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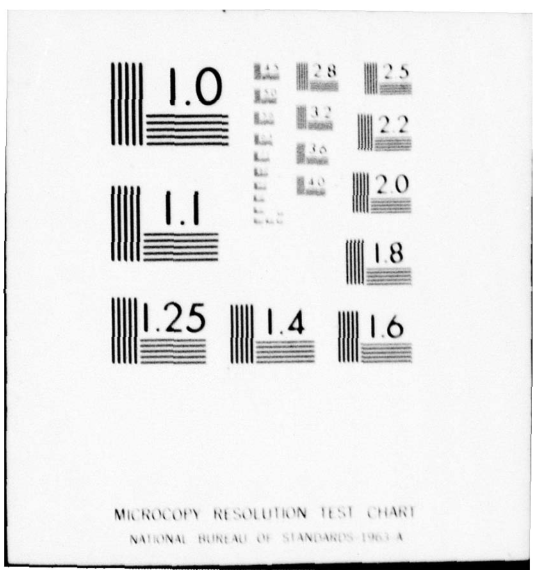
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PROCEEDINGS OF AFOSR/AFML CORROSION WORKSHOP

METALS BEHAVIOR BRANCH
METALS AND CERAMICS DIVISION

OCTOBER 1977

TECHNICAL REPORT AFML-TR-77-175
Final Report for Period 17-18 September 1975

AIR FORCE MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Charles T. Lynch

CHARLES T. LYNCH
Senior Scientist

FOR THE COMMANDER

GAIL E. EICHELMAN, CHIEF
Metals Behavior Branch
Metals and Ceramics Division

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Corrosion Maintenance	Stress Corrosion Cracking
Corrosion Prevention	Hydrogen Embrittlement
Corrosion Research	Accelerated Testing
Coatings	Environmental Effects

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The first part of the proceedings contains the detailed presentations of Air Force problems related to corrosion in Aerospace Systems, given by representatives of AF Systems Command, AF Logistics Command, and AF Office of Scientific Research. The second part reports the conclusions on research needs to meet these problems in six areas: (1) Coatings and Inhibitors; (2) Accelerated Testing and Realistic Test Environments; (3) Environmental Effects on Crack Growth Rates; (4) Stress Corrosion Cracking and Hydrogen Embrittlement; (5) Environmental Degradation of Electronic Materials; and (6) New Approaches → over

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Block 20. ABSTRACT

to Corrosion Problem Solving.

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FOREWORD

These Proceedings are published from the AFOSR/AFML Corrosion Workshop held in Dayton, Ohio, on 17-18 September 1975. The meeting was held under the auspices of the University of Cincinnati under Contract F33615-73-C05084 with Professor M. Hoch as the Principal Investigator, and Mr. Oscar Srp as the Project Engineer. The Proceedings were edited by Professor M. Hoch and Mrs. Jean Gwinn of the University of Cincinnati, and were distributed to the attendees and a limited number of other interested scientist and engineers.

The work was performed under Project 7351, "Metallic Materials for Air Force Weapon System Components", Task 735106, "Behavior of Metals", in conjunction with the related Inhouse Work Unit 735106B2 (now 24180301), "Environmental Effects". The Air Force portion of the program was conducted under the technical direction of Dr. Charles T. Lynch (AFML/LLN), Metals Behavior Branch, Metals and Ceramics Division, Air Force Materials Laboratory, Wright-Patterson AFB, Ohio, and Lt. Colonel Richard W. Haffner, Chemical Directorate, Air Force Office of Scientific Research, Bolling AFB, Washington, D.C. The original supply of Proceedings has been exhausted, and because of continuing requests for broader distribution, the Proceedings are being distributed as a Technical Report. The assistance of Mrs. Sally Gardner in the preparation of the manuscript is gratefully acknowledged.

AGENDA

AFOSR/AFML CORROSION WORKSHOP

17-18 September 1975

LOCATION: Imperial House - North
2401 Needmore Rd on I75 N
Dayton, OH 45414

SCHEDULE:

17 September, 1975

8:00-9:00	Registration
9:00-9:15	Introduction and Opening Remarks - Dr. H.M. Burte
9:15-11:30	Presentations by representatives from AFLC, ASD, AFOSR and AFML
11:30-1:00	LUNCH
1:00-5:00	Workshops - Topics to be discussed:
	I. Coatings and Inhibitors II. Accelerated Testing and Realistic Test Environments III. Environmental Effects on Crack Growth Rates
5:00	MIXER (Italian Room, Seven Nations Restaurant)

18 September, 1975

9:00-11:30	Workshops - Topics to be discussed:
	IV. Stress Corrosion Cracking and Hydrogen Embrittlement V. Environmental Degradation of Electronic Materials VI. New Approaches to Corrosion Problem Solving
11:30-1:00	LUNCH
1:00-4:00	Session - Discussions on workshop conclusions, immediate and future action items

SPEAKERS

AFOSR-AFML WORKSHOP ON CORROSION PREVENTION

17 September 1975

9:15 - 11:30

Opening Remarks

Dr. H.M. Burte
Chief, Metals and Ceramics Division
Air Force Materials Laboratory
Wright-Patterson AFB, OH

Welcome on Behalf of AFOSR

Lt. Colonel R.W. Haffner
AFOSR/NC
Boling AFB
Washington, D.C.

The Role of the University in Research Today

Professor M. Hoch
University of Cincinnati
Cincinnati, OH

AFLC's Corrosion and Maintenance Problems

Colonel L.C. Setter
Director of Aerospace Systems
Office of DCS/Materiel Management
Wright-Patterson AFB, OH

Corrosion Problems Encountered During Acquisition of AF Weapons Systems

Major Thomas K. Moore
ASD/YASM
Wright-Patterson AFB, OH

Corrosion on Related Aircraft Structure

Howard W. Zoeller
AFML/MXA
Wright-Patterson AFB, OH

Advanced Metallic Structures Technology Programs

Dr. V.J. Russo
AFML/LLN
Wright-Patterson AFB, OH

WORKSHOPS

I. COATINGS AND INHIBITORS

Includes Metallic and Non-metallic Paints, Plating, etc.

Chairman: Phil Parrish, ARO
Recorder: Gary Stevenson, AFML

II. ACCELERATED TESTING AND REALISTIC TEST ENVIRONMENTS

Includes Corrosion Prediction

Chairman: Bob Summitt, MSU
Recorder: Fred Meyer, AFML

III. ENVIRONMENTAL EFFECTS ON CRACK GROWTH RATES

Includes Corrosion-Fatigue
Corrosion Resistant Materials

Chairman: Ellis Verink, U. of Fla.
Recorder: Kirit Bhansali, AFML

IV. STRESS CORROSION CRACKING AND HYDROGEN EMBRITTLEMENT

Chairman: I.M. Bernstein, Carnegie-Mellon University
Recorder: Kirit Bhansali, AFML

V. ENVIRONMENTAL DEGRADATION OF ELECTRONIC MATERIALS

Chairman: L.J. Weirick, Sandia Labs
Recorder: Fred Meyer, AFML

VI. NEW APPROACHES TO CORROSION PROBLEM SOLVING

Chairman: W.A. Thompson, WRALC
Recorder: F. Vahldiek, AFML

A major factor for consideration in each workshop should be possible reductions in the tremendous maintenance costs now being incurred and expected on future aircraft systems.

WELCOMING ADDRESS

Dr. C.T. Lynch
AFML/LLN
Wright-Patterson AFB, OH 45433

On behalf of the Air Force Office of Scientific Research and the Air Force Materials Laboratory, it is my pleasure to welcome you to this AFOSR/AFML Corrosion Workshop. It is sponsored through the auspices of the University of Cincinnati and we are deeply indebted to Professor Michael Hoch, Mrs. Jean Gwinn, and other members of the University Staff for their support. This is the first meeting we have had, at least in recent memory, in which members of the Air Force Logistics Command, and several elements of the Air Force Systems Command: the Aeronautical Systems Division, The Air Force Office of Scientific Research, and the Air Force Materials Laboratory, have met together with leading corrosion experts from the academic community to discuss the topic of Corrosion Research as it directly pertains to the Air Force Corrosion Problems. We also have representatives here from the National Aeronautics and Space Administration, the Office of Naval Research and the Army Research Office, and enough industrial people to keep us from becoming too provincial.

It has been our growing opinion for several years that a new fundamental challenge to corrosion prevention and control arising partly from the high costs of doing business and partly from the burden of operating an increasingly older fleet of aircraft for longer lifetimes, should be amenable to an enlightened and vigorous research effort. Essential to such an initiative is the bringing together of leading members of the academic research community with people in the Air Force who see these corrosion problems on a daily basis. We believe that this will orient you to a relevant base for proposing the directions our future research should take. In using a workshop mode, we have the opportunity to obtain immediate feedback and constructive criticism of our present program efforts, and the opportunity for new, creative approaches from the give-and-take that such sessions usually include. We would also expect that as you return to your respective institutions, there the perspectives gained here on the problems we face will lead to further creative approaches to their solution. Through this meeting you should also gain insight on who we are, who is interested in what, and where to proffer your ideas. We, in turn, are delighted at the response of so many of you to give freely of your time and talent to us. The ultimate beneficiary of this should be the taxpayer if we assume even a modest success in these efforts.

There will be a series of presentations by Air Force representatives today followed by three workshops today and three tomorrow, and then a concluding open discussion session by all participants. The workshop topics are:

17 Sept.	I.	Coatings and Inhibitors
17 Sept.	II.	Accelerated Testing and Realistic Test Environments
17 Sept.	III.	Environmental Effects on Crack Growth Rates
18 Sept.	IV.	Stress Corrosion Cracking and Hydrogen Embrittlement
18 Sept.	V.	Environmental Degradation of Electronic Materials
18 Sept.	VI.	New Approaches to Corrosion Problem Solving

Please sign up for only one workshop each day. You may want to be in more than one on the same day, but that is a little difficult. You may go back and forth some, but it may interfere with the interaction within a group if you change very much. So please select the particular prime interest group, and we will encourage changes only if the attendance is extremely uneven. Each workshop will have a discussion leader and a recorder as indicated on your program. We will also have representatives of both the Air Force Systems Command and Air Force Logistics Command available for each workshop. They will prepare a summation of your workshop conclusions for the final general session. Again, our thanks for your attendance and participation. It is my pleasure to introduce the speaker for our Opening Address: Dr. Harris M. Burte, Chief of the Metals and Ceramics Division, Air Force Materials Laboratory, AF Wright Aeronautical Laboratories, AF Systems Command.

OPENING REMARKS

Dr. H.M. Burte
AFML/LL
Wright-Patterson AFB, OH 45433

Air Force interest in corrosion research should not be surprising to most of you, but there are some new dimensions to this interest. For many, our past research interest has been primarily to provide materials and processes for new aircraft or missiles, such as more corrosion resistant materials which do not require that we pay performance or cost penalties. More recently, we have recognized the need to pay more attention to the cost of maintaining existing fleets. Our existing fleet of airplanes is going to be with us for many, many years and the cost of keeping it operational is very large indeed. Corrosion, you will hear, is a big factor in this, and the challenge is: Can technology be applied to reducing this cost? Perhaps not enough attention has been paid to the scientific aspects of this problem.

Concern about corrosion is, of course, not restricted to the Air Force. Any number of advisory and study groups continuously view, with alarm, the costs of corrosion to the country and the need to do something about it. Recently there has been increasing national concern with the need to conserve nonrenewable resources, and therefore to put even more attention on being able to cope with corrosion. The extent to which some of this enthusiasm for conservation represents valid cost effective goals, you must judge for yourself, but it has focussed attention on problems akin to those we will be discussing here. Thus, there is reason to feel that what we do here may have value beyond the specific needs of the Air Force.

I don't think I need stimulate you further about the general requirements; we are going to hear more about them in the next two days. Let me rather introduce and ask you to deal with a point of view that is widespread in this country today, perhaps even throughout the world. Many users of materials and processes, the people who have the corrosion problems, believe that corrosion research in the last decade has done a beautiful job of adding to the scientific literature, of filling the research journals with papers, but has yielded little or nothing useful. Despite the concern about corrosion, I have heard many people in the materials application community say that there is nothing really new in the way of usable things that are available right now (or that are going to be emerging in the next five years or so) and that the problem is how to better use what we have. Even in the scientific community, despite a lot of talk about the need for research, there is little confidence. Just six weeks ago I listened to a national level research advisory group meeting at which one participant stressed the need for corrosion research to cope with some of the same challenges that I have just mentioned, and almost everybody else in the room jumped all over him (I just sat and listened) saying

"We accept all that, but the problems are just too difficult in corrosion to do good and useful focussed basic research. There are no good ideas, there are no good approaches, let's just sit back and let NSF fund some basic chemistry and maybe something will pop out someday." These are some of the thoughts and perceptions that pervade much of the scientific and engineering community today. In the next two days we, here, must test this poor prognosis. Is it valid and is there really not much we can do, or can we identify and define new and promising specific directions for corrosion research, or approaches where development might be attempted?

To do this we have brought together people who have an intimate knowledge of the possibilities and people who are very familiar with the needs. Some of you, particularly those involved in corrosion research should propose the possibilities, those areas of scientific research which might be more fruitful than others, which might yield something. Those of you who are close to engineering and maintenance must not only talk about the generic, broad needs, they must help define something we have called "windows", the specific use possibilities which not only provide focus to research but enable you to judge what it takes to make a given idea useful, and define the real parameters that must be studied. Let me give you an example (on a topic other than corrosion so as not to bias your thinking) of what I mean by a generic need and a window, and of a major AF program that emerged from an activity like our workshop.

