figure 12 — Contact Ultrasonic CRT Response

reflection is obtained. This inspection technique is very successful in detecting medium to large areas of corrosion but will not find smaller areas that are detectable using the eddy current technique.

Eddy Current Testings

To perform the high-frequency eddy current test, the instrument is calibrated using a known corroded sample. Typical eddy current response to exfoliation corrosion around installed fasteners is shown in Figure 13. The phase angle on the impedance plane cathode ray tube (CRT) is about 45 degrees at 20kHz and about 90 degrees at 50kHz. Hence, a more reliable inspection can be performed at the higher frequency. The use of high-frequency (100 to 300kHz) pencilpoint probes and a circle template is necessary in order to detect very small areas of corrosion. The circle template is centered over each fastener and a 360-degree scan is made with the eddy current probe. The

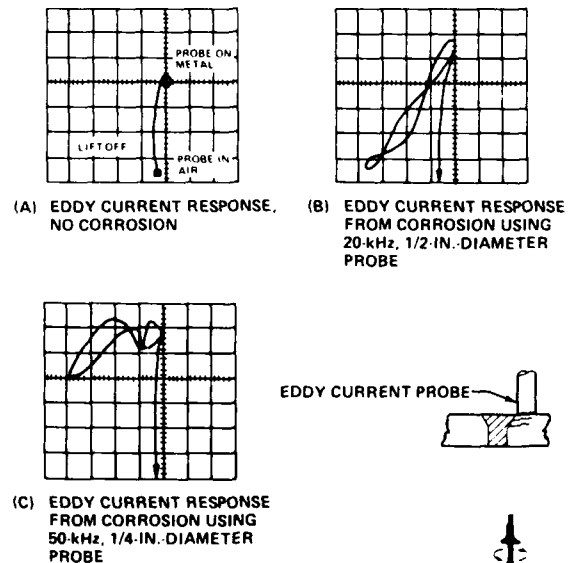


Figure 13 — Eddy Current Impedance-Plane Responses for Exfoliation Corrosion Around Fastener Holes in Wing Skins

corrosion response will appear on the CRT and remain there until electronically erased. This method is quite slow but has been shown to be accurate in the detection of very small areas of corrosion around installed fasteners.⁶

Eddy current testing (mainly low frequency) is being used to detect thickness changes, due to corrosion and cracks in multilayer structures. The use of eddy current instrumentation that indicates the amplitude and phase allows differentiation of corrosion thinning from spacing of layers, liftoff, and cracking. The low-frequency eddy current technique has been useful in detecting crevice or galvanic corrosion between aluminum skins and titanium doublers.

Whenever there is a contiguous fraying surface that can trap moisture between two dissimilar metals, a good possibility exists for the generation of galvanic corrosion. In the example of Figure 14, a titanium doubler was installed in the lower section of the fuselage and adjacent to the aluminum skin. The lower

portion of the fuselage (bilge) is a notorious collector of liquids and waste materials. Areas around lavatories, galleys, and batteries are especially susceptible to corrosion. In this case, moisture found its way into the crevice between the titanium and aluminum, and galvanic corrosion thinning occurred in the aluminum skin. The thinning is not detectable from the outside the aircraft until it has eaten completely through.

Acoustic Emission Testing

Modern adhesive-bonded aircraft structures are protected from corrosion by using bare (nonclad) aluminum, phosphoric or sulfuric anodic layers on the substrates, corrosion-inhibiting primers over the anodic layers, non-perforated honeycomb core and sealants over exposed adhesive fillets or fraying surfaces. Older bonded structures were made using clad materials, Forrest Products Laboratory (FPL) etch of the substrates, no corrosion-inhibiting primers, and perforated honeycomb core. These conditions enhanced the possibility for crevice galvanic corrosion attack between the adhesive and the adherents.

To further enhance NDI detectability of corrosion and water in honeycomb structures, personnel at McClellan Air Force Base in Sacramento, California developed the acoustic emission method for this purpose.⁷ The test is conducted by heating a local area of the structure and then placing an acoustic emission probe over the area and listening for emission caused by hydrogen gas or steam generated within (Figure 15). The test is conducted at about six-inch intervals over the entire structure. Reports indicate that the acoustic emission technique is capable of detecting both gross corrosion and corrosion initiation that is not detectable by other NDT methods. The method does give some false calls at times but is still considered the primary inspection method for checking honeycomb structures at McClellan AFB.

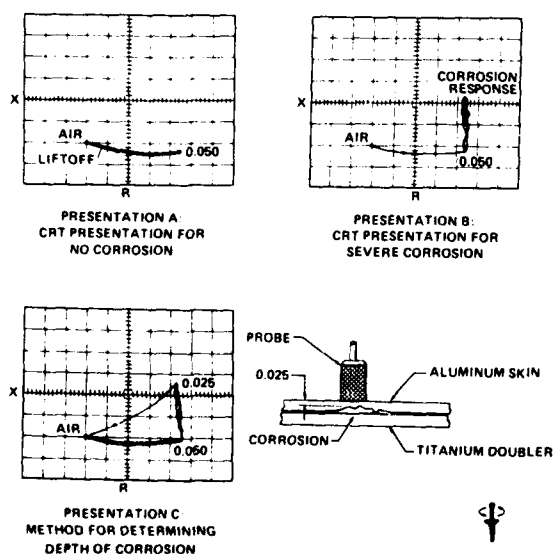


Figure 14 — Impedance Plane CRT Presentations for Corrosion Thinning

Corrosion Summary

Major concerns associated with corrosion, a destructive and costly enemy of aircraft durability, are that it is extremely difficult to predict,

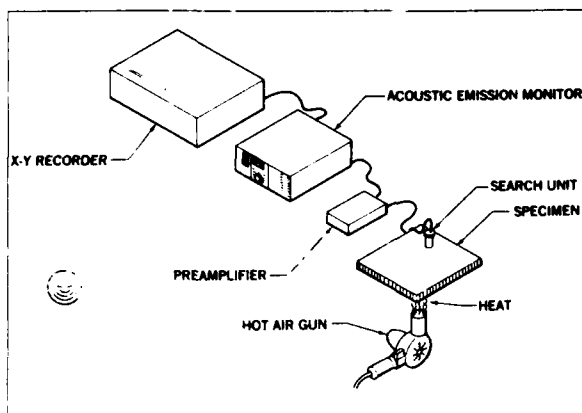


Figure 15 — Acoustic Emission Detection of Water Intrusion into Adhesive-Bonded Honeycomb and Corroded Laminates

to prevent, and to detect early in its formation. Access to corroding areas is frequently limited or impossible due to intervening structure. Therefore, conventional NDT techniques are often used to detect such corrosion and eliminate the costly and potentially destructive disassembly involved.

When the inspected area is physically accessible, visual inspection is commonly used for corrosion detection. Sometimes, tools such as magnifying glasses or borescopes are used for evaluation of less accessible areas. These inspections involve a search for change of color, texture, corrosion products, bulges, or cracks.

In the case of hidden corrosion, several NDT methods can be used: X-ray or thermal neutron radiography, ultrasonic, eddy current or acoustic emission.

- Radiography is generally used for its advantage in inspecting complex structures and revealing an overview of the status of a complete assembly.
- Ultrasonic testing provides a sensitive detection capability for corrosion damage when access is available to a surface with a continuous bulk of material exposed to the corrosion. Ultrasonic inspection is commonly used to detect exfoliation, stress-corrosion

cracks and general material thinning.

- Eddy current testing (mainly low-frequency) is being used to detect thinning due to corrosion and cracks in multilayered structures. High-frequency eddy current is most appropriate for detection of stress-corrosion cracks.
- Acoustic emission testing (employing heat-generated emissions) has been used to detect corrosion and moisture in adhesive-bonded metal honeycomb structures.

Although the above NDT methods have been used successfully to detect corrosion, with respect to the type of corrosion they can detect, they are not equal in the following areas:

- equipment
- size
- mobility or availability
- cost of performing the test
- availability of the test method to the operator

These test method factors are rated in Figure 16. Visual inspection is the primary corrosion-detection method. Non-destructive inspection is generally not used until corrosion has been detected during routine maintenance of the aircraft. Therefore, it is applied after the fact to similar structures on other aircraft in the fleet.

Gaps in Present Technology

Because NDI is an important part of aircraft maintenance programs, it must continually be improved to meet the challenges and demands of the industry. A few gaps still exist in the current technology:

- Specific NDI methods are used for each case of corrosion, based on:
 - Type of corrosion
 - Site of corrosion on aircraft
 - Access to corroded area
 - NDI techniques available to operator
 - Severity of corrosion
- Corrosion initiation or small areas of corrosion are difficult to detect
- Most NDI technicians have not been trained in corrosion detection

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DETECTION METHODS		EQUIPMENT					
		SIZE	MOBILITY	AUTOMATED	SPEED	COST	AVAILABILITY
VISUAL		SMALL	GOOD	NO	FAST	LOW	YES
TAP TEST		SMALL	GOOD	POSSIBLE	FAST	LOW	YES
ULTRASONIC		MEDIUM	GOOD	POSSIBLE	MODERATE	MODERATE	YES
EDDY CURRENT		SMALL TO MEDIUM	GOOD	POSSIBLE	MODERATE	MODERATE	YES
X-RAY RADIOGRAPHY		MEDIUM TO LARGE	FAIR	NO	SLOW	HIGH	MOST SHOPS
NEUTRON RADIOGRAPHY		LARGE	POOR	NO	SLOW	VERY HIGH	RARE
*ACOUSTIC EMISSION WITH HEAT		MEDIUM	FAIR	NO	MODERATE	MODERATE	VERY FEW SHOPS

* PARTS MUST BE REMOVED FROM AIRCRAFT FOR TEST.

Figure 16 — Rating of Test Methods

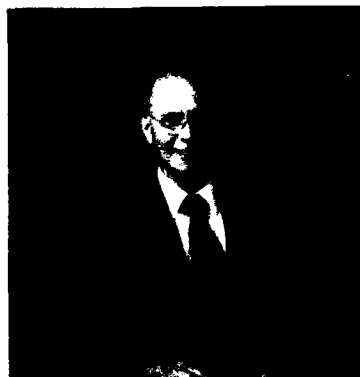
- Many NDE engineers are not familiar with corrosion-detection methods or techniques.

Improvements must be made in the above items to advance the state-of-the-art NDI technology concerning corrosion detection.

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ATA/NDT Forum



JAMES L. MORGAN

Manager, Inspection/NDT
Trans World Airlines

Good afternoon. It is an honor for me to speak before you this afternoon.

I am a member of the Air Transport Association Task Force on Non-Destructive Testing. This task force has had a number of responsibilities over the years. The primary responsibility of this group has been to conduct an annual ATA/NDT forum.

The purpose of this forum is to foster communication and cooperation on technical and practical aspects of NDT within the airline business. The first forum was held in Kansas City in June of 1957. In attendance were 36 representatives from 14 U.S. airlines and seven manufacturers.