One of the major factors in the cost of building and maintaining airplanes arises from the way that we now put them together. Currently, we take thousands of little parts and rivet or bolt them together. Not only is this a major element in the cost of production, the holes act as fatigue crack initiators repair of which is a major contributor to maintenance cost. If we could fabricate airplanes by adhesively bonding large parts instead of mechanically joining lots and lots of little parts, we might effect major savings. As long ago as the forties, I remember seeing a picture of a WW II jeep suspended in the air from a small adhesively bonded joint. This was a famous picture used to advocate the magic of adhesive bonding, yet we still don't use adhesively bonded primary structures in aircraft. When you next enter a 747, look at the door where some of the sheets are laminated together, and notice that there are lots of bolts or rivets also joining them ("chicken bolts" some call them). The problem is not in strength of an ideal bond, it has been in reproducibility, reliability, and durability in service. About a year ago, during a major workshop like this, many felt that the chemistry and physics of why this had been true in the past was not understood, and that using this knowledge one might be able to develop and demonstrate the reliability of major bonded structures for primary airframe use. This was the possibility. I've already talked about the generic need to find lower cost ways of fabricating airframes. The next step is to define a specific "window", a credible specific potential application for the technology. This helps to sell a program, it generates enthusiasm in all contributors, and most important, enables us to define the real problems to be solved. It also gives us a baseline against which to measure our progress. In this case we picked the fuselage which the AF was building for a new generation of transport vehicles. The prototype aircraft is being assembled in the standard way, using mechanical fasteners. A follow-on production decision is far enough in the future, however, that there is still time to develop and test a new adhesive bonding technology and a portion of the same fuselage will be built using bonded structure. This, if successful, will provide a technological alternative for the production decision. More important, however, the window provides a baseline: one can measure the new technology against the standard technology, and can identify the real problems that have to be solved. It tells you what it is you have to accomplish, and helps give you enthusiasm and a sense of accomplishment.

In our Workshop, we want to stimulate each other into generating specific research ideas, and seeing if we can match them with specific windows. If we are very lucky some ideas that emerge may already be backed by sufficient research that reduction-to-practice programs can be proposed. If an "innovative" new idea or approach is suggested ("innovative" to some, "radical" to others) I hope you will discuss how, in order to get to work, it will have to solve this, this and this problem instead of saying "that's a crazy wild idea, it won't work for this and this reason." In other words, you will communicate with each other instead of preaching to each other. I hope you won't be overly negative, but also you will not hesitate to expose the problems involved. Otherwise your research may follow the wrong directions and yield a "pretty" result which nobody will ever use. (Here is where a "window" can help.) However, even if we are not so fortunate, I hope that the least we produce will be a better appreciation of what the real in-service problems are, what the constraints are that solutions must cope with if they are going to be usable in a real world, and what new focussed research might be started. The AF is looking for additional proposals for research of this nature. I am sure that our colleagues here from other Government agencies have similar needs.

During the first part of the day, we will give you an overview of some Air Force problems. We will then meet in smaller groups combining some who know the problems with some who have a feeling for the scientific possibilities. It won't be easy, we will have to spend time learning to communicate. Don't hesitate to surface differences. If you don't understand each other, if you think someone is missing a point, don't hide that feeling, surface it and deal with it. Be objective yet supportive, communicate and stimulate each other.

WELCOME ON BEHALF OF AFOSR

Lt Colonel R. W. Haffner
AFOSR/NC
Boling AFB
Washington, D.C. 20332

Good morning. Thank you for coming. My job is to welcome you and express our appreciation to you for coming. As you just heard, there are several things we would like to have you do. First of all understand our problem and, secondly, help us by giving us some direction if that's possible and I think it is. I was talking to Dr. Lynch the other day and I said, "Ted, I don't have any slides to show and I haven't prepared a speech." He said, "If you don't have any slides or a speech, then you ought to tell a joke." I replied, "Well, I don't know any corrosion jokes." He responded, "Well do something." I answered that all my jokes were corroded, badly corroded, but that I didn't have any corrosion jokes. Therefore, I think I will omit the jokes and maybe we can get together later at the mixer and have a little fun.

In the meantime, let me emphasize several points. For the first time in a long time, just in the last five years, tremendous instrumental techniques have been developed that are now available and ready to use for investigating surface reactions in great detail and in amazing precision. We can literally look at a surface, pick off atoms one at a time, examine them and stick them back on the surface. You are all familiar with these many analytical techniques that can now be used to follow chemical reactions. Corrosion as we know it, and I speak of it very generally, occurs at a surface and is a chemical process. The trick is knowing all the chemical aspects of these reactions occurring at the surface so that something can be done about inhibiting or preventing corrosion. I'm not fool enough to disregard the laws of thermodynamics and say that we are going to prevent <u>all</u> corrosion. Certainly we cannot gold plate all our operational equipment or store it under an inert atmosphere. We have to operate where the salt spray and the high humidity is and survive all the other hostile environmental factors as well. But you will shortly hear of the problems: the cost to the Air Force, the difficulty in maintaining the operational fleet and the supporting ground equipment and the electronics that go with it. We are not dealing here with common, mundane corrosion problems such as what happens to boilers that are rotting away on Air Force bases; we are concerned about the high dollar value equipment that requires an exorbitant amount of money to maintain and keep operational. You will hear about that later so I am not going to steal any thunder from these speakers, except to say that corrosion problems cost many hundreds of millions of dollars. Needless to say if you could reduce any of that cost by even a small percentage, it would save the Air Force a lot of money. I think that is what we are interested in, not that we are going to eliminate corrosion completely because that is probably an impossible task. But we can cut these costs.

We have the problem of extending the old standard materials of construction to newer more exacting jobs and also the problem of learning about the behavior of new materials coming along. I can remember some of the new high strength aluminum alloys that we "snatched" from ALCOA and put on missiles in the late 50's before we really understood the metallurgy of the heat treating processes that were required. We found that we had brackets and things made out of these alloys that suddenly developed stress corrosion problems and no one knew what the solution was. So we went back to the drawing board. In other words we have new materials coming along that we understand very little about and old materials we are pushing farther and farther as we use them to construct very sophisticated equipment. The total materials problem is immense. Anything we can do to limit, control or prevent corrosion is going to save money.

Again, I will thank you all for coming. I hope we can have a relaxed atmosphere that will foster some good old fashioned brainstorming. If you have an idea don't be hesitant about tossing it out for discussion. People may take shots at it but don't worry about that. Communicate! If you have some ideas now is the time to try them out on your colleagues in an informal workshop surrounding and let's see what comes out of it.

I can't agree more with this concept of getting people who can do good research aligned with specific needs and problems, because I see many proposals that represent good science but are not very relevant. A man will come in and say, "I would like to look at the 110 surface of a pure crystal of tungsten." I will answer, "Look, we are not using very much tungsten in airplanes any more. Can you look at titanium or aluminum alloys or something that is a common material of construction?" He'll generally say, "Sure, is that of interest to you?" So, part of my job is to get people with ideas, good, inventive ideas with creative research objectives together with real Air Force needs. This workshop is aimed at doing just that.

The other problem now is that we just do not have enough money to push back all these frontiers at any reasonable pace - it is just impossible to do so. Therefore what we have to do is try to focus upon and do those things which have the highest probability of payoff with the limited dollars that we can spend.

In summary then, we must acquaint the scientific community with Air Force corrosion problems, encourage proposed solutions, and try to fund the most promising of these. Today we seek your advice and guidance in formulating a policy and a program for corrosion prevention. We will be looking at the output which you people will have as the basis for spending basic research funds in this area. It is important to us.

THE ROLE OF THE UNIVERSITY IN RESEARCH TODAY

Professor Michael Hoch
University of Cincinnati
Cincinnati, Ohio 45221

Gentlemen, some of you may have heard what I am going to say now because I have been talking about this for the past five years. Ten years ago a meeting where an industry group like the Air Force would meet with academic people would not have come to fruition. University professors are very independent by nature; that's why they go to universities to do what they want to do. Ten years ago everybody did his research and, as Harris Burte said, it filled the journals--one could not read all of the papers published but they were needed for promotion. About five years ago, a significant change occurred. Industry and basic research laboratories got reorganized and it suddenly became apparent that university people, engineers and scientists, ought to work closer with industry on some of its problems. Some faculty members refused; others responded to the challenge. We still have to keep in mind at the university that we have to be independent; we cannot just be at the whim of the Air Force or industry doing their work because then we may as well do it there. The faculty member has to keep in mind, first, that "his research has to be scientifically interesting and technologically important" and, second, "it is easy to perform and teach good science; it is very difficult to perform and teach good engineering." Also, for the engineer, both in industry and in the academic world, the main role is identifying the problem, analyzing the problem, and solving the problem. The first is the most difficult; the last the easiest if the first two are accomplished. It has been noted that the supermarket appeared because someone introduced the four wheel cart in which the housewife would load her groceries and thus be able to move around unhampered. To provide mobility for the housewife in the store was the problem.

In academia, we teach students, and we have to emphasize, that the "engineer's work should be technically sound, economically feasible, and since 1970 ecologically neutral." Aptitude for engineering is born with the individual and developed by education and training; it is difficult to acquire it. One of our major faults has been over the years to spoonfeed the students. We have to instill in students the ability and willingness to think for themselves and to stand on their own feet.

Since 1970, I have felt that industry, and this includes the Government, will need a lot of research done and will provide funds for it as you heard the two speakers say before me. A large fraction of this research will be carried out in connection with universities in science and engineering departments. This is so because, in spite of what people say, universities are more flexible than industry and government.

Universities have one big advantage: there are graduate students who, together with the professor, work on a problem using a certain approach. If it doesn't work out the student still gets his degree and the approach is put aside. In both industry and government it is easy to start a program but it is very difficult to stop it. It is important that faculty members learn to work with industry that they keep their independence and have their own ideas, but that they make no policy decisions connected with industry they work with. They ought to operate according to the principle of Herbert Stein, the economic advisor: "Be an expert on tap and not on top."

Finally, I will terminate with the standard statement of the materials community: yes...but.

AFLC's CORROSION AND MAINTENANCE PROBLEMS

Col. L.C. Setter
Director of Aerospace Systems
Office of DCS/Materiel Management
Wright-Patterson Air Force Base, Ohio 45433

It was very interesting to hear the remarks by the previous speaker regarding problems, in the Logistics Command we have all sorts of data coming in and as an engineer and now a manager, I can tell you that our major problem that I can see is trying to find data I can believe and trying to find a manager who will admit that he has a problem. Once I can get the manager to admit that he has a problem, it seems to be quite easy to go out and find people to solve it. But managers don't like to be disturbed, when they admit they have a problem - that ruins their whole day. I have the unenviable job of monitoring the condition of all the old aircraft in the Air Force. I also have drones, ballistic missiles, and some other things and I have two Boards, one of which approves modifications and those run from about half a billion to a billion per year and the other Board approves depot programs. Of the sixty-five fleets of aircraft, about a third of those come in periodically, every three or four years, to the depots for an overhaul. On all sixty-five of these fleets we have a sampling inspection every year called an ACI program, Analytical Condition Inspection program. This means that we take a sample size of about 11 or 12 airplanes out of each fleet and do a very indepth inspection to find out not only what is broken today but what is about to break next year. So we get a report card every year on all of these fleets. That information is principally what I am going to tell you about here. The one Board that I have - the MRRB, - Maintenance Requirements Review Board, reviews all these on a continuing basis, but principally during the summer months, so we come back with very nervous feelings as to where the fatigue is, where the wearout is, where the corrosion is. So with that, let me launch into these words to give you a feel for some of these specific problems and what the costs are.

We used to think the major problem regarding continued airworthiness of our aircraft was the condition of wear or wearout. Since many of our weapons systems were increasing with age, we now have B52's that are roughly 20 years old, F4's that are fifteen, even our C5's are showing signs of old age, we thought the wear problem was a very serious one and we thought that was the reason we brought airplanes into the depot. Our technical evaluations over the past few years have revealed that wear is not nearly as destructive a factor as corrosion. Corrosion presents a greater problem than wear due to the unknown factors which weigh in the situation and our inability to accurately track or predict corrosion. We don't know how to project that an airplane is going to be corroded. This is true even in avionics.

It's true to some degree in engines, it's true to a large degree in the structure itself. So don't assume that corrosion is hitting us just in the structural area, it's not, it is a very serious thing in avionics also.

In the next several illustrations, I will present the corrosion problem as we see it today, along with some background information which will explain events leading up to our present situation. I will also address several AFLC findings which contribute to the corrosion problem as well as some cost data for depot corrosion repair on a few selected aircraft. In the conclusions section I have a number of areas for consideration which hopefully will improve our aircraft condition in the years to come, and will enable us to more precisely define what our maintenance requirements are, thereby reducing costs. Table I lists the key elements considered.

Some aircraft seem corrosion prone right from the start, the C130 is one of these, and by the way none of my remarks are intended to offend any person or any company, I am just telling you what we see. The C130 started indicating corrosion problems quite early in its life. Corrosion in the design phase of aircraft production is a matter of concern to our engineers and considerable progress has been made in this area although the problem certainly has not been completely eliminated. The Air Force Logistics Command as a Command does not have a great deal of control over this design segment. Once an aircraft enters the active inventory, it then transitions from Systems Command over to Log Command.

One important aspect is the environment in which the aircraft is assigned. Unfortunately, our operational commitments often render aircraft reassignment from base to base impractical. In other words, we cannot manage a fleet to avoid corrosion, although we do try. The recently concluded South East Asia war environment is a case in point. Several aircraft, notably the B52G which was on Guam and the F4's which were all over, suffered considerable corrosion deterioration during their tenure in SEA. In addition, large quantities of a particular model and series subject to this environment have created a forcewide condition. By the way force has replaced the word fleet for obvious reasons. So we talk about a "B52 force" now, I guess we don't want to use the Navy term. The cost impact of these corrosive conditions will be discussed later when I address the depot costs for corrosion repair. Although Southeast Asia was particularly bad for corrosion, we also have some locations in the U.S., such as on the Gulf Coast, Patrick AFB, which is a dreadful place for corrosion, that are just as bad as Southeast Asia.

In early 1970, we initiated a study group to develop Depot Level Maintenance Requirements based on sound engineering data. Surprisingly enough, this had never been done. The Maintenance Requirements

TABLE I

AIRCRAFT CORROSION

OVERVIEW

- PROBLEM TODAY
- BACKGROUND
- MRRB FINDINGS
- COST DATA
- AREAS FOR IMPROVEMENT

Board developed several management programs to better determine when aircraft required depot maintenance and in what areas this maintenance was necessary. The Board determined early in its existence that the presence of corrosion was already a serious factor on most aircraft. In addition this problem made it extremely difficult to establish valid depot maintenance cycles due to the inability to predict from year to year to what extent and in what areas corrosion had developed. The problem and areas of concern are given in Table II.

An example concerns the C118 which is the military DC6, a propellor airplane. Several years ago this aircraft had its depot cycle changed from 2 years to 3 years. This three year cycle appeared to be the most accurate and cost effective based on known conditions in supporting engineer rationale. The MRRB found, however, due to the extensive corrosion developing in the structure, such areas as floor beam fittings, the wing spar caps, and the fuselage skin lap joints, that considerable expenditure through drop-in type maintenance had generated. This meant that many of these airplanes could no longer wait 3 years to get back to the depot. They had to come back for heavy maintenance at some midpoint. As a result of that for the first time we decreased the depot cycle on that airplane to 2 years. The problems in developing maintenance cycles are only the tip of the iceberg as we see it.

Treating corrosion begins at the home base and must be dealt with on a day-to-day basis. In many instances, organizational units are severely hampered in adequately treating corrosion and in preventing it from developing. Units are often undermanned in their maintenance personnel and frequently a base lacks a corrosion specialist necessary to produce good results. Many outfits use corrosion work for punishment. So there is that sort of psychological problem and in addition many of the ones that I have seen are very poorly equipped. Facilities in many cases are inadequate due to capacity, atmospheric conditions, ventilation, or possibly they don't exist at all. Weather is another factor. Most aircraft are scheduled to be washed and corrosion checked every 30 days; this is nearly impossible in many colder areas for many months at a time. As a result aircraft sit on the ramp and deteriorate; for example, i.e., many of the 707 airliners fly something on the order of 3 to 4000 hours a year. Our tankers which are a similar aircraft fly an average of 350 hours per year. They fly one-tenth the amount that an airliner flies. They sit on the ramp, sitting SIOP alert with a full load of fuel. So you not only have corrosion setting in, you also have stress corrosion. They have a lot of landing gear problems. Swapping out landing gears on a large fleet is a very expensive thing. We are now doing it on the B52's and the F4 nose wheels. That involves something like 3,000 airplanes.

Entry of these aircraft into the depot is not the end of the line so to speak, and does not create the good condition that you might expect. Now other forces present themselves to detract from good expected solutions. The treatment of corrosion is, in most cases, and

TABLE II

AIRCRAFT CORROSION

PROBLEM

A. • BACKGROUND

• DESIGN

• ENVIRONMENT

B. • FINDINGS

• MRRB

• CYCLE

• ORGANIZATIONAL PROBLEMS

• DEPOT PROBLEMS

if caught in time, a base level maintenance task. When these tasks are delayed and scheduled for accomplishment at a depot the manpower may not be available. Our depots are authorized just a certain number of people and we try to put those people on the most difficult tasks, things that require heavy maintenance and heavy equipment. So if we have to pull these people off and put them to working corrosion then somebody suffers. Other work is not accomplished.

Now determining how much of a certain maintenance job is caused by corrosion is a very subjective thing, so you'll have to take my numbers with a grain of salt if you will. The B52G's were located on Guam for over two years, nearly all of them came back in very bad condition. I have actually poked my pencil through the side of the B52G in a pressurized area, corrosion was that bad. Every year we bring about 50 B52G's into Oklahoma City for overhaul; they average over 22,000 manhours. Now these manhours cost us something like $20 per manhour. Of that, 9100 manhours - we estimate - is caused by corrosion which is something like 40%, and you can see the kind of money we spend every year just on the B52G's. Now these numbers were quite interesting to me because they were lower than last year. Last year our estimates for corrosion ran more like 40 to 50%, so assuming that we spend about 600 million dollars per year on depot programs, about 250 million per year is spent on corrosion in aircraft structures. The F106's, located at Tyndal on the Gulf Coast, are developing very serious corrosion problems. Many of you are well aware that corrosion and fatigue and wear all work together - I will talk about that later - but I spend much of my time on the road working fatigue problems. I am trying to get the fatigue engineers interested in meshing the two disciplines together so that when we work a corrosion problem we also determine the corrosion effect on the fatigue life and vice versa. The two work hand in hand, but I haven't gotten anybody's attention so far. I hope some of you will give that some thought.

The C141 is a relatively new airplane, but we have had trouble in the bilge area. Any cargo plane is going to have trouble in the area below the fore because that is where people spill hydraulic fluid, coffee, and the urinal always leaks. In the B52G's, we have spent an average $10,000 per airplane because of urinal problems. Sorry for the subject, but it is a very destructive thing. You can look in any old transport and find common problems all through it. We have always had a battle with the base level maintenance people as to who should do corrosion. We have always said they should do it because it is such a simple job, it's simple if you do the corrosion treatment when it first starts. And they say no, because the airplane goes back to the depot in three years or so and the depot will always fix it. That's right, we fix it but by then it is very serious. So, we haven't solved that problem yet. The magnitude of current depot costs for corrosion repair is given in Table III.

TABLE III

DEPOT CORROSION REPAIR

SYSTEM	PDM MAN-HOURS	CORROSION MAN-HOURS	PERCENTAGE	ANNUAL CORROSION COST
B-52G(50)	22,358	9,100	40%	$9,100,000
F-106(71)	3,932	807	21%	1,145,940
F-4E(135)	3,757	678	18%	1,830,600
C-141(90)	10,302	2,980	29%	5,364,000

Areas for improvement are given in Table IV. First of all it is imperative to correct the corrosion problem in its infancy before it increases and depot repair then becomes mandatory. So we feel that definite improvement has got to be made at the organizational level and we have the staff and the using commands working on this. We realize there are funds limiting factors, such as inadequate facilities and some of these are quite difficult to remedy. Another is training, improved training programs are necessary for maintenance technicians to learn proper corrosion treatment techniques. Only through proper indoctrination and increased emphasis can everyday corrosion care become a reality. As I mentioned earlier, most aircraft are scheduled for washing every thirty days. Unfortunately, the general procedure consists of aircraft washing alone without a complete corrosion treatment by qualified corrosion control specialists. We have made recommendations to the Air Staff to correct this. So, we feel the most important single factor remains our inability to track and predict corrosion. We just don't know how to do it. A corrosion prediction matho model will allow us to do two things: First, and the most important of the two, it will allow us to do sensitivity studies to determine where is the best place to invest money. Is it by buying primer (new primers by the way run up to $27.00 a gallon) we don't know whether that will have a payoff or not. Some of the new paint is very expensive and it is getting more expensive. Some of it requires rather exotic conditions for application. An air-conditioned hanger with a lot of special equipment is required to apply some of the new paint, and even then we don't know if it is much of an improvement over the old paint. Many of you are well aware of all the variables in attempting to predict corrosion, you know it was not too many years ago that people said we could not predict fatigue either. Well, in many cases, I still say we cannot predict fatigue, but at least we can come a lot closer than we used to. If you have a C130, for example, based in the Philippine Islands, I can tell you for certain that in two years the airplane will have a very serious corrosion problem and I can tell you right where it will be. We used to divide cyclic test data by a scatter factor of four, I think I could guess closer than that in corrosion today. I think many of you could also. In fatigue, we also use a technique called "Identification of Hot Spots." We identify on the F4, for example, some thirty-nine hot spots in the airplane that will always fatigue first. We track these, we inspect these areas, and I would like you to consider as a similar technique, identification of corrosion hot spots and track those by finding out what is the material, how often is it painted, what kind of primer, so the Crew Chief doesn't have to inspect the whole airplane. He can inspect just those certain hot spots, assess the condition and if he finds certain conditions there then the airplane goes directly into corrosion treatment. We see corrosion as our major single problem in the Logistics Command as far as depot maintenance costs are concerned, so I am quite optimistic from what Dr. Lynch (AFML) has told me about his math model that we can define corrosion and come up with something far better than all the motherhood statements we have heard in the past, and I don't mean to put down any of the research work that has been done. Some excellent work has been done. But we must find a way to predict and define quantitatively what is it that is causing corrosion and what is the best way we can invest some money to slow it down or prevent it.

TABLE IV

AIRCRAFT CORROSION

AREAS FOR IMPROVEMENT

- ORGANIZATIONAL AND INTERMEDIATE LEVEL
  - TRAINING
  - CORROSION TREAT AND INSPECTION CYCLE
- CORROSION TRACKING AND PREDICTION PROGRAM

QUESTIONS AND ANSWERS

Question: How are the base level maintenance programs conducted?

Answer: We have maintenance programs now that say to the base level maintenance people you must put your F4's in phase inspection every 600 flying hours; or in other fleets, it will say every 60 to 90 days. When the airplane goes in for that isochronal or periodic inspection, it is to be washed and given some corrosion treatment. The B52H's, when they were here at Wright-Patterson, were to be given a three day corrosion program, I believe it was every 60 days. Wright-Patterson is pretty bad for corrosion. I'm not sure of the 60 days but I am sure of the three days. What that amounted to was the first day the B52 got washed (it takes all day to wash one); the second day they did some minor corrosion work; and the third day they got the airplane ready to fly the fourth day. So we found that the airplane did not get really three days of corrosion work, it got one day or less. So there is a strong tendency to put off corrosion treatment because it is not going to "bite me on my shift," it is going to hit somebody else five years from now. I sympathize with the operators, I've spent many years as a pilot and realize that nobody can get really concerned with something that is going to happen to an airplane five years or eight years from now. I'm more concerned with "is it going to fly tomorrow." So there is a difficulty there in determining who's got the responsibility.

Question: I was wondering more about the corrosion maintenance itself, is it mainly washing and painting?

Answer: It is. The top of the wing of the C141 has corrosion around the fastener heads. In many of them if you walk along the wing you will see discolored fastener heads, indicating corrosion under the paint and you chip away the paint and sure enough it's there. Well to get rid of that is to take a glass bead blasting machine, an air pressure machine, hold it down over the fastener and that will clear all the paint and corrosion away. You then sand it down smooth with emery cloth, reprime it and repaint. With this method you immediately run into problems. Nobody wants to use the glass bead machine anywhere because the glass dust gets in your lungs, it gets in your hair and clothes and it is a serious problem. It also gets into the fuel tank, in instruments, and the engine, so it is a very difficult thing to work with. However, it can be very effective if it is used right. So instead of people using this technique, I found them using rotary files where they stick something in the end of an electric drill and proceed to buff the corrosion off. Well they would not only file off the corrosion, they would also file off the rivet head. One well-meaning GI in Georgia drilled a hole right through the aft longeron about the size of a dollar. He meant well; however if he had drilled it three feet further aft, we would have had to scrap that airplane. So some of the work our people do is quite poor.

The corrosion work that I see, in general, I would prefer that they not do at all. I just wish we could afford to do it in some specialized facility where you have the experts who know how to do it right.

Question: Does fatigue and corrosion work together, for example on the C-5?

Answer: I wish you would pick another example. It has fatigue problems and we lay hands on the C-5 so much, it doesn't represent a typical airplane of any kind. It has a low flying rate and requires frequent fatigue inspections. So I don't think it would be representative of transports, as far as corrosion prevention is concerned.

Question: How about corrosion on the F-111?

Answer: Let me give you an example on the F-111. We found that the honeycomb on the vertical tail of the F-111 was debonding. We found the GI's in the field would cut out that section, repair it, paint it over then we would check it in the depot when it came in and find that corrosion had set in in that whole area. We recently found that same thing happening in the rear pressure door on the C-141 fleet. Just about a week ago, we approved a modification to replace all the honeycomb doors in the C-141's with corrugated doors, because when corrosion sets in we are unable to repair them. We finally admitted that so now we are going back to Gooney Bird technology so we can work with structure we know how to fix.

Question: Does the C-5 have corrosion problems?

Answer: I am not aware of any corrosion problem on the C-5. Don't let me impress you that all my news is bad, I have seen some excellent work on corrosion in the C-130's. Really very fine, and other airplanes as well so we are doing well.

Question: Is ACI (Analytical Condition Inspection) data used for corrosion work prediction?

Answer: We have that plus a mountain of 66-1 data, accident and incident data and also CIE data. CIE data means that out of a fleet of 500 airplanes we will take another sample of about 11 or 12 airplanes and extend that sample six months beyond the normal cycle. Then another sample six months further. So let's say all the F4#'s come in 4 years, 11 of them come in every 4-1/2 years and 11 different ones come in every 5 years, so that data plus ACI data allows us to try to find an optimum cycle; we are always searching for that. The math modeling we use for that hasn't given us a whole lot of help. It is more a matter of technical judgment.

Question: What is the reason for landing gear problems?

Answer: The reason is T6 heat treatment. If I had my way we would never again buy any primary structure made out of T6. It's absolutely bad news. I could give you many examples. We are switching to T73.

CORROSION PROBLEMS ENCOUNTERED DURING ACQUISITION OF AF WEAPONS SYSTEMS

Major Thomas K. Moore
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Colonel Setter has described some of the corrosion problems which AFLC experiences. These problems are of considerable concern, and unfortunately all the systems which he has described were originally purchased for the Air Force by the Air Force Systems Command.

As a member of the Air Force Systems Command, let me first say that, among the young engineers whom I see, there are two areas which they almost universally do not adequately understand and which they must learn after they come on the job. The first of these areas is mechanical fasteners and joints; the second, finish systems and corrosium protection. I would like to talk briefly about these two areas, and then I would like to speak about some of the actions which the Air Force is taking to try to reduce the corrosion problems in new systems and to prevent the recurrence of some of the problems which are currently being experienced.