At the first meeting the group was interested in exchanging ideas and information between the airlines, and other interested organizations, on X-ray methods for inspecting aircraft. By 1958, two foreign carriers, Air France and SAS, also attended the meetings as well as representatives of the then newly organized FAA. The first mention of ultrasonic and eddy current inspection methods appeared on the 1958 agenda.

The 31st ATA/NDT forum was held last August in Minneapolis. In attendance were over 340 people representing a variety of disciplines involving NDT activities. Representatives from 21 U.S. and Canadian airlines and 36 foreign carriers attended the latest forum. In addition to conducting this annual forum, the ATA Task Force has also been involved in many other endeavors. Among them are the creation of safety standards to be observed by airline radiographers; the establishment of a data file of the NDT equipment and a list of airframes and power plants used by each airline represented at the meetings. We have assisted in establishing the Spec 100 format of vendor produced NDT manuals covering their product. We have given assistance to the FAA flight standards service in the development of advisory circulars relating to NDT practices. Committee members have served as representatives on various national and technical committees and have provided reports on these functions at the regular ATA/NDT meetings. Examples of these include the American Society for Testing Materials, American Society for

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Nondestructive Testing, and American National Standards Institute.

Now, as in the past, the forum functions to present common problems and stimulate discussion among the members and manufacturers as to ways to solve these problems. Just this past August, at the forum, the Boeing Company representative presented papers on inspection of lap seams. This is an important and a very interesting subject to all air carriers. Many questions were asked and many answers were given on that subject. And, as Mr. Hagemaiier demonstrated, the same type of discussion that he just gave you is offered by representatives at the ATA forum.

Another subject that is of great interest to me is what it really takes just to go out and do an inspection. The manufacturers give us methods of doing it, but what are all the different things involved?

Among these I would list things such as the technique. The technique to do the job is dependent on the focus of the inspection. By focus I mean the direction of the inspection or the intent of the inspection or the orientation of the inspection. What type of a flaw is it? Is it a crack or is it corrosion or is it a void?

Where is the flaw? Once again we have to consider the orientation of the inspection.

How accessible is it? How much opening up is required. This is a consideration any time you have an aircraft out of service. Do you have the time to do it on the subject maintenance visit?

What sensitivity is required? This requires information from the stress people—they usually determine what the lead crack is and the propagation mode and this determines our inspections.

We must consider logistics in the equipment decisions. Can I afford a new Whizzit? Well, if I've decided I can and I've bought one, I might find that I have this nice piece of equipment, but I don't have the people trained in all of the places that I need to use it. Equipment sensitivity is continuing to grow with each change and state-of-the-art improvement that we get.

Flaw detectability goes along with the sensitivity required. The condition of the material

and the human factors will enter here. Is the instrument user friendly?

How complex is the application? To be effective, our instructions must be very clear. What supplemental equipment may be needed? There is usually a test standard involved. We need to consider the certification of the test standard. There is a project in one of our ATA committees right now to consider this and how to approach it with the manufacturers, and the vendors who sometimes manufacture test standards for us.

What are the inspector's qualifications? Is he experienced? Is he certified? Are his working conditions comfortable? Procedures may be written without first being tried in the real world, only to find that we provided access, but we can't get to it and the procedure doesn't work.

These are all important considerations, and they're all within the context of the ATA/NDT forum.

It is in this framework of the ATA that an Airline Inspection Task Force was formed. Our latest project has been to develop the curriculum for the in-house training of NDT inspectors. Once adopted by the carriers it will serve to standardize the NDT training program by specifying the minimum class content and training manhours.

Last January the task force received formal approval to proceed with this project. A draft copy of this document was submitted to the operators in April. They indicated their approval, with minor changes. The final version of this document is nearly complete for distribution as an ATA specification, ATA Spec 105. This is the recommended guideline for training and qualifying personnel in nondestructive testing methods.

This guideline will be available for each airline to use in the formulation of their training program for qualifying NDT inspectors.

An interesting finding during our discussions formulating these guidelines is the difference in management systems within which we must operate to accomplish the same thing. Each airline has a different labor contract relationship or there may be no contract at all. Those with no contracts are free to develop

James L. Morgan

specialty groups which management can control, and provide training and utilize people where needed.

Another airline may have a labor contract which allows little or no management control over who is selected. This system would suffer from many defects, including having to constantly train new people. Seniority is not a good criteria for the selection, training and qualification of NDT personnel. However, with the use of this document, Spec 105, a program can be set up to be compatible with any management situation. It will provide a tool for the airline to implement their in-house program for the most efficient, effective inspector training by using the same technical terms and equipment that is in use by the group that he will be working in. It will be the most cost effective, due to the flexibility with which the training is available to the inspector.

The requirements of our inspections are determined by the aircraft. The methods we use to do the requirements are determined by the manufacturer. There are optional ways to inspect, but the procedure is determined by the manufacturer. There are also mandatory inspections, which experience has shown should be thoroughly understood and followed.

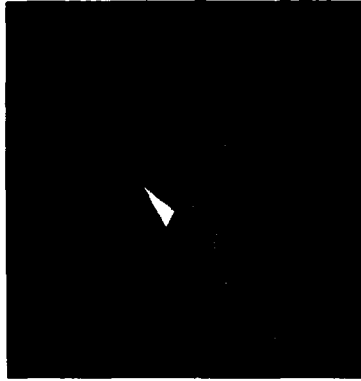
The methods of NDT inspection are many, there are tried and true techniques. There is a need for innovation in these fields to aid in maintaining and extending the air worthiness of the nation's aircraft. I have spoken about the result of the inspection being dependent on the accurate statement of the inspection procedure, the training and qualification of inspection personnel and the equipment and facilities needed.

Included in any talk of NDT inspection should be a "wish list." I would like to see any new system to be reliable and cost effective. Give us improved detection with computer enhancement; and reduce the incidence of false finds — the bane of all NDT inspectors. To make a first-find crack inspection with a rapid, large area inspection system would be the ultimate tool, but it seems to be contrary to all that is in existence today. A first-find crack would be at the onset of the cracking problem, which would mean you are looking for a very small crack. All of our systems for detecting small cracks inspect a very small area with each scan. The large area scan is used where you are looking for a large defect.

The ATA/NDT forum has served well to help the airlines stay abreast of the needs and issues in our industry. Airlines share a common problem, aging aircraft. This phenomenon will not just go away. Its demand on maintenance and inspection functions will continue and increase. Nondestructive testing shares this problem. It's the lion's share. It's this share that is causing the rapid change in the NDT operation. It is evolving from a sometimes used tool, to a continuing series of mandated or mandatory NDT inspections. Each of these inspections require a greater and greater degree of expertise and more and more man-hours of inspection.

The demands placed on NDT inspectors as a result of this increased work load call for the best possible training and equipment to ensure they have the best technical skill and equipment to accomplish his job.

NDT Evaluation



BRUCE A. KOTZIAN

FAA Aviation Safety Inspector — Maintenance

Good afternoon. Yesterday morning Mr. Ramakis addressed this conference on ongoing aircraft maintenance evaluation by the FAA. Part of the evaluation is to examine the operator's nondestructive testing program. I've been asked to give a thumbnail sketch of what areas of nondestructive testing (NDT) are being evaluated.

Each evaluation team spends about two weeks performing the evaluation at each of the operators. The first week is spent reviewing the paperwork. We take a look at the NDT manuals and their contents. We examine work procedures by reviewing the work cards and NDT techniques used by the operator. We evaluate the manufacturer's service bulletin, matching that against the techniques used by the air carrier and we review the operator's training programs, classroom training, on-the-job-training and the experience of the NDT inspector.

The second week we evaluate the aircraft in its heavy maintenance "D" check. We evaluate the NDT inspector performing the actual inspection on the aircraft, on all shifts. We sit

down with the inspectors on each shift and query their observations on NDT procedures and training. We also review the operator's NDT equipment to see if it meets today's demands, plus we are interested in what steps have been taken to have state-of-the-art equipment to meet the future needs of aging aircraft inspection.

All this data that we're acquiring is entered into our computer program along with other aging aircraft evaluations. And as Stephen Bobo discussed, we're on the 11th aircraft and we're going up to 90.

What are our observations so far? We have found some operators using some antiquated equipment even though they have the state-of-the-art equipment on hand. In many cases the NDT section is not separate from the quality control department, which presents training problems for the operator. The lack of standardization between the manufacturer's service bulletin presents a problem for the operator. Most operators seem to have a difficult time in purchasing state-of-the-art NDT equipment and

Bruce A. Kotzian

there isn't any standardization in the training programs between operator to operator nor to the manufacturer.

In summary, as I said earlier, there are 11 aircraft that have been evaluated, and we plan

to look at approximately 90 aircraft total. We hope to have a good idea on how the operator performs nondestructive testing. We will look at the problems that he faces and help him solve them.

Session V: Human Factors



CHAIRMAN WILLIAM T. SHEPHERD, PH.D.

Manager, FAA Biomedical and Behavioral Science Branch

When we were asked to take part in the Aging Aircraft R & D program, we thought this would be a pretty tall order. We have done a fair amount of work on air traffic control problems and we had to grapple with just what it is we could do, what we could produce for this program.

After some debate we decided the best thing we could do would be to provide information. That is essentially what we are going to do for the next couple of years. We are going to provide information that will be useful to designers, manufacturers, and, included in that of course, would be the people who deal with things like maintainability.

We want to try and help the air carriers and their maintenance operations including, repair stations and not the least of which — the FAA. We want to provide a compendium of information and we'll call it a handbook for now.

We may end up with things like video tapes and other forms of media. But what we want to do initially is provide information dealing with such topics as information transfer. How do you write an AD? What's a good

way of presenting a service bulletin? What are good ways of writing work cards?

We want to provide a sort of menu or selection of things that would be useful to a wide audience. We would like to talk about things like training and selection of maintenance technicians and inspectors. We want to deal with questions related to the work environment. What constitutes a good one and what are bad things to have in your work environment?

Equipment, maintenance equipment, job performance aids — there are all sorts of new technology coming on the scene now and we would like to be able to describe that. Also worthy of scrutiny are inspection methods, human limits and physiology, vision, color vision, vigilance, boredom and complacency. Those topics that are very prominent and have been shown to be important in recent years.

We have already started our research activity. One of our speakers this morning will tell you a little about some of the work already done at Pan Am at JFK.

We send our people on aging fleet evaluation visits. So far we have been to United, Pan

William T. Shepherd

Am and Aloha. We have been to Henson at Salisbury, TWA at Kansas City and Tramco, a repair station in Everett, Washington. There are many more site visits planned and we intend to have more of our people on each one of these.

The intention is to try and gather as much data and information as we can related to human factors aspects of the maintenance inspection business. We have some of our people from CAMI, the Civil Aviation Medical Institute in Oklahoma City, managing this particular task.