Mechanical fasteners and joints are a fascinating area of study, although in many cases, they are not adequately understood, and frequently they are the point of origin for failures, whether fatigue or corrosion. In a structural sense, joints are where the action is. Fasteners transfer the load from one portion of the structure to another. They hold the structure together. Fasteners in aircraft are highly loaded, complex, critical parts. I have several examples of these to show you. I can assure you that they are precision parts, made through 40- or 50 production process steps, including forging the head, grinding the shank, heat treatment, rolling the threads, plating, and hydrogen bake-out. All of these steps must be accomplished under very closely controlled conditions, if we are to achieve adequate static strength, fatigue life, and corrosion resistance in the end product. It has been said by some people that if you can make a threaded fastener from a material, you can make anything from it. Fasteners such as these are subject to fatigue, corrosion fatigue, stress corrosion cracking, hydrogen embrittlement, galvanic corrosion, uniform attack general corrosion, and pitting. They and the holes necessary for their use are the sites of the vast majority of the corrosion and fatigue problems which we experience on Air Force aircraft. The consequence of these corrosion and fatigue problems are almost always serious, frequently expensive, and unfortunately, occasionally fatal. On an automobile corrosion and fastener failure might cause a fender to fall off and yet the car would still be operable. In aircraft if corrosion causes a wing to come off, the consequences are catastrophic. An example of one of the problems which we are examining at the present time in new design is the question of how do we fasten advanced composite components.

In Figure 1, you will see a small coupon test showing three different fastener materials. The material in the middle which is showing the corrosion is A286 Corrosion-Resistant Steel. It is commonly used in aerospace fasteners today. The other two materials are: the hexagon-head bolt Ti-6Al-4V, which is also used in many aerospace fasteners, and the internal wrenching screw (Multiphase MP35N), which is a nickel, cobalt, chrome, molybdenum alloy. The least expensive and most commonly used of these materials is the one which is showing the greatest corrosion here in graphite.

Moving to my second area of discussion, the components of a good finish system are not widely known. Some chemical companies, some metal producers, some civil engineers, and some aerospace prime contractors understand and use good finish systems. Unfortunately, there are many suppliers who do not. Figure 2 shows a component of an electronic countermeasure pod which had been in service for about a year. I was called in and asked for some advice by this program's director, since his new pods were giving unacceptably low service lives when they were deployed for use. You will notice that the aluminum skin has had only a chromate conversion coating and that this skin is pitted. The structural ring at the corner of the picture is made of 17-4 precipitation hardened steel -- corrosion resistant steel -- and you will notice that there was no attempt to seal the crevice between the 2024 aluminum and the 17-4 steel. As a result, we do have products of corrosion beginning to accumulate in the crevice. Some of the fasteners here in the aluminum were alloy steel, and their only corrosion protection is a black oxide layer on them. The engineer at the company which produced this pod went to great lengths to explain to me the very beneficial qualities which the black oxide coating did give. However, while it may have given many beneficial qualities, one of them does not seem to have been corrosion resistance. By contrast, the cadmium-plated fastener seen along the backbone of the pod shows no signs of corrosion.

At this same plant (Figure 3) I was examining assemblies which were undergoing testing, when I noticed that some of them were already corroded. The particular picture that I show here is one of some electronic filters. This I cannot claim as new. It had four hours operational service and had been out of the factory for almost a year. The ones which I saw in the factory were not quite as corroded, but they clearly were corroded. The manufacturer was not able to identify this as corrosion, however, until it was explicitly pointed out to him as such. I think that this points out that we have problems even among the organizations which have considerable engineering sophistication, and let me hasten to say this particular manufacturing facility employs in their engineering office more than 2,000 engineers and is considered

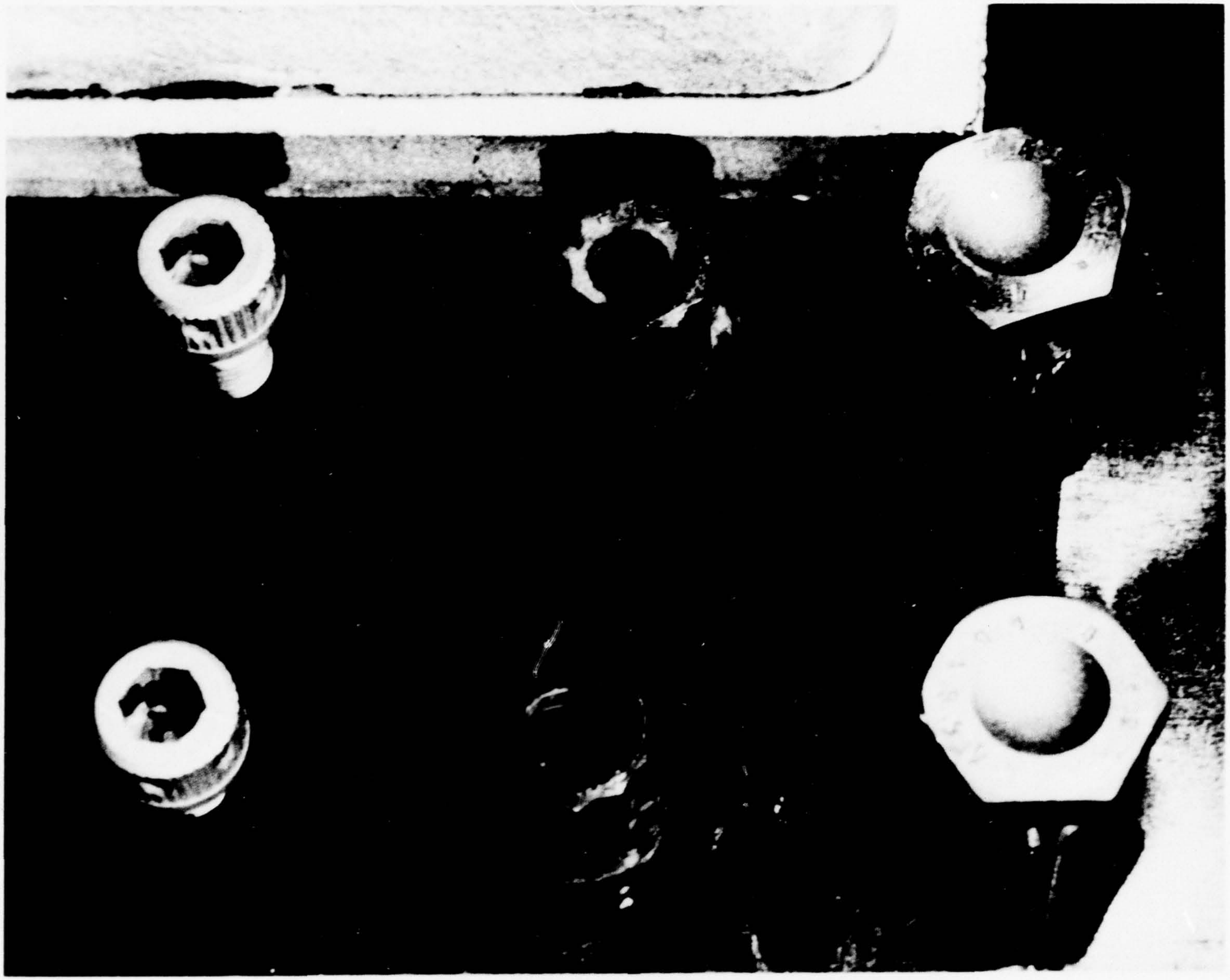

Figure 1

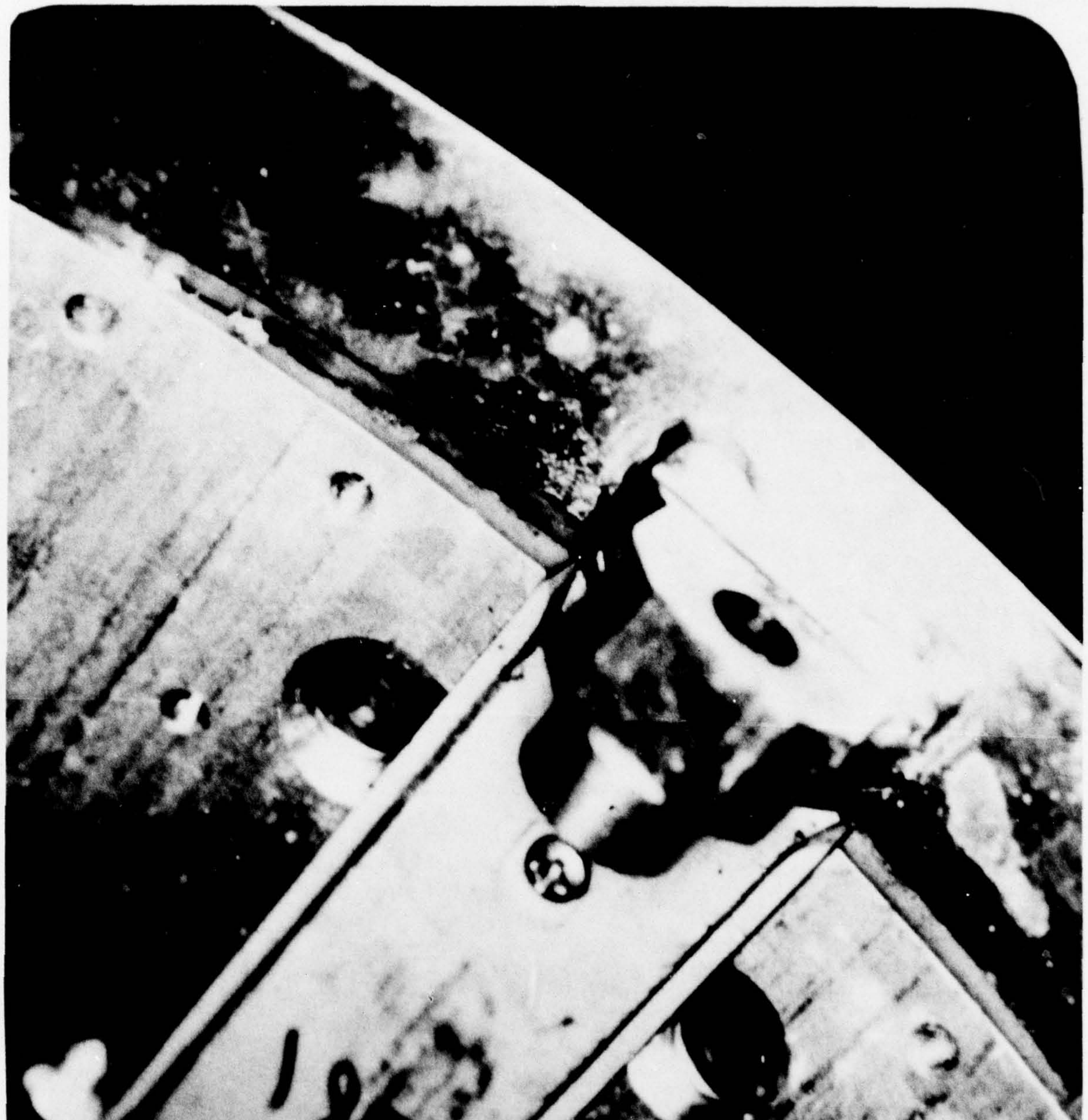

Figure 2

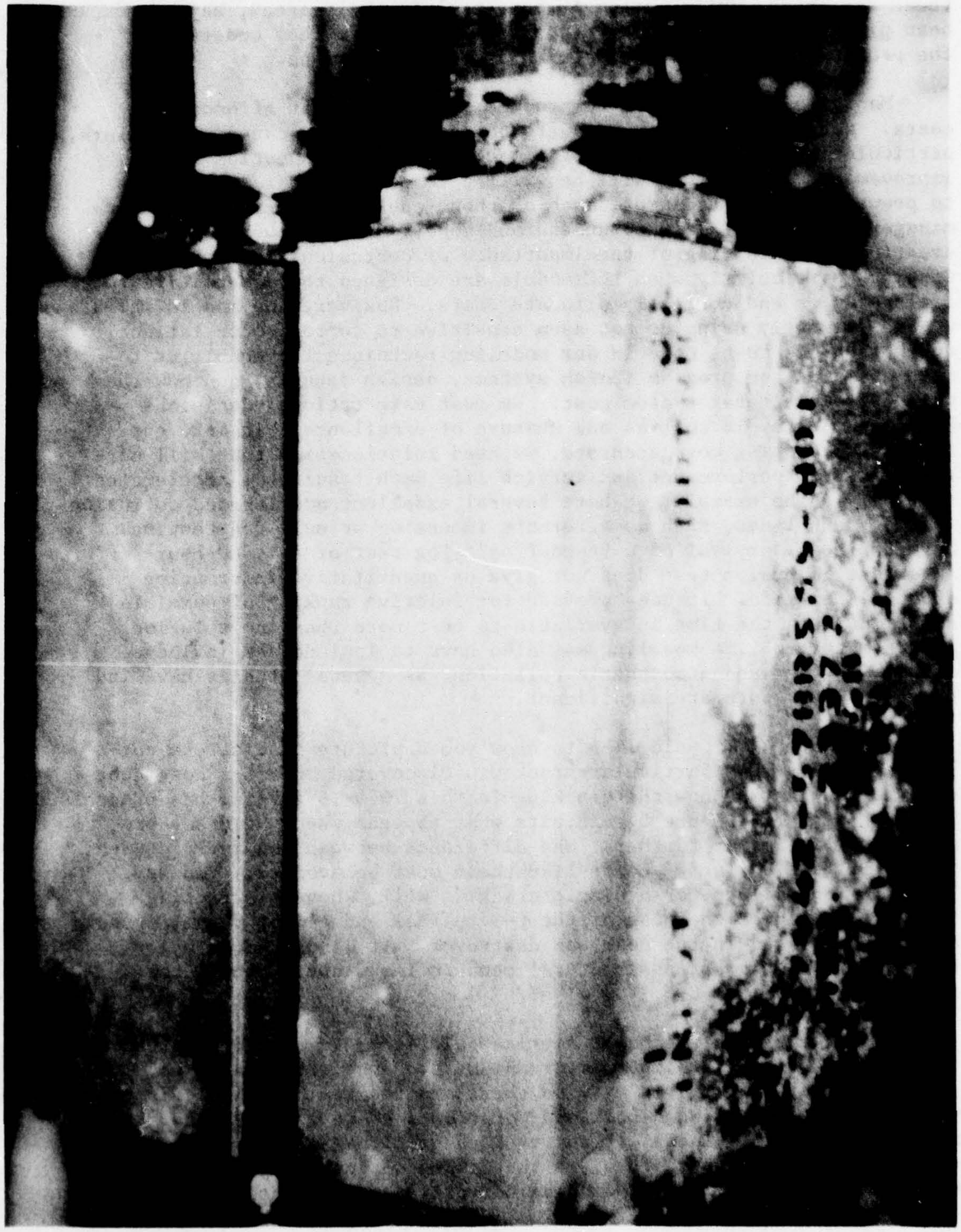

Figure 3

a technical leader in electronic equipment. Unfortunately, many of these engineers, while extremely competent in their areas, have not been given an exposure to what corrosion is nor do they understand the problems which it can create in systems operations.