We are also looking at human factors associated with nondestructive inspection, human engineering of equipment and training issues.

What we want to do is to get as much input as we can to our program. Since we are hopefully providing useful information we really need to get a lot of this from the user community, that is, the industry.

By all means, feel free to communicate with us on things you think are important to this effort. Our ultimate product is going to be an information compendium covering all those topics I mentioned earlier plus others, too.

We have already held one human factors

conference. We held a kickoff conference last year. We used it to scope the problem and to calibrate things for ourselves, and in that conference we identified a number of topics that were more prominent than others.

Among them as I mentioned earlier, are information transfer and training. Now we are planning another conference for December 1989. We are going to dedicate that conference to the one topic of information transfer.

We hope to deal with a whole spectrum of issues. We are in the process now of formulating our speaker list and we would be happy to take any suggestions on that too. What I would like to ask any of you who would be interested in providing us some input, is make your wishes known to me.

We want to get information from air carriers, training organizations, people who are in the business of training A & P mechanics and the training organizations within air carriers. We also would like to talk with NASA and DOD representatives since they may have some special expertise that may be applicable to the civil side. And of course, we want to talk to the academic community. We intend to have our next human factors conference in June 1990.

The Vigilance Phenomenon



EARL L. WIENER, PH.D.

Professor of Management Science
University of Miami, Florida

I'd like to talk to you today about a basic human factors phenomenon, the vigilance phenomenon and the problems when we apply that to the inspection of one kind or another.

The vigilance story has an interesting history, which I'll briefly give you. During WW II when the RAF was flying long missions over the Bay of Biscay on anti-submarine patrols hoping to catch a surfaced submarine, it was noticed that the radar operator seemed to be the last one to see the target on the radar scope.

Someone else would walk past the radar scope, bend over and say, "How about that one right there?" The radar operator would say, "Oh, yes! I never saw it." So it looked as if the person most qualified and in the best position to spot the radar target on these long, monotonous patrols was the one least likely to do so. The problem was taken into the laboratory and this was the beginning of the scientific study of human vigilance or watchkeeping, and it was found that the decay curve for alertness was very rapid, far more rapid than anyone had ever thought.

In a matter of less than half-an-hour the

probability of detection started to drop to about half of what it was under alerted conditions, and continued to drop throughout the flight.

Let me outline what I am going to cover today. In the basic vigilance process, I'll talk about how it is applied to inspection and what the problems of the inspector may be, and then look ahead into the future.

These are the elements of a vigilance task. First, the signals are subtle. By the signal I mean whatever it is the person is looking for, be it a crack in a component of an aircraft or a defect in a manufactured good or a surfaced submarine showing on radar — that's a signal.

A vigilance task looks at signals that are subtle. They have a low signal-to-noise ratio and often they are evanescent, that is, they may appear and then disappear rapidly and the vigilant inspector has to catch it while he can.

There are a class of signals which expand and become more conspicuous over time. I am thinking of something like a radiologist looking at an expanding tumor. That is, month after month he may x-ray a patient and the target in this case would be a tumor which is getting

more and more conspicuous as time goes on. But for the most part in your industry, we're talking about flaws which are fairly constant, although I suppose one could argue that a crack might open up and become more conspicuous over time.

The second feature of the vigilance task is low signal rate. That is, low probability events. Namely, the lower the probability of the event, the lower the probability of detecting it.

The final feature is that the events occur with temporal uncertainty — they are random in time. One cannot predict the appearance of one of these events and, furthermore, they are independent of previous events. That is, after you see one of these events it is no more or no less likely that another event will occur in any specified interval following this.

Figure 1 shows the typical vigilance function, the decline of vigilance or probability of detection over time. The time period in this particular experiment was only 48 minutes and the decline in the probability of detection is apparent.

This is the so-called vigilance decrement and it appears in almost every experiment that

has ever been done. We can duplicate the radar operator and his loss of vigilance in the laboratory very easily. We see from the first to the second twelve minute period a drop from 70 or 75 or so percent down into the 60 percent range and then it continues and levels off. Sometimes one sees an upswing in the last period of the experiment.

Figure 2 was an experiment in which subjects were trained the first day by various training methods and then on the second day, labeled Day Two, they ran under the most sparse condition with no training aids available. You see the slight increase in performance, which was realized with an investment of only a 48-minute run.

In general, with vigilance and inspection tasks, practice alone does not improve performance. But one can find training methods that are effective in increasing the performance level, that is, the probability of detection. Merely practicing the task, continuing to do it over and over does not lead to an improvement in performance. But there are methods that can be applied that will increase the probability of detection of the signals.

The signal rate effect in Figure 2 and the parameter of those 16, 32 and 48 curves, were the number of signals that were introduced during the 48-minute experimental run. You could think of that as the number of defects that would appear as the person did an inspection task over a 48-minute period.

The larger the number of defects, (the poorer the quality of the product) the higher the probability of detection. This is one result that has held up for years from one experiment to the next. It is almost irrefutable in its constancy and a conclusion one might draw is that a higher quality product will lead to the worst inspection. When the probability of a defect being present is low, the probability of finding it will be low.

Figure 3 shows more data from the real world of inspection. This vigilance curve is one that I produced a number of years ago by creating a computer driven adaptive vigilance task such that the size of the signal increased if the inspector missed and decreased if he caught the signal.

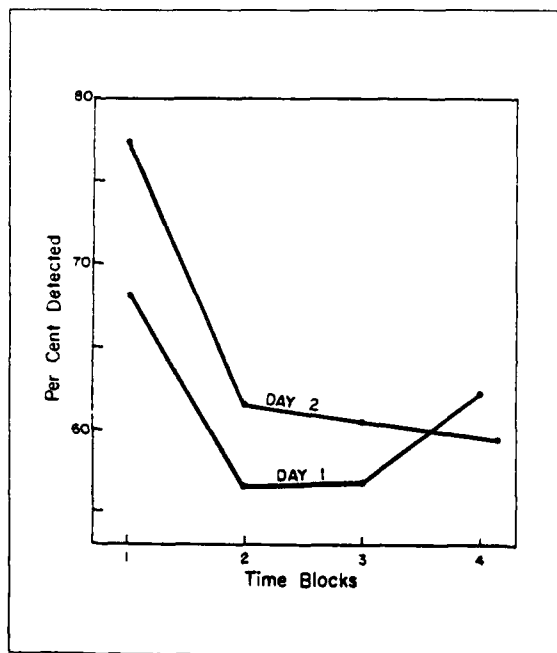


Figure 1

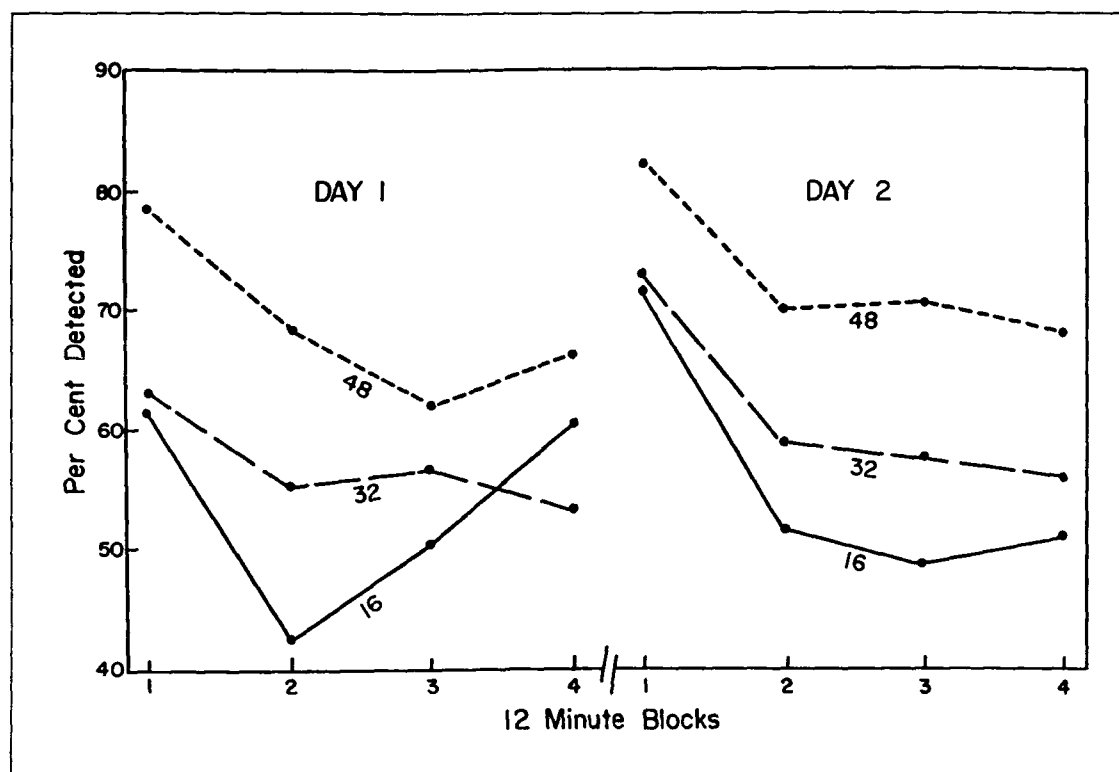


Figure 2

Therefore, the size of the signal was continually adapting according to his proficiency, set for a target detection rate of 75 percent. If he fell below 75 percent, the gap opened up, so to speak. And, if he overperformed by detecting better than the target of 75 percent, the task got harder. So it got harder or easier depending on his level of performance, and as you can see this is the width (w). The curve is drawn upside down to make it look like a typical vigilance curve. As before, 32 signals were presented in 48 minutes, and the width of the signal necessary to lead to a 75 percent detection rate, increased, a new definition of vigilance decrement.

The application to your area is that if you want a constant probability of detection, you can expect that over time the vigilance rate, the size of the signal (defect or flaw) one looks for, must increase. If you are looking for constant size signals, as before, the probability of detection will decrease.

Let us focus on the human inspector with

the point being that the human inspector is influenced by the environment, physical and social, in which he operates. He is not operating in a physical or social vacuum. He is influenced by economic conditions. He is influenced by social conditions, including peer pressure from his fellow workers and managerial pressure as well, often managerial pressure to pass goods rather than to reject them.

He is also affected by standards, specifications, training, experience and the payoff to him is the cost of the two types of errors he could make. Figure 4 is a typical decision payoff matrix.

When there are only two choices, the inspector can accept or reject an item and there are two possible conditions of the item. The product can either be effective — good, or defective — poor. One can then cast this into a two-by-two decision matrix.

If the product is good and he accepts it, that is a correct decision. If it is defective and he

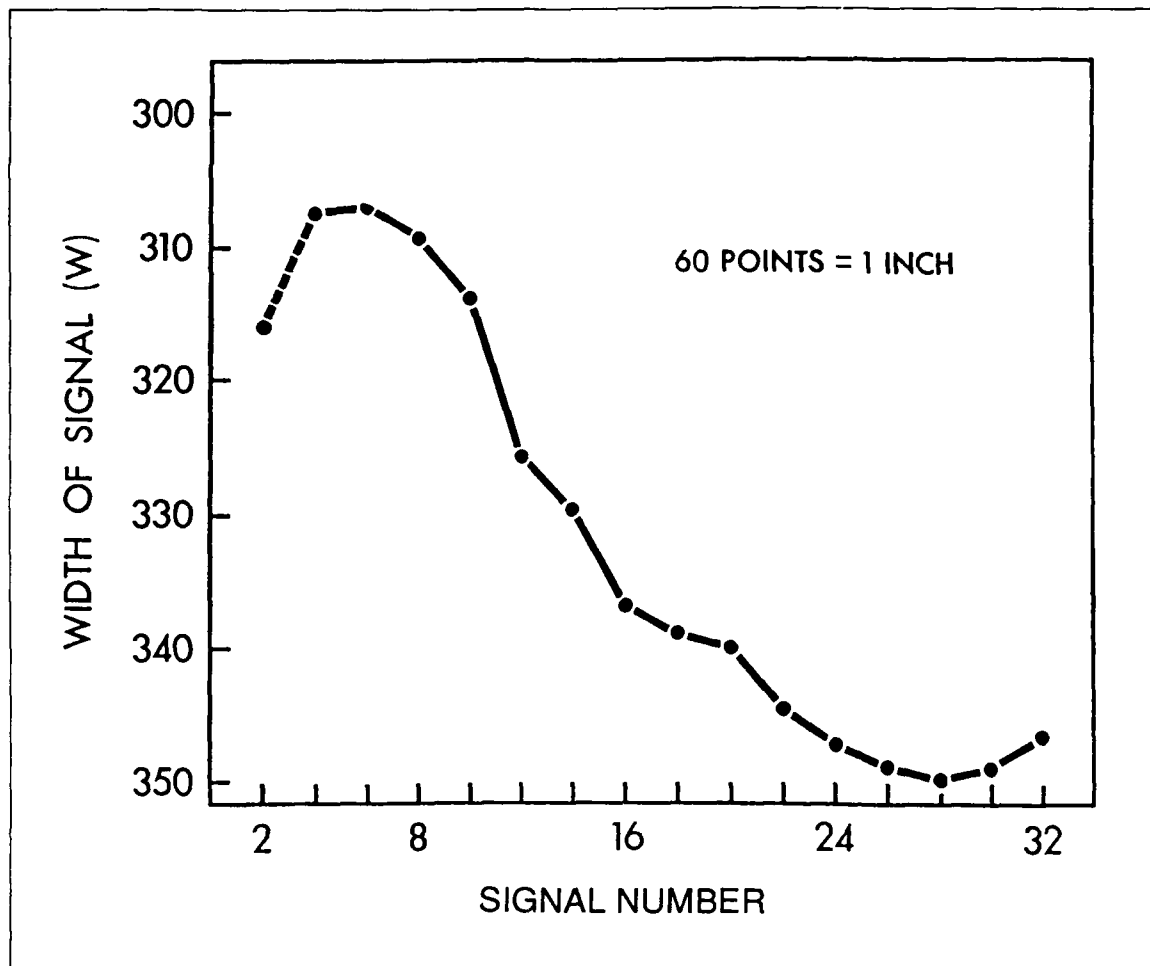


Figure 3 — Airframe Structural Integrity Program

rejects it, that is correct. But let us focus for now on the two erroneous decisions that can be made.

One erroneous decision is that the product is effective but he rejects it. That is called a Type One Error. That carries a price, V_{re} , the value or cost of a false rejection.

The cost would be acceptable goods that have been rejected and carry the price of reinspection or scrapping something that is good—all the work that would be involved in either reclaiming or replacing rejected goods that should not have been rejected.

Perhaps far more serious would be another corner of the two-by-two matrix and that is when defective goods that are passed on, Type

Two Errors. They carry with them a price, V_{ad} , which would be the value or cost of accepting a defective item.

What the inspector must do is balance the cost of those two errors. One cannot eliminate those errors altogether but one tries to minimize the total cost of those two items. Let me give you a few examples of detection rates from real world inspection tasks published in the inspection literature and I ask you to focus on the last column in Figure 5. These are typical inspections where the goods are reinspected and the rate of rejection can be found. The percentage of detection is alarmingly low.

These are real world, not experimental, data. You see detection rates as low as 30

		PRODUCT EFFECTIVE	PRODUCT DEFECTIVE
DECISION	ACCEPT	CORRECT ACCEPTANCE Vad	TYPE II ERROR
	REJECT	TYPE I ERROR Vre	CORRECT REJECTION

Figure 4 — Decision Payoff Matrix

AUTHOR	DATE	PRODUCT	% DETECTED
Jacobson	1952	Solder joints	83
McCornack	1961	Various	30-91
Chaney/Teal	1967	Machine parts	30-50
Sheehan/Drury	1971	Metal hooks	57-80
Fox	1964	Metal coins	55
Jamieson	1966	Telephone equip.	41-70
Rigby/Swain	1975	Various	30-90

Figure 5 — Examples of Accuracy in Inspection Tasks

Earl L. Wiener

percent there. The average is somewhere around 60 percent. In other words, an awful lot of goods are going through.

Figure 6 does not show the false rejection rate, those cases where good, acceptable, effective goods are rejected. There can be more than two states. It is possible to classify product into k states, yielding a k-by-k decision matrix.

Figure 7 are data from 39,000 inspections of a small metal hook. This is a relatively high quality product; 98 percent of the hooks were effective and two percent were defective. About four out of five of the defectives were detected here and rejected; and about a fifth passed the inspection and became Type One errors.

So, in summary, I'd like to say that the vigilance problem is severe, it's built into the human. It is difficult for the human to maintain alertness over time, and that time period is far less than an hour, really more like half an hour, in which one would see a significant decline from an alerted condition to a far diminished performance curve.

There are things that we can do about it. We

can change the nature of the task and perhaps give better inspection tools and training as well.

I want to point out that there are ergonomic methods that can be used to overcome this problem. But it cannot be overcome by selecting better workers. That has not been proven to be effective at all. In fact, there is a kind of a reverse thought there. It has often been felt that the low end of the intelligence scale in the work force might be the best inspectors: dull people for dull jobs, but that has not been proven to be the case at all.

I have reviewed the literature on selection of inspectors in a chapter in Dr. Drury's book. Attempts to improve inspection performance by going out and selecting the right people to do the job have not proven to be effective at all.

So I would put my money into ergonomic improvement, job redesign, better tools and better training; and, not be led into the trap that there are some good guys out there, if you could only find them, test them and bring them in.

INSPECTOR'S CLASSIFICATION	QUALITY 1	QUALITY 2	QUALITY 3	QUALITY 4	QUALITY 5
	V 1.1	V 1.2	V 1.3	V 1.4	V 1.5
	V 2.1	V 2.2		OVER-RATED	
	V 3.1	V 3.2	V 3.3	V 3.4	V 3.5
		UNDER-RATED		V 4.4	V 4.5
	V 5.1	V 5.2	V 5.3	V 5.4	V 5.5

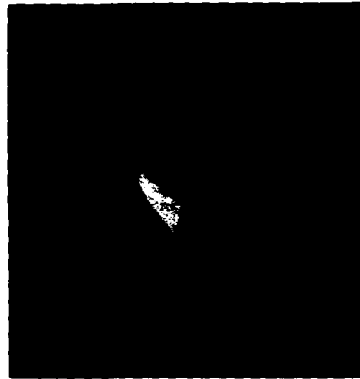
Figure 6 — Utility Matrix for K-States

DATA FROM 39,000 INSPECTIONS

INSPECTOR'S ACTION	PRODUCT DEFECTIVE	PRODUCT EFFECTIVE	TOTAL
ACCEPT	134 (.0034)	38,195 (.9793)	38,329 (.9828)
REJECT	646 (.0166)	25 (.0006)	671 (.0172)
TOTAL	780 (.0200)	38,220 (.9800)	39,000 (1.0)

Figure 7

Industrial Inspection



COLIN G. DRURY, PH.D.

The Center for Industrial Effectiveness
State University of New York, Buffalo

I am going to talk about inspection, particularly industrial tasks, so I am beginning where Earl Wiener ended.

He showed how a human being does an inspection job, starting off with laboratory data and then moving to field data from inspection situations in factories. I am going to start straight out with inspection data from factories. Almost all the data I have is from actual plants that we have worked in. This is not laboratory oriented work.

For many years we have studied human factors inspection and quality control in manufacturing industry. The challenge is to apply it to the industry of aviation inspection, aviation maintenance.

The human as a technical system is what I want to emphasize first. We know a lot about the human as a mechanical, cognitive system, a system you can put numbers onto and get data from to find out how to do things better and how to optimize. Next, I want to give you some case studies from manufacturing. I have chosen a couple which have shown how you

can inspect better, how you save money by doing good human factors work. Then I'll talk about what we can change and what we can't change and, finally, how we proceed from here—my views, not necessarily the official views of the FAA.

The challenge is to take a typical aircraft inspection situation and find out how to do it better. We are just starting task analysis of inspections. We are visiting inspection and maintenance sites to analyze how the job is being done as a starting point for how we can help people do it better.

You can treat inspection as a single task or take it apart into its components. I am going to break them down a bit using simple task analysis or task description of an inspection job.

A part comes to the inspector who, first of all, searches to find if there is anything there that is of interest. The search can either be visual, (and I will concentrate on visual search today, because it is an area you can quantify and it is still the cornerstone of lot of lot of our inspection) or it can be NDI or any other proce-

ture we are using for searching. Once the search procedure has found something called the flaw, something which is interesting — it may or may not be a fault — you then have to decide. Is it a good item? Is it a bad item? Is this fault too severe? Is it not severe enough? You have to compare it against standards.

So there is a search task, a decision task and then disposal of the item. In industry this means put it on the conveyor, put it in a different box. In aviation inspection it means write it up or take some other action.

This can be visualized as a model rather than a list. (Figure 1) An item comes to the inspector, who, if it is a visual task, fixates a small area. The inspector can only fixate a small part of this area because it is impossible to see everything in one glance.

If they find a flaw in it then they go into the decision making box in Figure 1. If they do not find a flaw in it then they go around and fixate another small area and continue the search process. If they find a flaw they get down into the flaw rejectable box and then decide whether to accept or reject the item.

But if there is no rejection, if the flaw seen is not sufficient to cause rejection, then they have to decide whether it is worth continuing to look. From Figure 2, the inspector decides whether there is time left to continue searching. Whether management or the inspector makes this decision, a decision will eventually be made. The inspector will eventually have to call this good item good. The point about this model is that it says the only reason you ever accept something is that you cannot spend more time to look any further for defects. The truth is that the only reason we accept anything is that we have decided that it is no longer worth searching.