Managers are motivated to produce good systems at affordable costs. Nevertheless, many managers do not understand causes of failure, particularly when failure is not immediate. Their education needs improvement so that they will be willing to commit program resources to prevent delayed failures, such as those caused by corrosion. Since managers generally claim to understand money, a very powerful tool for creating understanding of the importance of corrosion is Life Cycle Costing, particularly when LCC models are designed to be sensitive to failure modes and correctly allocate costs. However, the models which we are presently using do not seem sensitive to corrosion or fatigue, and work needs to be done in our modeling techniques to enable us to make decisions on program finish systems, design details, and how they will influence total system cost. We must make rational decisions based on life cycle cost as one measure of excellence. To make our Life Cycle Costing more accurate, we need relationships that will correlate system performance and service life with results of accelerated testing. As an example, we have several excellent accelerated corrosion testing techniques, such as alternate immersion or salt fog testing. Nevertheless, survival of a 96-hour salt fog test or a 1,000-hour alternate immersion test does not give us quantitative information about system life. It does provide for relative ranking of possible solutions when the time is available to test more than one solution. Accurate system life modeling may also have to include the influence of both weather and atmospheric pollution, as several studies have indicated these factors are significant.

In Figure 4, I would like to show you a picture of a stress corrosion crack. This particular crack was discovered on a C-5 nose door visor. You can see how the cracking in this 7075-T6 forging has progressed. The next picture (Figure 5) exhibits what happens when the crack progressed a little bit further. The difference between the two pictures is 2.4 million dollars. Costs like these must be avoided. You say, "2.4 million dollars for a single crack?" Well, when this fitting failed, it allowed the nose of the C-5 to fall and all of the electronic equipment located in the nose was destroyed. It also created major damage to the aircraft's structural members immediately behind the pivoting nose of the C-5.

In talking with the major American airlines, we are finding that they consider their two most important maintenance problems to be corrosion and fatigue. In my mind these <u>are</u> the two principal aircraft wear-out phenomena. When Lockheed Corp. decided to re-enter the commercial aircraft business, it surveyed the airlines and found that these were items of interest. Thus, in the design of the L1011, Lockheed went to great lengths to produce as corrosion and fatigue resistant a

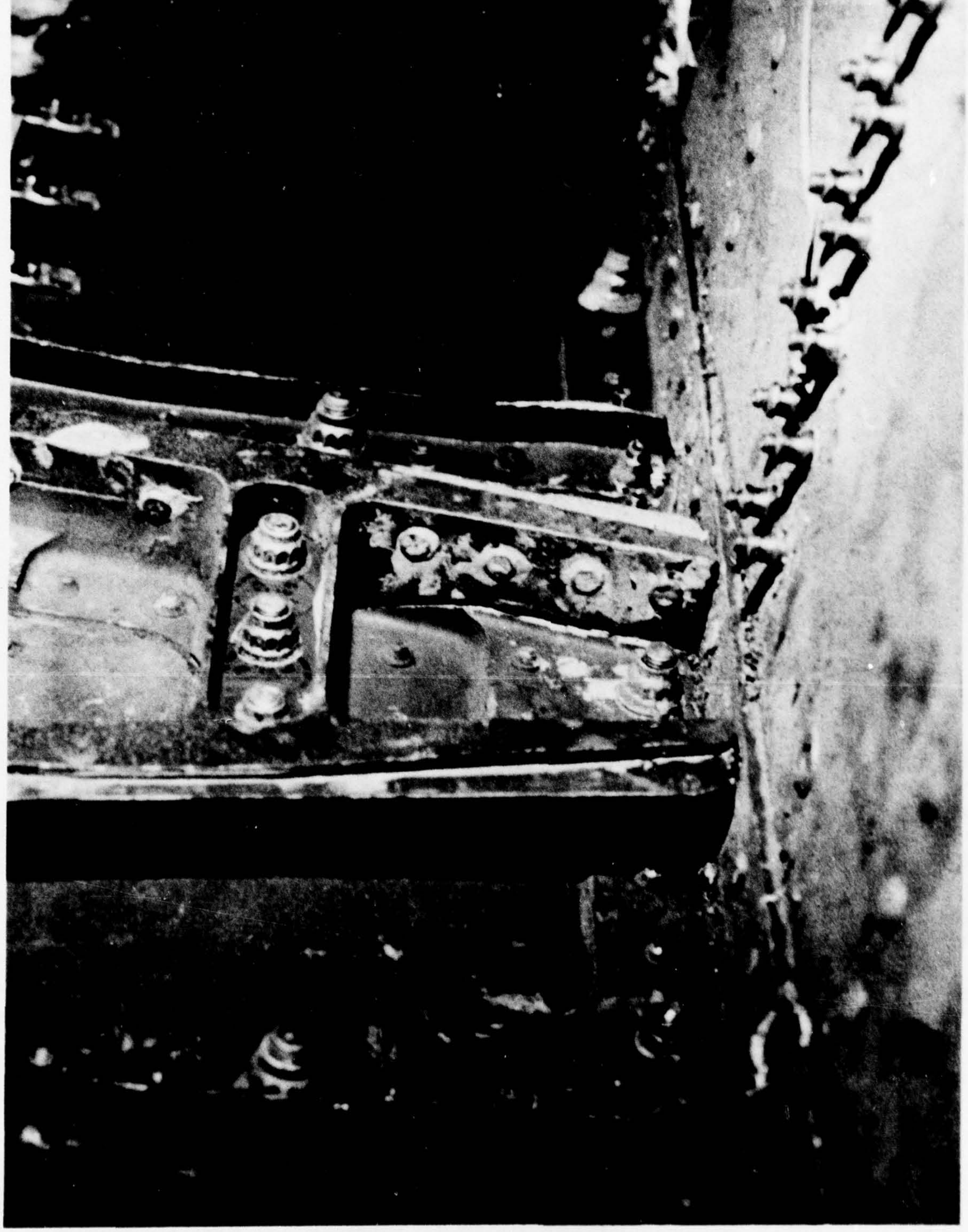

Figure 4

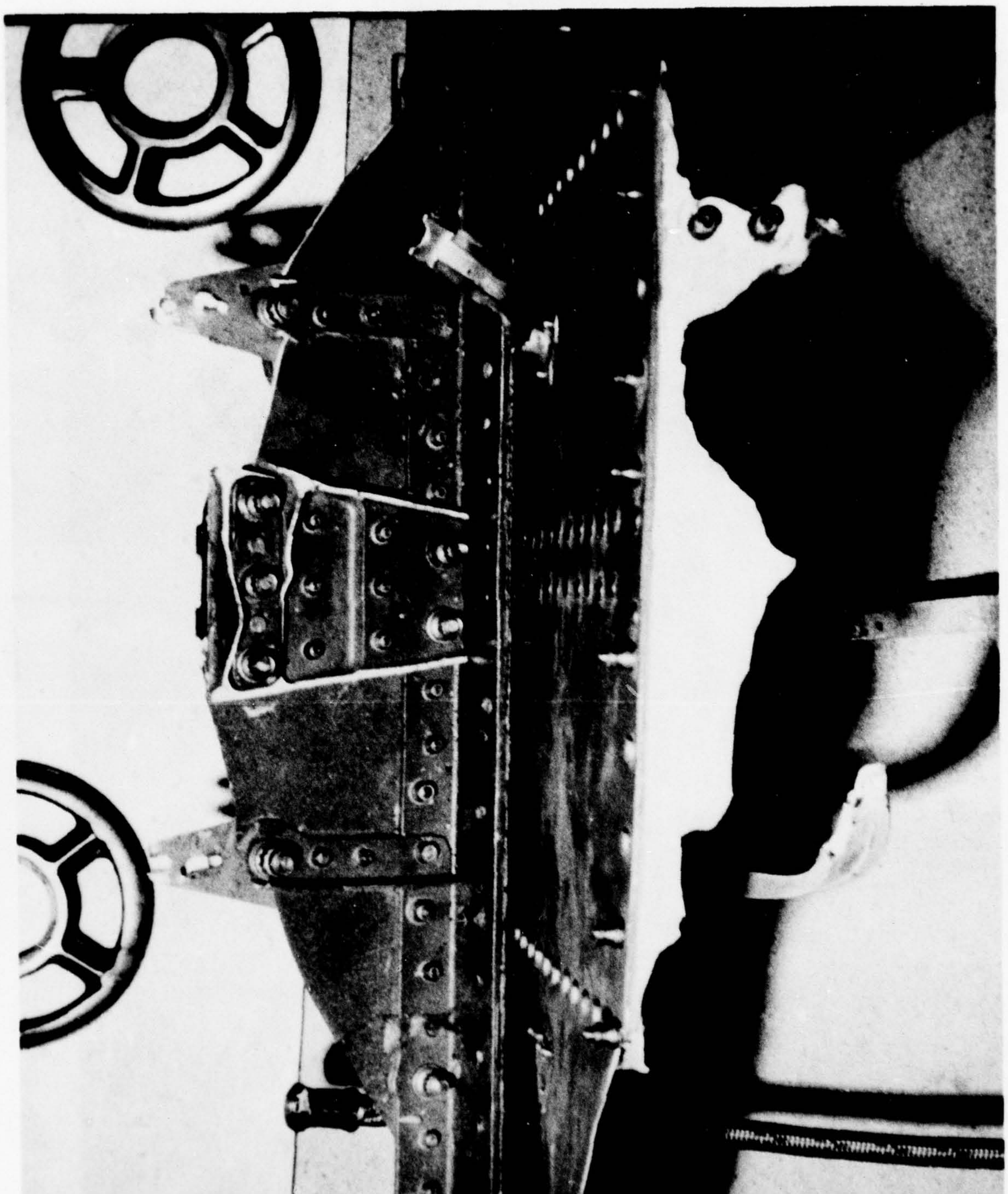

Figure 5

design as they could, including the use of skins and stringers which were clad on both sides; bonding numerous components together, as well as riveting them, which you might say is in a sense, wearing suspenders and a belt; and choosing materials which have low potential for corrosion and which have excellent service histories. I mention this experience which Lockheed had because I believe that perhaps the airlines have been more successful in impressing on suppliers the need for corrosion resistance than we in the military have been.

This is a condition which we are trying to correct. We have organized corrosion prevention advisory boards on new systems to provide early knowledgeable review of design for adequacy of corrosion prevention.

The Materials Lab has prepared and is presently having printed a new military standard (MIL-STD-1568) for corrosion prevention during aircraft design which lists in one location a large number of the prohibitions and recommended practices which will yield longer service life for our aircraft. We in the Aeronautical Systems Division are similarly taking action to improve the corrosion resistance of the aircraft whose development we sponsor. Changes take place slowly; however, there have been in the last 10 to 15 years several changes that have been instituted. For example, we have almost completely halted the structural use of magnesium in aircraft, because while magnesium can be protected against corrosion, we have found that we in the military services have not been successful in keeping magnesium protected against corrosion. And another example: we are presently instituting severe limitations on the use of 7000 Series Aluminums in the -T6 condition, because of their potential for corrosion when heat treated in this condition. We have been reviewing a number of our design and structural guidelines and normal practices; we are carefully re-evaluating the use of aluminum core honeycomb, and I think that I can safely say that most of us are convinced that we must at least use a very corrosion resistant aluminum core. And there is some question if any aluminum core honeycomb should be used in new aircraft design. We are going further. We have issued a damage tolerance specification (MIL-A-83444) which our aircraft must meet. It requires the use of linear elastic fracture mechanics in the analysis of our structures. It acknowledges the influence of stress corrosion cracking in our structures, and it calls out a minimum flaw size which must be assumed present for the purposes of analysis in our structures. We are further in the process of amending our fatigue specification for aircraft (MIL-A-8866) and our structural test specification for aircraft (MIL-A-8867) to require the definition by the contractor of the chemical environment in which fatigue testing will take place. This will require innovative thinking on the part of all of us who are involved in aircraft structure design, testing, or certification. It also would be a very fruitful area of research for those of you who are challenged by the problem of relating service life to accelerated testing.

Gentlemen, I think that in closing I can say that there are opportunities to do better. In the past we have made mistakes, in the present we are learning from our mistakes, we are changing our requirements; we are attempting to provide corrosion resistant long-lived structures for the Air Force. In the future further challenges await all of us as we seek to increase the effectiveness of our systems.

CORROSION ON RELATED AIRCRAFT STRUCTURE

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It is almost impossible to hear it happening, and it is very difficult to see. If it's felt, it is probably too late. Yet this process is constantly occurring everywhere and has an economic cost of $15 billion per year. No, it is not the rise of consumer prices. This very expensive and often serious problem is corrosion.

I am going to discuss three major types of corrosion: general or uniform, localized and intergranular attack. General or uniform corrosion takes place when an entire surface corrodes (Figure 1). Magnesium corrodes uniformly (Figure 2) if not properly protected. Transmission housings manufactured of cast magnesium are successfully used in helicopters. The Dow 17 or HAE coating appears to be an adequate surface finish for magnesium. Localized corrosion involves pits, crevice formation, and exfoliation (Figure 3). Exfoliation around fasteners (Figure 4) is a serious problem in aircraft structure. The use of over-aged aluminum alloys, T-76 temper, and the installation of fasteners with wet zinc chromate primer has reduced the exfoliation corrosion in aircraft. The question is always asked how does a corrosion pit or crevice initiate and how does it grow? What causes them to stop growing? A number of investigations have been conducted in these areas with articles reported in various corrosion magazines.