From Figure 1, we can derive some consequences. First, if the item is in fact good, then to get down to the reject box, you have to do two things in series. You have to find a flaw that is not really a flaw, which means the search process has to fail. And, you have to call the flaw a fault, which it really is not, which means the decision process has to fail. Hence, if you want to make a Type One Error of a false alarm, you have to make two errors in series.

However, if the item is in fact faulty, then to

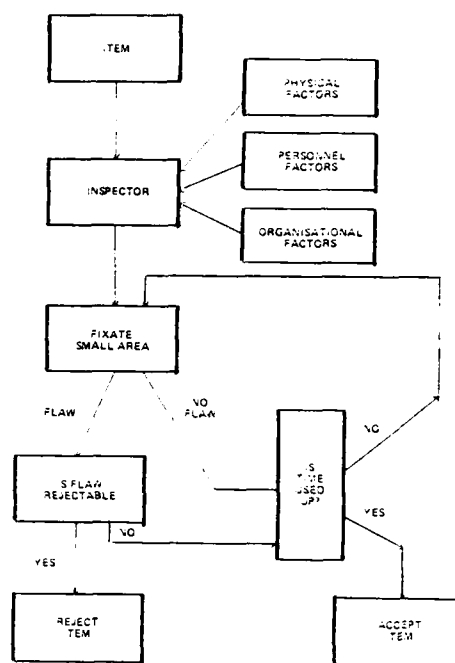


Figure 1

reach the accept box, you must do two things in parallel. Either the search can fail to find a defect, or when the defect is found, you can come to the wrong decision. So it is hardly surprising that there are a lot more errors in terms of missing signals than there are in terms of false alarms because one of them is a serial process and the other one is a parallel process. This model begins to explain some of the data that Earl Wiener discussed about why you tend to get more missed defects than false alarms.

We have seen that there are search and decision making in this simple task analysis. Those are the two error prone parts of an inspection job and we have to examine them a little more deeply to find out something about them.

Search can be visual, which I have talked about already. It could well be procedural as when you are searching lower rivets with an

NDI device to detect any cracks. That would be a procedural search rather than a visual search.

A decision to make is where you compare an indication to standards. You compare a blip or a trace on your machine against a standard that you stored in your head or a standard that you have physically used to calibrate the machine.

We thus have a model of the inspection process we can work with, a model which works just as well with pure manual inspection as it works with machine-aided inspection. The same thing applies equally well to totally machine inspected inspection. There is still a search portion and a decision portion. If you have ever analyzed the literature on, for example, printed circuit board inspection using purely automated devices, you can find exact parallels between what I am saying about the human and what is going on in the machine.

Let us examine in more detail one of the two error prone stages: visual search. Figure 3 shows an example of an industrial task where a person is searching for a bad solder joint. It is very difficult to tell when you have a good joint and when you have a faulty one. The inspector performs a search task of this sort by having an area in which the fault can be seen, a small area around the line of sight which is called the visual lobe. Within this visual lobe, you can see a defect. Outside this visual lobe, you cannot see it. The inspector searches the item by moving this visual lobe successively to different portions of the visual field. Some obvious consequences of this are if you have a fixed size of visual lobe then the longer you spend searching the more coverage you get and the greater your probability of detecting a fault.

Thus, something as simple as how long you give a person to do a task, is very important in visual search tasks. Search is what is called a resource limited task. It uses the human resource of searching and the more resources you can put in it, the better. You can tell resource limited tasks because the longer you give a person to do them the better job they do. Figure 2 gives an example. You can see a defect clearly within a certain area and outside that area you cannot. The actual size of the visual lobe of course depends on the size of the defect

you are looking for, the lighting, the contrast and many other factors. We can do the same thing for decision making tasks. Here we examine a flaw to see whether it is better or worse than standard. The standard may well be held in memory, which brings in another fallible human information processing component. Almost all of the components of the human being are fallible, as are almost all of the components of machines. In human factors engineering we are doing just as we do with any other human endeavor--trying to build an infallible system with fallible components.

Earl Weiner has discussed signal to noise concepts. A fault is a signal, a non-fault is noise and the Type One and Type Two Errors trade off against each other so that as you get more of one you tend to get less of the other. Decision is what is called a data limited task. Usually, the time taken to make the decision is fairly short. The inspector either comes to one decision quickly or comes to the other decision quickly. Looking at the fault for longer usually does not allow you to make a better decision, hence it is data limited. The data or the signal to noise ratio of the data coming in is typically poor, causing problems of decision accuracy.

To give you an example of a decision task, Figure 3 shows some work we have done on printed circuit board inspection where you compare a good board against a faulty board or potentially faulty board and the display gives you both of them together so that the inspector can do a direct comparison. You can make a comparative judgment of whether an item is faulty, rather than an absolute judgment, which is much more error prone. In decision tasks such as this, the two errors trade off against each other.

Figure 4 plots the two inspection outcomes against each other. Each point represents one of seven human inspectors in an experiment in the glass industry. The inspector whose point lies at the upper end of the curve finds about 80 percent of the defects but only accepts about 50 percent of the good items. The person whose point is at the bottom right finds 95 percent of the good items (so he does not make many false alarms) but, he only finds 30 percent of the defects. Neither performance is particularly

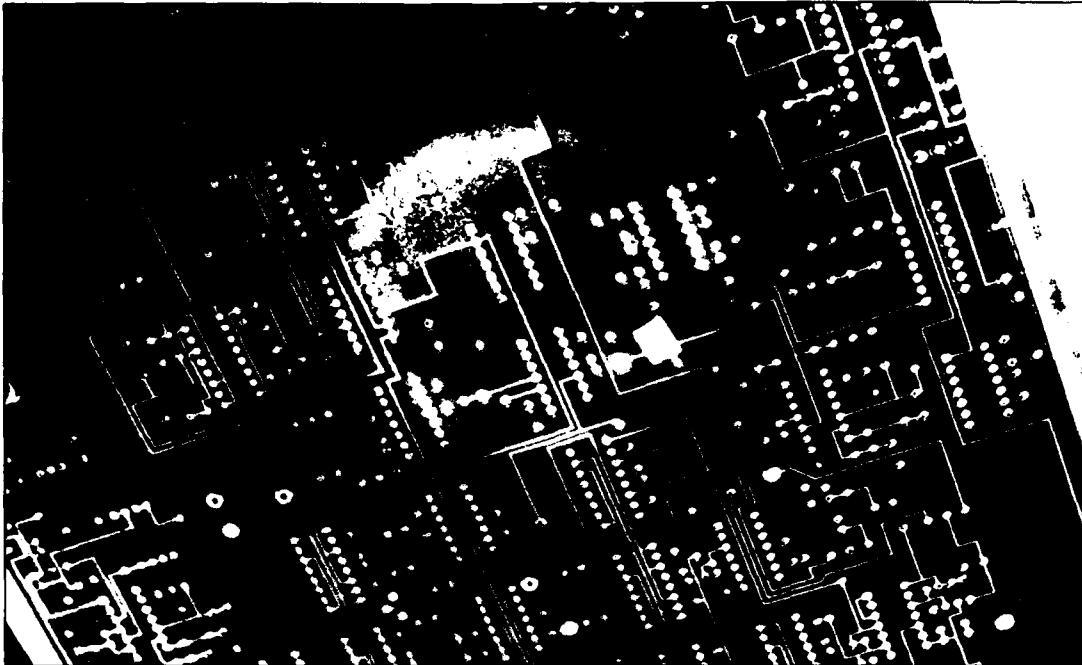


Figure 2

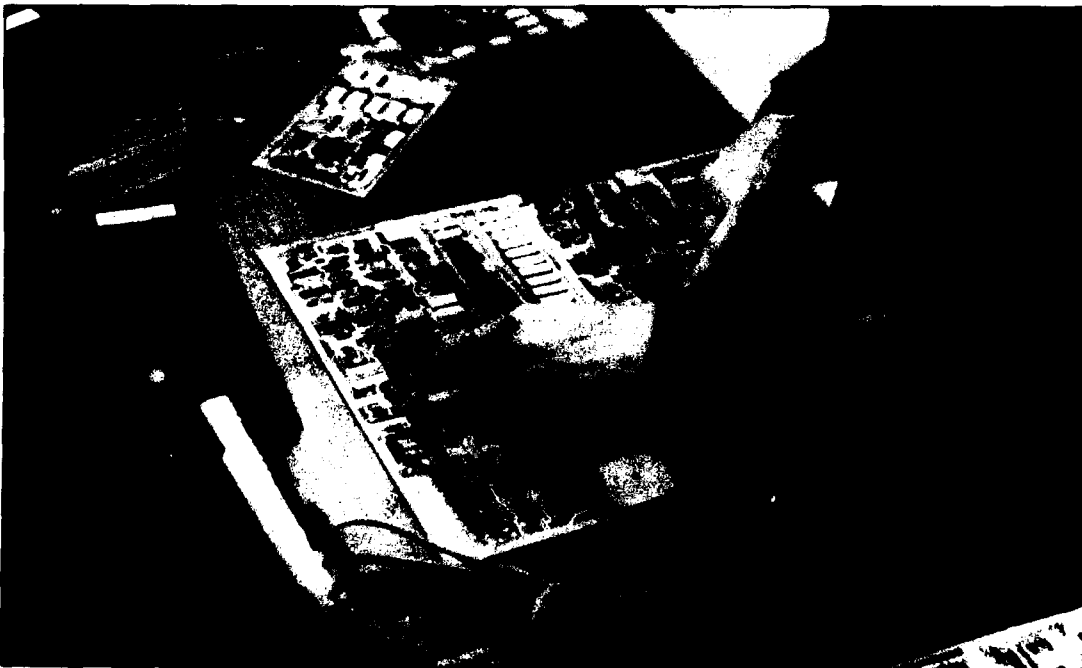


Figure 3

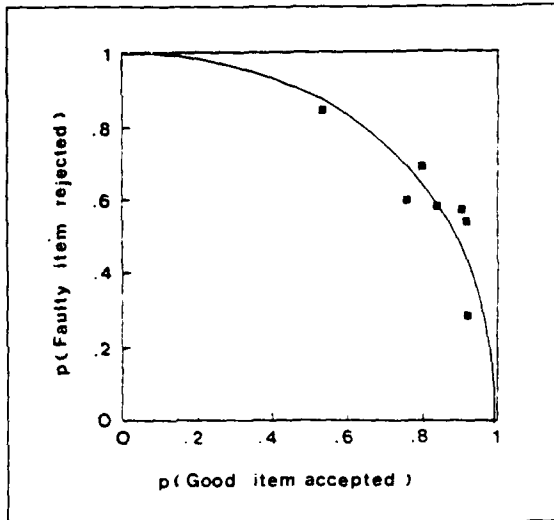


Figure 4

good. Such a graph is a natural consequence of the way people behave at a low signal to noise ratio. They trade one error off against the other. The question for us today is that when an inspector is looking at a particular area of an aircraft fuselage, how does he trade these two errors off against each other?

Fortunately, we have years of lab work to show us how people perform these trade offs and can begin to answer the question. Two case studies from the manufacturing industry show that we have been doing this for some time.

The first case is on the inspection of aircraft bearings for jet engines. We first performed an inspection task analysis to find out how this is currently done. We looked at many of the factors concerning how people perform this task, ran experiments on it and came up with improvements, many of which dealt with workplace design and many of which dealt with training. The company we worked for asked us to design and run a training program for the inspectors. We used off-line training, both to retrain existing inspectors and for the initial training program for people coming into the system. The inspectors had been doing this task from five to twenty years with an average of about ten years of inspection experience. We retrained them. Retraining them cut their error rate in half, even for people who knew what they were doing and had been doing it for a

long time. But as Earl Weiner said, there is a difference between training and practice.

Training people who had been doing it for a long time can make dramatic improvements in their error rate but we were able to take people off the street and have them more accurate than the current inspectors in a two-day off-line training program. They could do a better job at detecting the difference between good and faulty items on all the various criteria. This task was fairly complex and there were many different criteria.

The second case comes from the glass industry and involves inspection of sheet glass. Figure 5 shows the effect of a change to a new inspection system. The new system consisted of rapid feedback to inspectors, by performing a small sample check on the inspectors, to be able to help them do a better job. It involved telling them what sort of faults they were missing and telling them what sort of faults they were being too harsh about. In other words, we were giving feedback. Inspectors always have feedback because they get customer complaints but that is very slow feedback. The new system provided feedback within minutes of their making a decision.

Providing such rapid feedback resulted in a major increase in discriminability. A change in discriminability from 2.5 to 3.25, as shown in the figure, represents a halving of the misses for a constant level of false alarms. The change had an enormous impact on that particular facility at zero cost, because the company was providing feedback anyway. We just provided it more rapidly.

Human factors engineering recognizes that there are only two changes to be made. You can change the person to fit the job, or you can change the job to fit the person. Either way gives a match between the human and the job which is what human factors is all about. Fitting the job to the operator involves selection and placement, training and retraining. Fitting the job to the operator covers equipment design, environment design and job design. To perform any of these "fits", we need a model of the human being during the job. We already have seen two such models, visual search and decision making.

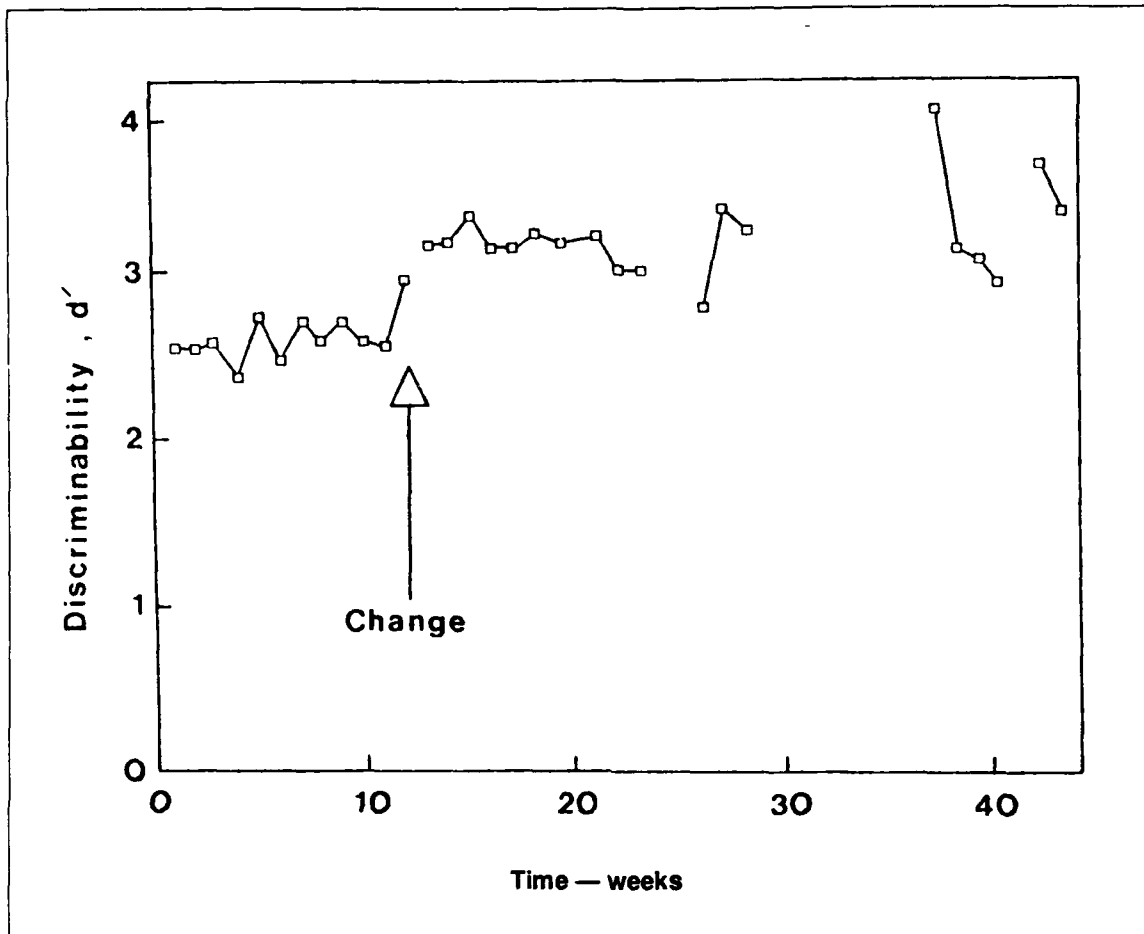


Figure 5

Let us consider the design of training programs. In progressive-part training, a task is built up from its components. The trainee starts with one part of the job, say A. This is learned to criterion. Next another part of the job, B, is learned to criterion. When both are mastered, they are then learned together to criterion. Then you add a third task, C. Learn to do all three to criterion, and so on. In each case, the trainee does not just sit there listening, which is probably the least effective form of training. You have to get active responses by the trainee and control feedback during training. Tell people how well they are doing and don't cut out the feedback entirely when they get into the plant. That is the difference between practice and training.

A second area of fitting the operator to the

job is selection and placement, which is a favorite because it apparently costs little to find the right person to fit the job. There are large individual differences in inspectors. Some people are better than others. So we would expect to be able to develop a good selection procedure for who is going to be a good inspector. What are the correlates of a good inspector? We have done a number of studies on this. What we found is that we can get some parts of our selection procedures to correlate with some aspects of performance, but the tests do not generalize well. A good inspector on this inspection job is not necessarily a good inspector on another inspection job. We have not found an "inspection type."

The best test we found is a small simulation of the actual task. If people do well on the

simulation, they are likely to do well on the task. After considerable work it is not a particularly revealing statement. We have to look at selection again in the aircraft inspection context but it is not where I would put my money for effective results.

Where I would put money is on job design and equipment design; decision aids at the work place. In Figure 4, showing printed circuit board inspection, you have two circuit boards and you can compare one to the other. This is an effective job aid. So is feedback to the inspector. Feedforward to the inspector is telling the inspector what to expect and also can be very powerful. Maintaining vigilance is equally important.

What is needed now is human factors input into the inspection process, which is what the FAA is sponsoring. Two things need attention; one is improving the number of human factors people who are going to interface with this system. If there are just two or three of us we cannot do the work required. The other aspect of this is to get what we know about human factors rapidly into the system so it can help in advance of the research findings that we hope to generate.

Here is the challenge. We would like to take an inspection situation in aviation and know as much about it as we do about industrial inspection, so that we can make the same sort of improvements as we did in industry. Improvements are there to be made and are cost-effective if we apply knowledge correctly to do this.

As an example of changes that are possible, consider the information used. Going around some of the inspection work places, I have seen pieces of information in hard copy (pencil and paper) pasted onto the wall. So I went back through my library and looked at rigging notes from WW I and found the same sort of things—points to observe when overhauling machines. I also went back to my father's notes, he was a fitter in WW II. His notes showed how to repair cracks and holes in windows of aircraft. He also had some diagrams of how to sew up the fuselage of a Mosquito bomber, which was made of wood. What I see is that things have not changed much. We still have information upon the walls

telling us how to do things and we have to go and get this information before we can use it. Technology is now getting to the point where we should be better able to provide this information to the operator at the working point. That is one of the things that I'd like to see us doing, supporting the inspector in a difficult and vital job.

The next steps are task analysis and task description. This is where we are now, trying to describe what has to be done in the whole maintenance field, and is one of the major jobs that needs to be done before serious research can begin. Task description tells us what people have to do. From this task description we take quantitative data on human capabilities and compare it with the task demands to create a task analysis. This tells us where the errors are likely and it also tells us how we should organize our resources to make sure that we are doing the right thing with the human factors input. It allows us to concentrate on those actions which will have the major impact on reducing inspection errors.

The short term changes are, getting knowledge out to industry quickly, getting more human factors involvement, and getting people in human factors fields who do not know aviation inspection up to speed so they can start working on these problems.

The next step is to aim for long-term changes with research on equipment design. From what I have seen of some of the equipment it does not fit good human factors principles. The signal and noise are not widely different on many instruments.

In environmental design, much of the aircraft inspection is performed in what industry would call peculiar environments, both in terms of the physical environment, (the lighting, the glare, the noise, the thermal environment), and also, the managerial environment (eg. coming in at night and having to get a lot of inspection done quickly so that the company can begin to schedule all the maintenance). There are many environmental factors in here: job design research, how you provide the feedback and feedforward in a sensible way. All of these depend on knowing the human operators as a technical system.

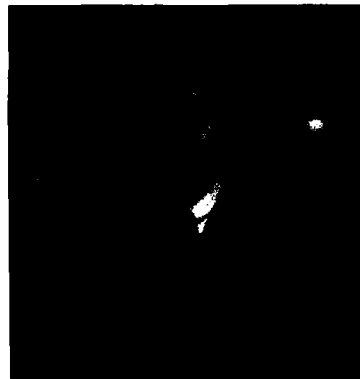
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Unless we have good quantitative data on the human being then we cannot design for the human being. This is where we have to interface between the human factors knowledge that has been generated in labs and factories all

over the world for many years, and with the particular system of aircraft inspection.

The challenge is to take a job that we all know well and make it easier and better for the operator to be more effective. Thank you.

Allies in Maintenance: The Impact of Organizational Roles on Maintenance Programs



JAMES C. TAYLOR, PH.D.

Professor of Human Factors
University of Southern California

Good morning, everyone. It is a pleasure to be able to attend this conference on aging aircraft and I am happy to be able to address you on a part of human factors that we often overlook in aircraft maintenance.