More investigations have been conducted regarding intergranular or stress corrosion than any other type corrosion. The first aircraft accident I will discuss illustrates intergranular or IG corrosion in 2024-T4 aluminum alloy.

A cargo aircraft arrived at Dover AFB from overseas. The crew received word from the tower to hold as the landing field was temporarily closed. During the holding period the right wing failed. No turbulence was reported in the area. The forward lower spar failed at a bolt hole (Figure 5). The holes are used to attach the leading edge skin to the spars. Cadmium plated alloy steel fasteners are used to attach the leading edge skin. IG corrosion was found in the failed bolt hole (Figure 6). The cargo fleet was inspected. The bolt holes which contained evidence of corrosion were reamed and installed with oversized fasteners.

Stress corrosion cracking involves a complex interaction of sustained tension stress and corrosive attack that results in rapid cracking and the premature brittle failure of a normally ductile material. These conditions are necessary for stress corrosion cracking:

1. A corrosion susceptible material,
2. Sustained tensile stresses, and
3. A corrosive reaction.

The major sources of stresses in aerospace components are from:

1. The thermal treatment,
2. Assembly or fit-up stresses, and
3. Service or static stresses.

Sometimes it is necessary to have the accumulated total of the stresses before failure occurs in a normal service atmosphere. Many times a newly manufactured part will fail from stress corrosion cracking even before it is assembled into a structure due to high residual stresses from thermal treatment. The most susceptible grain orientation is the short transverse direction which is always present to some degree in the forging parting plane (Figure 7). For high strength aluminum alloys, stresses as low as 6000 psi across the short transverse grain can cause stress corrosion cracking (Figure 8). Stress corrosion cracking of forgings or extrusions has caused the majority of the primary structural failures of Air Force systems. The fracture surface of stress corrosion failures is generally characterized by a brittle (intergranular) cracking zone progressing from an origin in a circular or semi-circular crack front, followed by the normal ductile fracture pattern of an overload failure (Figure 9). During 1960 through 1970, in AF Systems, 7079-T6 aluminum alloy forgings were widely used. This alloy has the highest transverse mechanical properties of the aluminum forging alloys. These properties are obtained through a cold water quench (70^{o}F). The T-6 condition in other aluminum alloy forgings is obtained through a warm water quench (140^{o}F) and the residual stresses resulting from the cold water versus the warm water quench are considerably higher.

An aluminum alloy, 7079-T6, outer cylinder of one of our aircraft failed on the alert pad (Figure 10). Examination of the cylinder revealed that the failure did not occur in the parting plane but 90^{o} from the parting plane (Figure 11). Analysis of the failure area revealed the presence of considerable transverse grain in the fracture area. The service stresses were higher in that area than at the parting plane. The investigation showed the method of breakdown of the pre-forging stock resulted in transverse grain runout in areas other than the forging die parting plane.

A fighter aircraft suffered a left main landing gear malfunction during a routine take-off. The pilot burned off the excess fuel and attempted a landing which resulted in collapse of the left gear and loss of the aircraft. The landing gear was manufactured from 7079-T6 aluminum alloy. The gear separated at the parting plane of the forging (Figure 12) initiating from a stress corrosion crack (Figure 13).

A pressure cylinder containing helium which is used on a missile for auxiliary actuating flight control power, ruptured and fragmented while in a storage bunker. The helium bottle is located in the aft end of the missile. The cylinder is fabricated from 18 percent Ni maraging steel and heat treated to a mininum yield strength of 206 ksi. Visual examination of the failed cylinder (Figure 14) showed numerous cracks in the inner surface of the bottle. Little or no deformation was associated with the crack sites (Figure 15). Further examination of the fracture (Figure 16) showed that before final overload occurred, the cracks had established a slow stable growth rate. Fractographic examination of the crack surfaces by the transmission (Figure 17) and scanning (Figure 18) electron microscopes revealed an intergranular cracking mode typical of stress corrosion cracking. Metallographic examination of a cross section of the cylinder wall through a crack revealed secondary branch cracking which is further evidence of stress corrosion cracking (Figure 19). The cause of the stress corrosion was attributed to small amounts of residual water and chlorinated hydrocarbons left in some bottles after welding and prior to charging the bottle with helium. The remedy was to lower the helium pressure from 7700 psi to 4500 psi and replace the maraging steel with another material, 4130 alloy steel, heat treated to only 150 ksi tensile strength to make it less susceptible to stress corrosion cracking.

In summary, the Air Force has tried to minimize corrosion and its detrimental effect on structures and components. The application of over-aged aluminum alloys and the -T7 temper has eliminated the exfoliation and stress corrosion cracking which confronted us during the 1955-1970 time period. The recommendations of the material and corrosion engineers are being considered early in the aircraft design phase.