As air transport carriers are pressured to increase the number of passenger seats available, the job of the air carrier's maintenance system increases in complexity and becomes even more crucial for the quality of maintenance provided. This is a chaotic environment! The problem of aging aircraft is the most critical one facing an industry already confronted with more than its share of crises over the past decade. The need for reform in maintenance has become more urgent than ever before.

Attention to the human factor in maintenance is growing, thanks to conferences such as this one. There is a risk, however, in regard-

ing the human factor merely as an individual automaton, directed to use skills learned in vocational schools or in "by-the-numbers" military training. Instead we need to begin to understand and reform the network of relationships, commitments, loyalties and motivations of all human roles in air carrier maintenance — not only those of A&P mechanics, avionics technicians, inspectors, and their unions; but those of maintenance supervisors and foreman, technical trainers, maintenance managers and FAA inspectors as well.

Flexibility in and anticipation of response to unpredictable events and situations in a chaotic world is what is needed in maintenance today. Such adaptability requires a system of allies among the various maintenance roles, allies in their shared understanding of business constraints, passenger service and pilot support.

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But such reform has not been shown to work in industries where a top-down management style is the norm, or in companies experiencing bitter labor relations. What will work, under any circumstances, are genuine alliances in which mechanics and their unions join with managers and the FAA to design and implement reforms.

The present problem

In aircraft maintenance there is hardly anything published about human factors at either the individual worker or organizational levels. There are few references in the human factors or organizational studies literature on maintenance and even fewer on aircraft maintenance. A recent search of published references from the 13-year period 1976-1988 yielded only 15 papers in the latter category. Of those found, a number dealt with the physiology of human response. Examples of these include discussions of the effect of location, shape, or convenience of cockpit controls (such as for ejection seats in military aircraft) serviced by mechanics. Only a few studies discussed the whole person in context.

One reference described and reported technical advances in aircraft engine design that were developed to make field maintenance duties soldier-proof. This reference to eliminating the human factor through technology (or at least as much as possible) is an alternative to the notion of a system of allies — but such an alternative isn't necessary in my opinion.

Technical advances, in some cases even total automation, can be used to strengthen the maintenance system's human response to its chaotic world. For instance, one air carrier reported reforming a rule-based maintenance software system, originally intended to direct mechanical work, into a supplemental tool for mechanics. The results included retaining the cost benefits of the former system while improving maintenance quality and mechanic satisfaction. The carrier calls this reform changing an "Expert System" into a "System for Experts."

Some reference has been made to maintenance

people being complex and intelligent, but this is countered by statements that mechanics are still "doing what they're told," but do not show that they "know what they are doing." A number of ATA sources state that around 80 percent of all cracks in aircraft are found by visual inspection, presumably by persons doing a complete, general walk around, and not by persons looking specifically for cracks. These alert people are probably not in the category of doing just what they are told. They are going beyond the formal confines of their jobs and are acting in a complex and intelligent manner.

Of course this not surprising, people generally do work beyond the borders of their job descriptions, and in line with the expectations of those around them. It is ironic that we become most aware of such informal accommodation when it is suddenly withheld. An example (probably familiar to the present audience) is the time during the late days of the Carter administration, when air traffic controllers "worked to rule" as a protest, by maintaining the safe but unrealistic distances between planes specified in their work rules. (This was before they took matters further and actually went on strike in 1980). When this slowdown happens in Britain it's called "working to rule." At the time it happened here, FAA spokesmen called it "malicious obedience." Controllers had been expected to balance safe flight and on-time landings even though they had not been given explicit direction or permission to close distances between aircraft.

Expectations are the essence of social roles and they require a network of relations (sometimes positive and constructive, and sometimes not) with others in the work place, elsewhere in the organization, and with outsiders.

Social roles in aircraft maintenance

Peoples' roles at work vary from their jobs. Jobs are formal statements of what we agree to perform, while roles rely primarily on the communicated expectations of others, and of our perception of those expectations that often

go far beyond mere job descriptions. The mechanics who actually perform aircraft maintenance not only do what they know, but doubtless know a lot more than they do. It would be valuable to assess the areas of common expectations among the various roles in the total maintenance system. This means understanding how technicians, inspectors, managers, flight crews and others can share common goals, can share awareness of resources to deal effectively with the aging fleet, or how they can collectively understand "hot spots" on particular types of aircraft.

There are a number of questions that such an assessment might address. For instance, to what degree do the various roles in maintenance understand one another and the overall safety system? How similar and intense is the commitment to safety and quality of the aging fleet by all persons in the maintenance system? Can steps be taken to create a common language of safety and quality among all of the various roles? What would such a language look and sound like? For example, would it be based on the aircraft themselves (JAL's dedicated maintenance teams make this a requirement). Or perhaps such a language could be anchored in a shared maintenance paradigm ("damage tolerance" is a case in point). Or might it reflect one of the various total quality management programs currently popular among American manufacturing management? Is a pioneering effort to create true joint technician-management commitment worth considering—and are the needs great enough and the groups close enough in their wishes and expectations to make it possible? In short, how should change be approached?

A first step

Now is the time to visit and to observe (and eventually survey) a sample of American air carrier maintenance operations. This should include observation of the maintenance and inspection work process as it relates to fuselage corrosion and cracking. Additionally, management practices should be reviewed, to the extent they are visible, to assess how they affect

the practice of aircraft maintenance, particularly as it relates to the aging fleet. The sampling of sites should consider carrier size (being certain to include at least one commuter line carrier) and location of sites around the country.

The object of this series of visits is to examine practices within the context of a socio-technical systems model, examining work places and practices to discern whether a common language of work exists. The specific focus would be the routine maintenance operations related to older aircraft. Such a study would seek to identify some innovative, insightful and appropriate styles, practices, and company cultures.

Socio-technical systems management

The basis of STS management is that organizational systems have a technical function, a common language, to perform in a complex and turbulent environment. Aircraft maintenance organizations need to retain their efficient, responsive and reliable operational services; while improving their response to the special problems of the aging fleet. They can begin to do so by developing explicit mechanisms that ensure collaboration and shared expectation between groups. In doing so we begin to deal with the human factor in a larger sense.

A lot of information has been developed on STS management. It is an aid to understanding and designing organizations. The products of the approach follows.

Technical analysis of a maintenance process is expressed in terms of the mission and unit operations of the work process. Once the boundaries of input into the system and output from it have been defined, it is possible to identify state changes in the throughput as it is directed toward the conscious purpose of the enterprise. These state changes will often be found different from the departments and functions of the typical organization for that industry. Identification of key factors or variances is the second part of the technical analysis. This is the important task of describing normal deviations in terms descriptive of the

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throughput, and then identifying the most crucial of those for the purpose and product of the enterprise. These key factors will often include the "hot spots" mechanics and inspectors evolve for themselves, but may also include important variances previously overlooked because they do not show the direct results on product, but play an important, if indirect, upstream function.

Analysis of the management of these key factors frequently reveal that they are often not controlled where they originate and that much of the control is undertaken long after the variance limits are exceeded. This is a design decision — whether by omission or by commission.

Often managers feel capable of making organizational decisions based on intuition and experience. But the issues of aircraft maintenance today have become extremely complex. Thus, many of the structures that seemed intuitive have proven unsatisfactory. Among the many organizational forms that have been tried are assigning inspection and maintenance to separate departments, organizing all systems maintenance strictly by application domain. In short, the maintenance staff structures that may have proven adequate in the old days are breaking down in the era of complex planes and turbulent environments, when strategic planning must include all parties to the work.

Until maintenance organizations are appropriately structured to their joint commitments and expectations, it is unlikely that anything can be done to build a strategic maintenance function. New methods, policies, technologies and people won't help if the design of the organization impedes people's best efforts. Each organization needs to be designed to suit its own business, its own people, and its own future.

The key variance control analysis described above provides an important opportunity to see how conventional ways are often inappropriate because of the difficulty of communicating among groups. The social systems analysis examines the work-related interactions among people in an enterprise. It permits description of the coordinating and integrating buffer between the technical transformation process and the demands and constraints of a turbulent

environment. Any organization, if it is to survive in those environments, must perform four basic functions. First, setting and attaining performance goals. Second, adaptation to the external environment. Third, integration of the activities of people within the system; and forth, long-term development. The task for the social analysis is to describe the ways that these necessary social system functions actually get carried out in a specific organization, and to evaluate how effective these methods are for satisfying the human and technical requirements of the enterprise. The focal role network and social grid are tools for attaining this product.

Here are some key bases of organizational design as they apply to maintenance organizations:

- The technical bases of cooperative work. To build an atmosphere of cooperation, the design of the organization must ensure identifiable product lines for every group within maintenance. When charters are unclear — either poorly defined, too broad, or inconsistent — the natural drive for excellence is thwarted. A healthy organization design should provide a crystal clear definition of the business of each group within the maintenance function, as well as of the business of the overall carrier.
- The explicit interdependencies in organizations. When organizational structure is stated simply in terms of boundaries, territorial battles can be minimized. However, interdependencies may not be clear. When collaboration is required, it is not clear who is serving whom, and who had leadership responsibility for which issues. Organizational design should provide clear guidance on how the various maintenance functions work together.
- Structural dependence on higher management. Many problems may be invisible in the presence of a top management team that is friendly and works well together. Nonetheless, this is a fragile truce. Furthermore, an inordinate amount of management time is spent resolving problems that arise from a dysfunctional organizational

James C. Taylor

structure. Clearly an organizational structure that depends on the good will of senior managers is not a high performance organization.

The issues above are all the sort addressed by socio-technical analysis and design. Such a study would describe (and recommend where possible based on best practices) strategies for overall improvements in the normal maintenance

and inspection processes, as well as in management style and support activities.

Using these tools to create allies in maintenance is a way of fixing the problem, not merely fixing the airplane. It is a way that has proven powerful to organizations within PG&E, AT&T, and major auto companies, in their pursuit of success and survival in their turbulent environments. It seems timely to begin to look this direction in air transport as well.

Guest Speaker



THE HONORABLE TOM LEWIS

Congressman, State of Florida

Speech presented by Dr. James C. Greene
Science Consultant, House Committee on Science, Space and Technology

Congressman Tom Lewis, who is Vice Chairman of the Subcommittee on Transportation, Aviation and Materials, asked me to let you know that he regrets not being able to be with you today. I will read Congressman Lewis' remarks as if he were giving them.

I am pleased to have the opportunity to address the Second Annual International Conference on Aging Aircraft sponsored by FAA. As many of you may remember, I also had the privilege of addressing the first conference on June 1, 1988.

At that time it was not clear to me if FAA was willing to make the commitment necessary to accomplish the operational objectives and research and development goals recommended by the conference. Now, 16 months later, we are seeing significant activity.

First and foremost, the Secretary of Transportation, Mr. Skinner, and the FAA Administrator, Mr. Busey, are working as a team. The winds of change are both kinder and gentler.