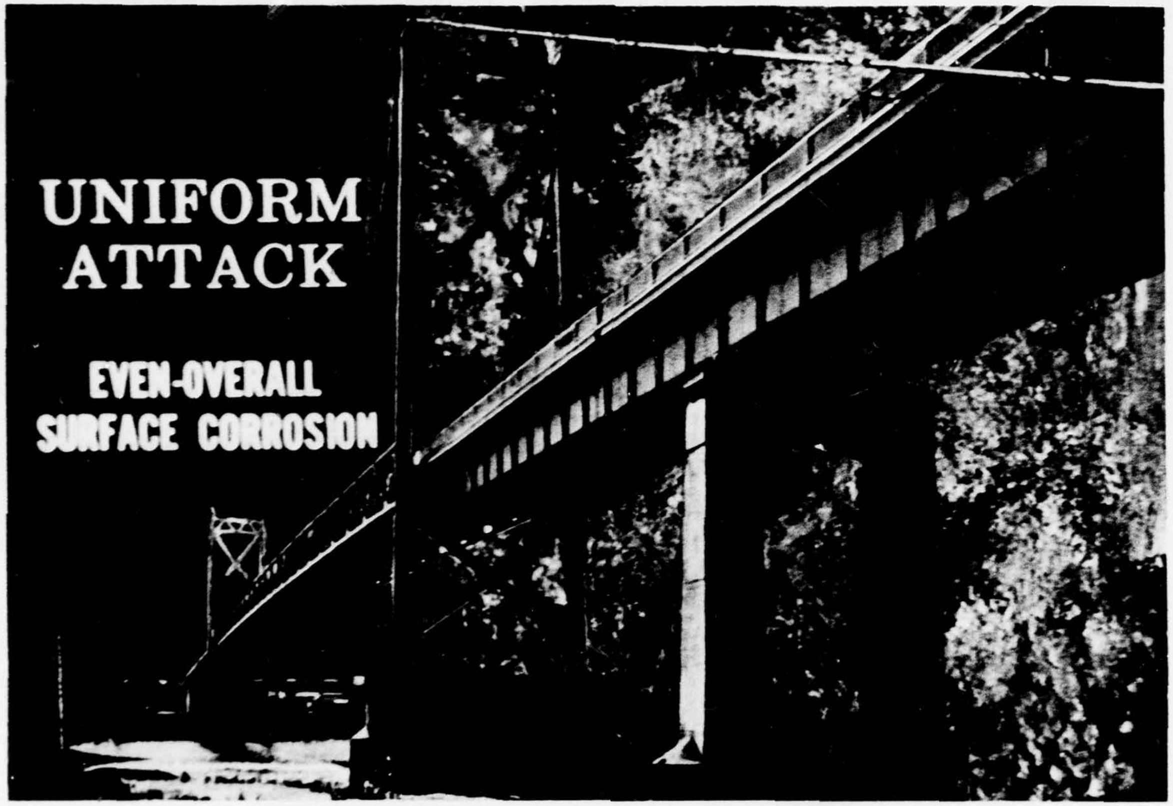


Figure 1. Even overall surface corrosion

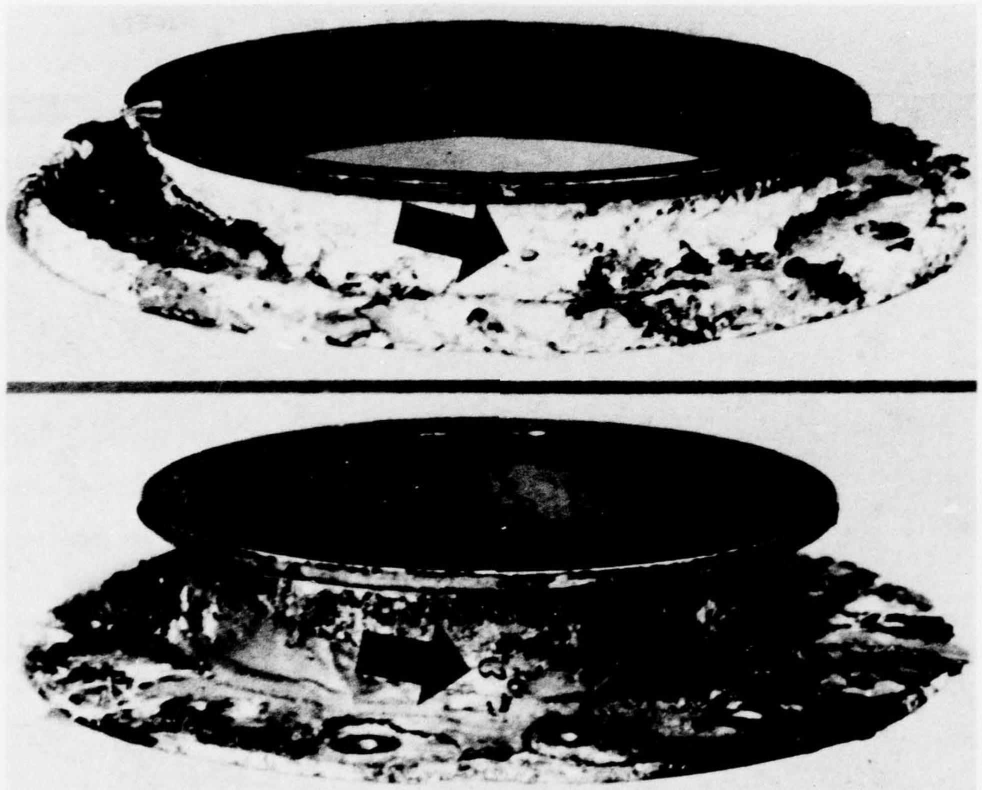


Figure 2. Magnesium casting-corrosion

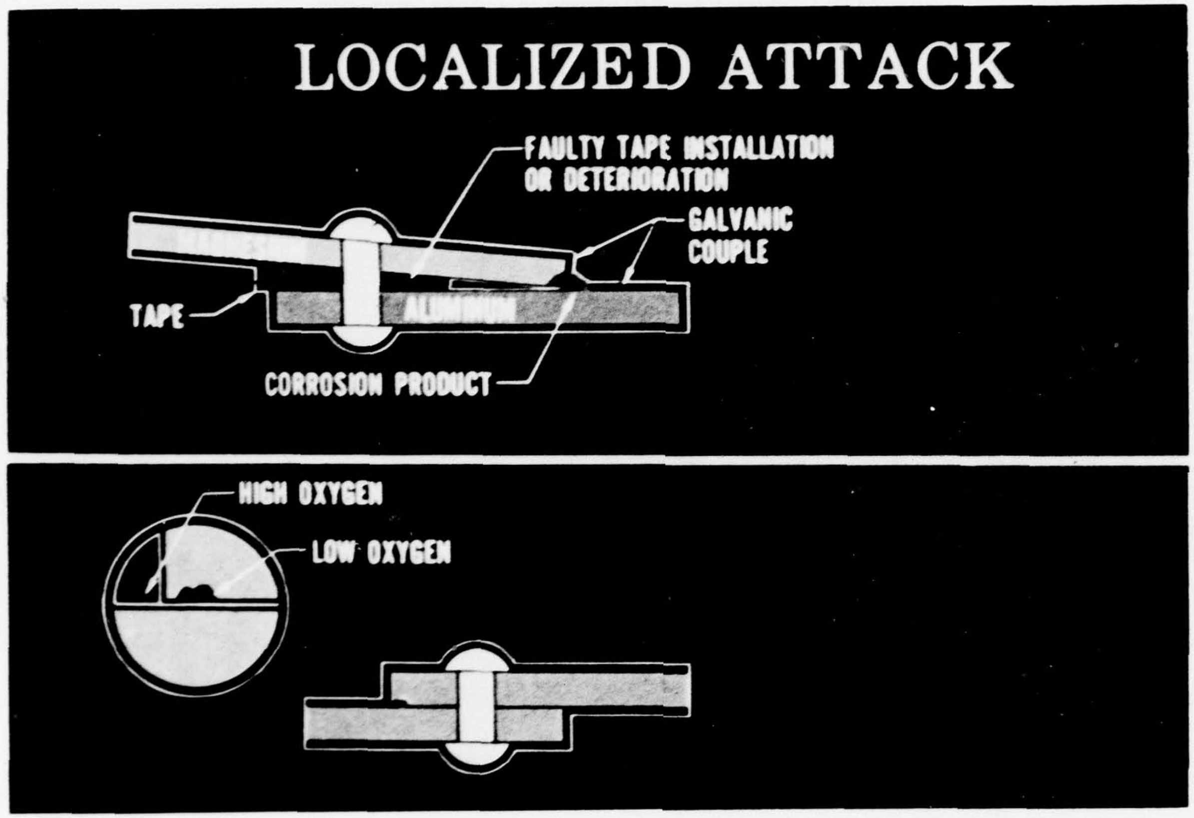


Figure 3. Corrosion-localized attack

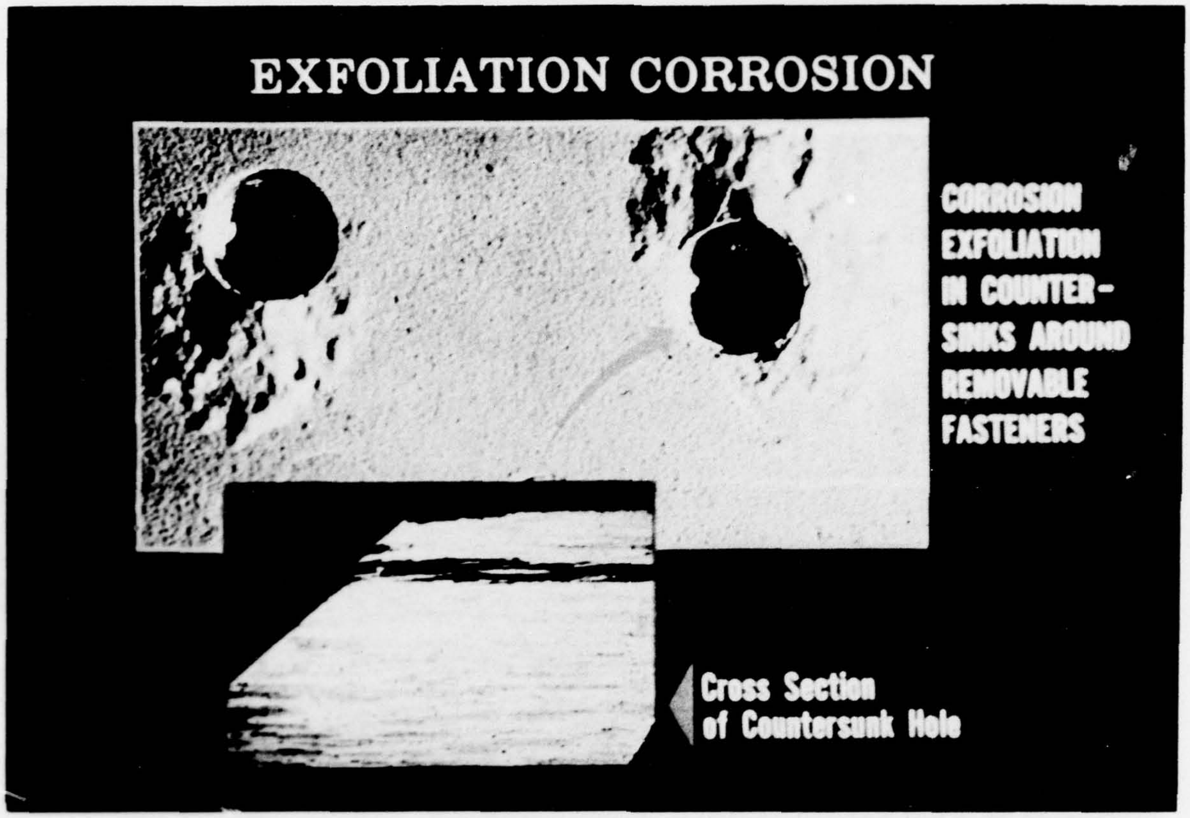
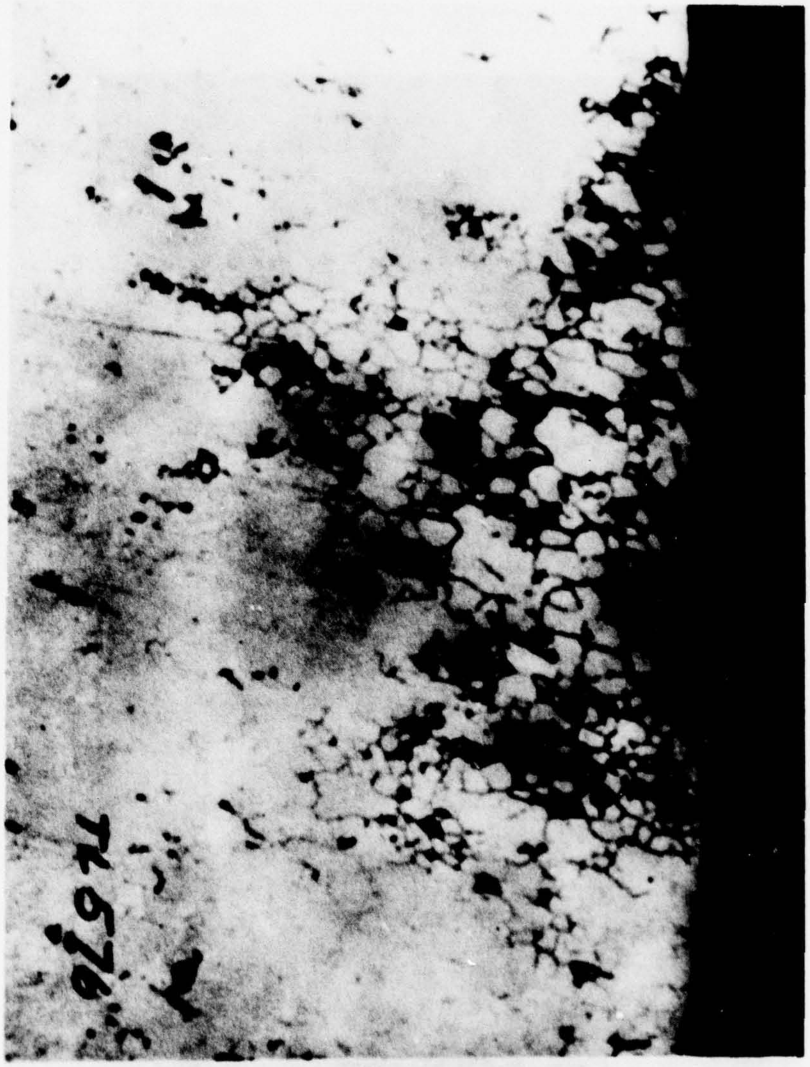


Figure 4. Exfoliation corrosion around bolt holes

Figure 5. Wing spar - single hole on left side contained IG corrosion - Material 2014-T6



I.G. Corrosion Found in Bolt Hole

Figure 6. Close-up of IG corrosion in bolt hole

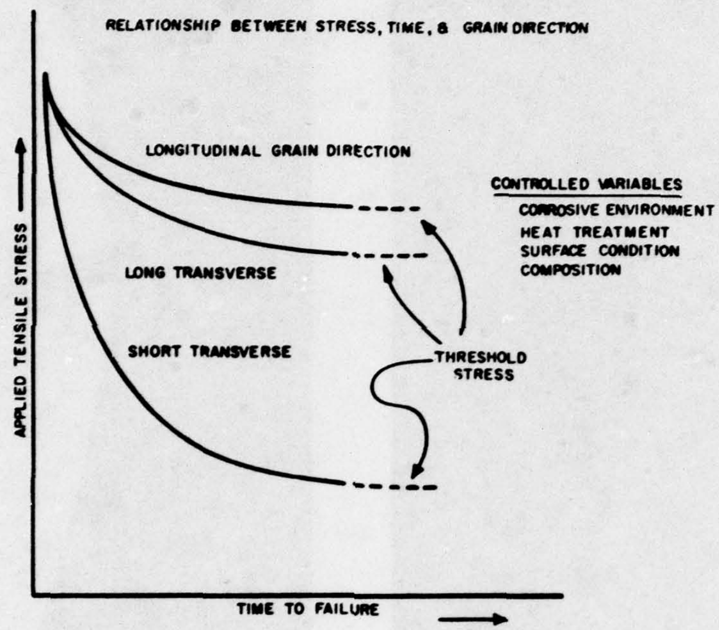


Figure 7. Stress corrosion cracking susceptibility

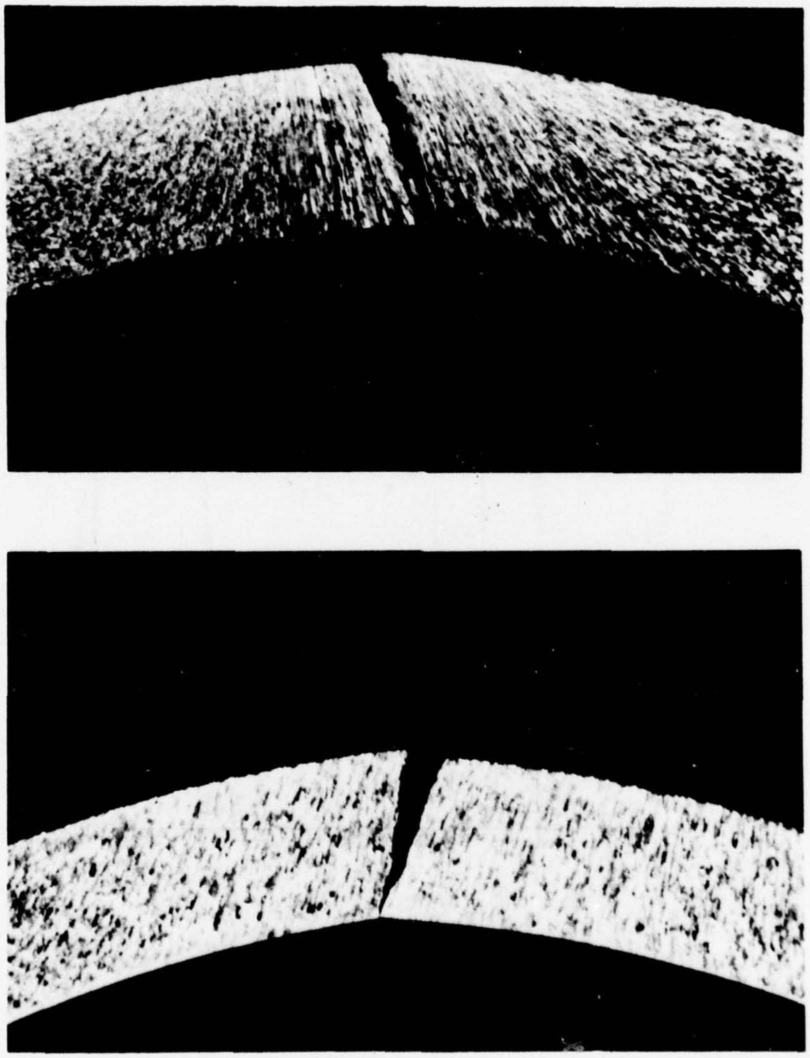


Figure 8. Short transverse grain in forging parting plane

Figure 9. Stress corrosion initiation site

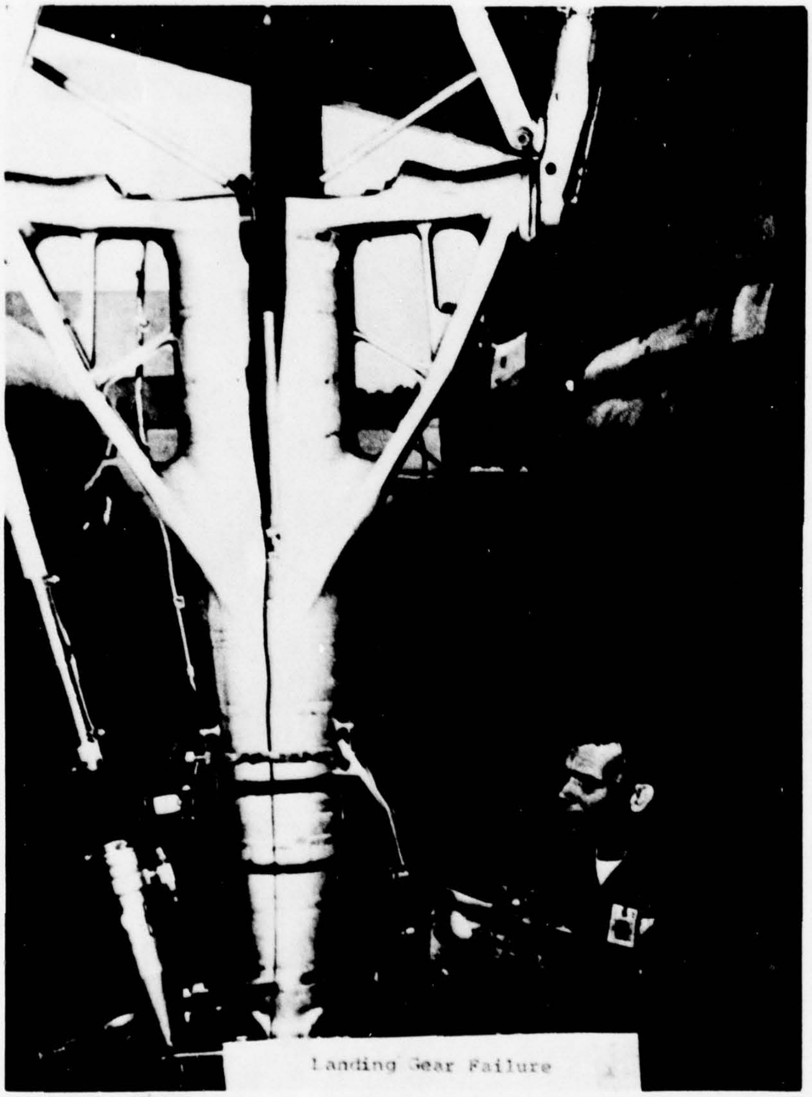


Figure 10. Landing gear cylinder - operated down center - Material 7079-T6 aluminum alloy