More important however, their goals are to address aviation problems, such as aging aircraft safety, effectively and efficiently.

The National Aging Aircraft Research Program, begun earlier this year, is one positive result of this leadership. It demonstrates that there is a commitment to implement the goals and objectives of last year's conference.

Just last week, at the FAA R & D Conference, Mr. Busey released the revised research plan that contained details of the Aging Aircraft Research Program. If anybody can successfully implement this plan, the dynamic duo of Skinner and Busey can.

Congress has also been active in the area. One week before the first Aging Aircraft Conference, I introduced the Aviation Safety Research Legislation. The bill mandated that FAA spend 15 percent of its research funds for long-term research.

Specifically mandated was research, and this is a quote, "to develop technologies and to

Tom Lewis

conduct data analyses for predicting the effects of aircraft design, maintenance, testing, wear and fatigue on the life of aircraft and on air safety. To develop methods of analyzing and improving aircraft maintenance, technology and practices, including non-destructive evaluation of aircraft structures."

Other congressmen supported this concept because 161 days later the bill became Public Law 100-591. And, not a single representative or senator voted against it as it passed both houses of Congress.

One reason for this strong support is that so many members of Congress hear from their constituents about their concerns on the adequacy of air safety. This, coupled with the fact that almost all congressmen are frequent flyers and understand their constituents' concerns, accounts for much of the congressional support for aging aircraft research.

Aviation is almost unique in the business world in that there are essentially no organized groups that are advocates for the flying public. Consequently, people look to Congress to be their spokespersons. This has led to congressional concerns about the adequacy of FAA's aging aircraft safety programs.

For example, the fiscal year 1990 funding level for aging aircraft research is \$4,000,000. Up from zero in fiscal year 1988. Is that an adequate level? Will it permit the development of non-destructive inspection technologies that will detect problems before they become accidents? I am not sure that it is.

In the House Transportation Appropriations Bill, we were successful in getting the FAA research budget increased from \$165,000,000 to \$185,000,000 for fiscal year 1990. This will translate into increased funding for aging aircraft research as well.

With the surplus in the Aviation Trust Fund there is no reason why the research funding level should not be significantly higher. But it is not and we must increase our efforts to convince those who control the use of the Trust Fund to spend it for important aviation programs, such as aging aircraft research. That is what it is intended to be used for.

In order to have an effective research pro-

gram there must be effective agency management. A General Accounting Office report that I requested, cast doubt on the management techniques of the past. For example, GAO found that during fiscal year 1988, funds were transferred among 70 of 101 subprograms in FAA's research program.

Moreover, GAO expressed concern about the agency's ability to meet its goals and objectives because there was no consistent criteria on which to base these transfers. I do not think that it is possible to have a viable long-range research program if the funding levels are consistently changing.

In addition, this will make it almost impossible for FAA to attract qualified scientists and engineers to conduct aging aircraft research. Even so, it is no longer sufficient to wait until an accident occurs before beginning an aggressive research program in accident prevention.

Tombstone technology is not an acceptable research policy. I believe that the American people demand more and the improvement in the technology will certainly lead to more breakthroughs in aging aircraft safety that will permit better inspection and preventive maintenance.

We have made great strides during the past year in addressing the safety problems associated with aging aircraft. But we must not be satisfied until there is a long-term research program at FAA that coordinates data and fills gaps that may occur between different, non-federal research and development efforts.

To fulfill that goal established by the Aviation Safety Research Law, Public Law 100-591, requires a commitment by the Secretary of Transportation and the FAA Administrator. Now, I think we have that commitment and I will work with them to fulfill this goal of making travel in aging aircraft safer.

This time next year we should see a larger research budget requested by the administration and approved by Congress. We should hear research papers from FAA scientists discussing preliminary results of research projects underway at the agency.

We should see the implementation of an aggressive long-term aging aircraft research program. That may be a little bit easier. The

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Transportation, Aviation Materials Subcommittee, yesterday, passed legislation that would allow FAA to give competitive research grants

to universities so that they can contract for needed research.

The American people are asking for this commitment and deserve nothing less.

Summary Remarks

CONFERENCE CHAIRMAN THOMAS E. MCSWEENEY

I want to thank everybody for being here. Who would have ever thought last year that after holding an aging aircraft conference and having 400 people attend, that we could turn around and have 340 people attend a year later on the same subject. I think it says a lot about the interest that is out there worldwide. Of the 341 people in attendance, over a hundred people registered with addresses outside the United States. Those people represent many different countries. I think that is a wonderful tribute to the aviation community in getting behind a program like this. I know there were side meetings in the evenings and all of you probably feel as I do that many times that is where the real business is done. I think we need to continue the dialog we have started.

I want to thank the representatives from the Joint Airworthiness Authority who are here. They have a big share of this program and the FAA really appreciates their support.

Travel is international. The products are international. There is no such thing anymore as a U.S. airplane. It might be put together here but it is 50 percent somebody else's parts. That goes for Airbus and other manufacturers as well. We are a real international community and I am glad to see that we have continued with that in the aging aircraft area. I asked the session chairmen to summarize what they thought some of the topics of interest were that were discussed.

In the structural fatigue area, there was a lot of discussion about proof pressure testing and I am sure that will go on as that concept is pursued. Some people indicated that the concept was misunderstood. As we get more information about it and the research is done, I think people will soon realize what the objectives are.

There was some discussion about 100 percent sampling versus 100 percent inspection.

It's clearly an issue, there is no question about it. Does looking at one airplane tell you anything about another one? It may do so in someone's fleet. It may have less importance in someone else's.

There was some concern expressed on the FAA's new policy of replacing materials in known problem areas. That is certainly something that is revolutionary and we expected a lot of discussion on that.

There was some concern expressed about other problems. We talked about the 737 upper splice and the upper rivet line on the splice but what about the lower one?

I think one of the elements of the aging aircraft program is that we try to make a commitment, hopefully all of us, that the program won't end. Certainly 757s, Airbus 320s, MD-11s and Fokker 100s are going to age some day. We need to make sure that the lessons learned in the last year, and to be learned in years to come, are put to use predicting age time and doing what is necessary so we don't have another major structural failure due to aging. The FAA has clearly been pushing in that area—to make sure that we uncover all the aging problems, not just the ones that are here today facing us.

There was a lot of discussion about adhesive bonds. In the loads area, there was some discussion about the hub and spoke concept. Are the flight profiles that we are using in computing the loads meaningful in this new hub and spoke concept? That is a good question.

Is the environment that we use in our fatigue analysis the right environment?

There was some discussion about uniqueness of operations. I do not know that anyone would argue with the fact that Part 25 doesn't really differentiate between types of operation. There is a fatigue spectrum used. It is a broad

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spectrum and is probably a very conservative one.

But there is really no way, without going back and doing the number crunching, of saying, "your operation is different and, therefore, you can have a different design life." If that in fact is a goal, then I see a lot of work that needs to be done.

I am encouraged that other people are talking about that issue. It really shows that the basic issues behind the fatigue spectrum are being discussed. Corrosion clearly was a much-discussed topic. Some of the recommendations seem to suggest we standardize on one program throughout the industry. Whether that is possible or not will be determined by the airlines.

Concern was expressed that visual inspection may not be adequate for corrosion. Hopefully, some of our NDI research that is being done and some of the new techniques that are being developed may help us in that area.

There was some concern expressed over the fact that there was no incentive for corrosion control when there are short-term leases. Clearly, it's one of the issues, one of the problems. I have attended a couple of leasing seminars in which aging airplanes were discussed, and it is of concern to the lessors to ensure that, after their airplane has been leased by five or six different airlines over 10 years, that they have a product at the end that has some market value to it. That is a big concern. I see eagerness on their part to move toward standardized maintenance manuals, standardized corrosion control manuals and procedures so that these can be written into contracts.

In this country, we are moving away from zinc chromate. That is going to present some very significant issues and problems that have to be dealt with. I know the aluminum manufacturers are looking at new alloys to try to make things better.

It sounds as if the panels were pretty much on the mark as to what needs to be discussed. In NDI and NDT there seemed to be some indication that there were a lot of techniques out there that were doing a good job.

Training was clearly identified as one of the issues that needs further discussion. Should

inspection procedures throughout the industry be uniform? Should they not be uniform?

I was glad to hear NASA is moving in the direction of trying to turn over some of that new technology to the industry and to look at how it can be used in the typical airline operations. I find that very encouraging. I also have noticed that the airlines are themselves asking "How can we do things better?" I have heard people say they only allow visual inspections the first four hours of the shift when the employees are sharp and eager; that they do not do them two shifts in a row with the same person. They try to vary their tasks so that boredom and other human factors issues, can be addressed.

In the human factors area, there was some discussion of training and how to design it, and the important human factors that go into training, the sociological and the physical environment in the work area.

Some of the remote devices may allow the inspector doing the actual inspection to do it away from the airplane, with a robot actually doing the inspection. Those are schemes that show that some of the problems are being addressed.

Even though we have gone a little over a year since the Aloha accident, the average person in this country, and worldwide, is still concerned about aging airplanes.

I think Congressman Oberstar's example of the concerned farmer in Minnesota was a good example of that concern. I have had not only the press and TV talk to me about aging aircraft but I have had people who travel call me and want to know if airplanes are safe. The average person is clearly concerned about aging aircraft. In fact, when people find out I work for the FAA, they ask me, "What are you doing about aging airplanes?"

The press interest is still there. The number of phone calls I get are down but the interest is still there. They still want a report on it. We technocrats have to find a way of telling the press and the public what we are doing about aging aircraft. I think we are doing a lot of good things and they seem to appreciate what we are doing about it. I think the press has a big role and I see them taking that role. I have seen

Thomas E. McSweeney

some articles recently about some of the good things we are doing and some of the positive things that have come out of the aging aircraft program.

I think the industry and Congress are taking up that role. While we are being scrutinized over our aging aircraft program, we are also being congratulated for the things we have done.

The last point I would like to leave you with is that I see the aging aircraft program as ongoing. History shows a 30-year aging aircraft program with 10-year cycles. We had major meetings or major events every 10 years, approximately. We need to change our approach and say that we do not want to become complacent or solve this problem and relax until we have another problem. Our vigilance must be constant.

The key is to get in front of the problems and not wait for another event like Aloha to shake us into doing something. I think from all of these meetings we ought to be able to get the expertise to predict aging airplanes better than we ever have before and we should be able to do what is necessary in the initial design, and in follow on, to make sure that we do not have a major event 10 years from now that causes us to rethink aging airplanes.

I want to thank everybody for coming. We have already started to look at when and where we are going to have the Third Annual Aging Aircraft Conference.

If anybody in the audience has suggestions about how to better do the agenda, and topics that should be discussed, please let us know. I ask that you send your comments to the Flight Safety Foundation. We could use that in planning for next year's conference.

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