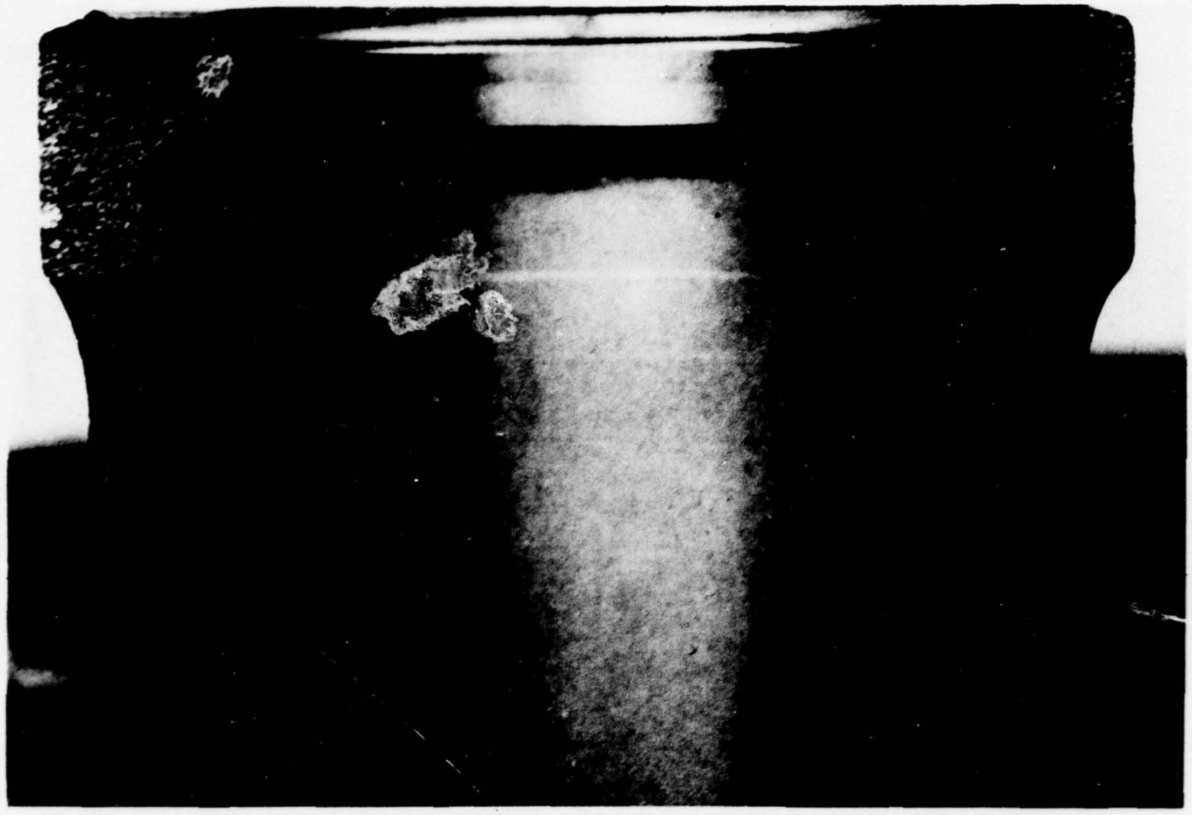


Figure 11. Stress corrosion initiation in upper dome of the outer strut

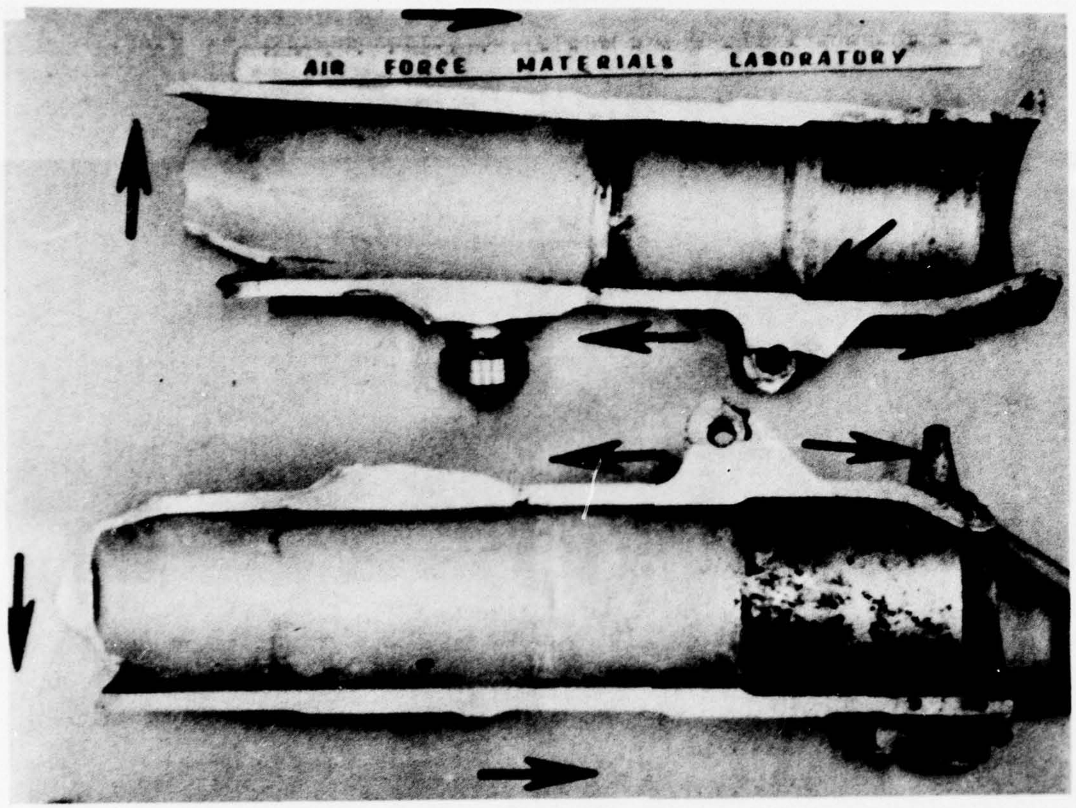


Figure 12. Landing gear outer strut - Material 7079-T6 aluminum alloy

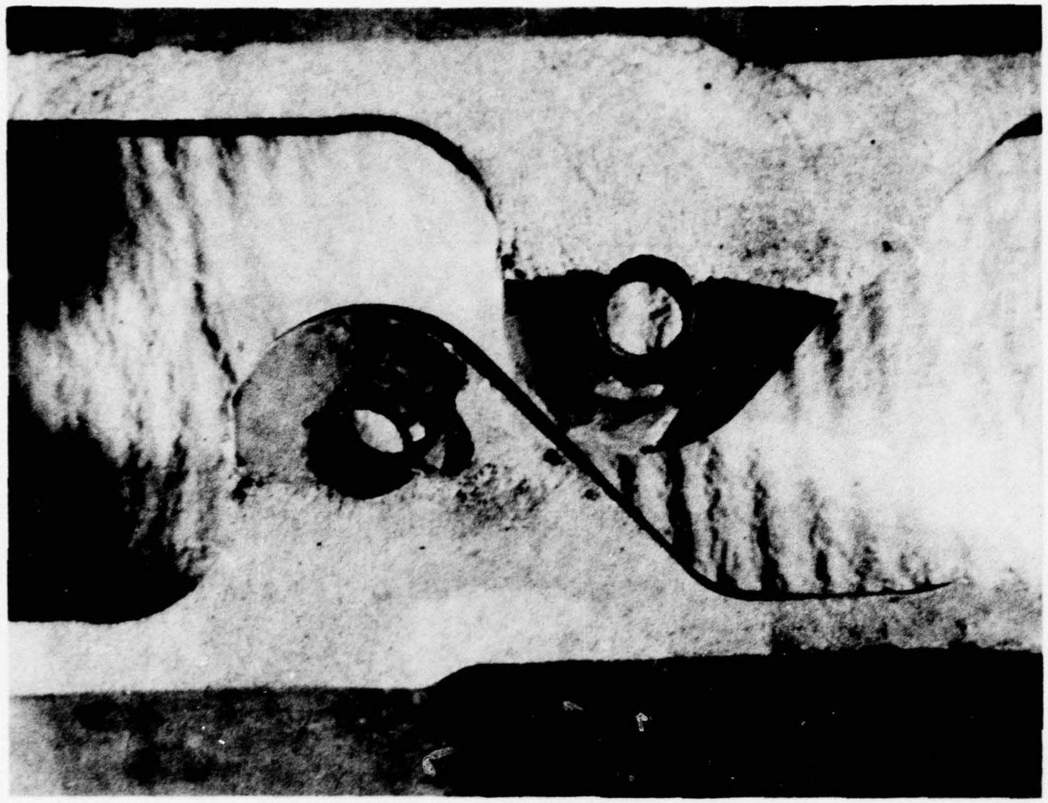


Figure 13. Arrow shows initiation site of stress corrosion cracking

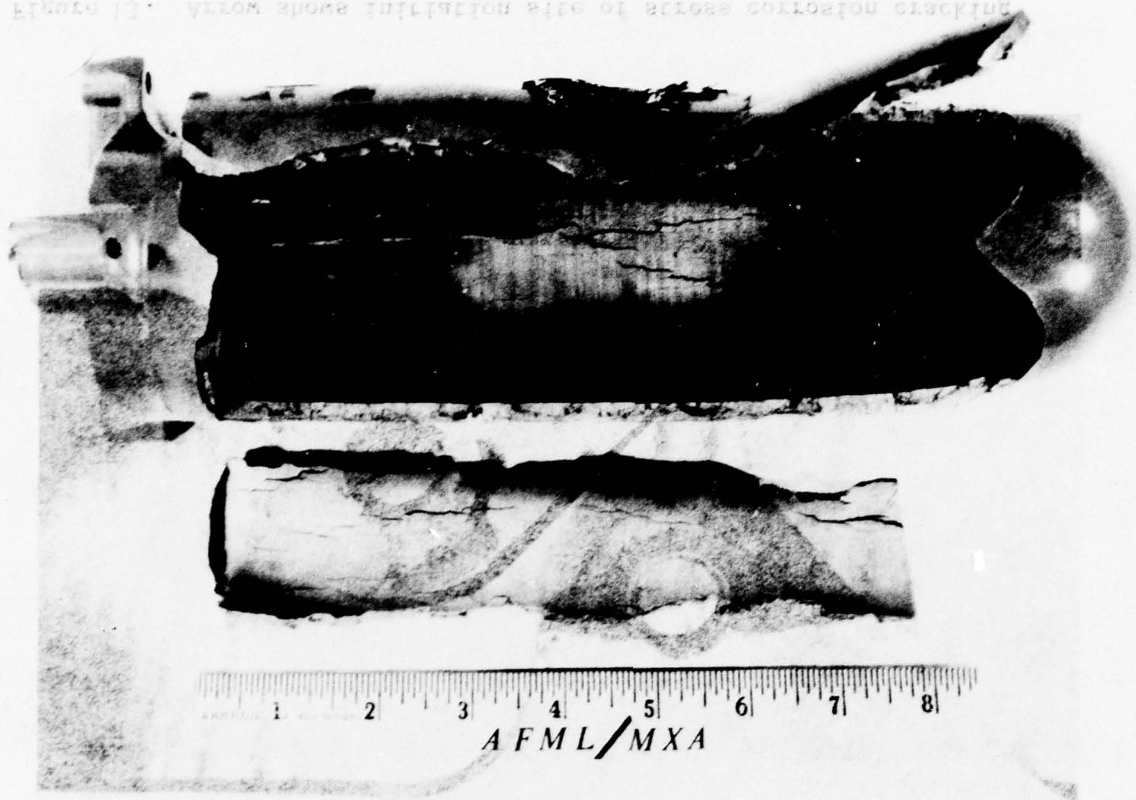


Figure 14. Failed helium bottle showing extensive multiple cracking

Figure 15. Close-up of failed helium bottle inner wall showing numerous cracks on the inside surface

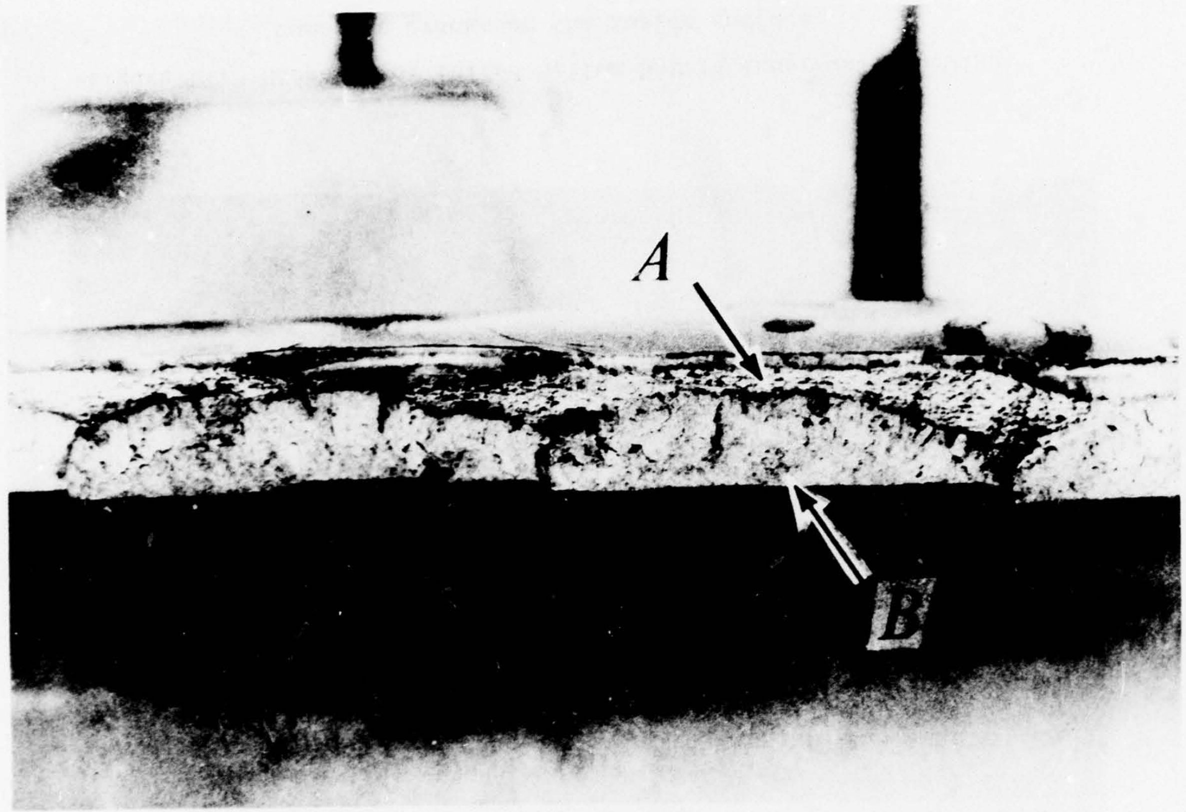


Figure 16. Fracture surface. Cracks progressed slowly to approximately 0.180 inch through the 0.200 inch thick wall before bursting occurred.

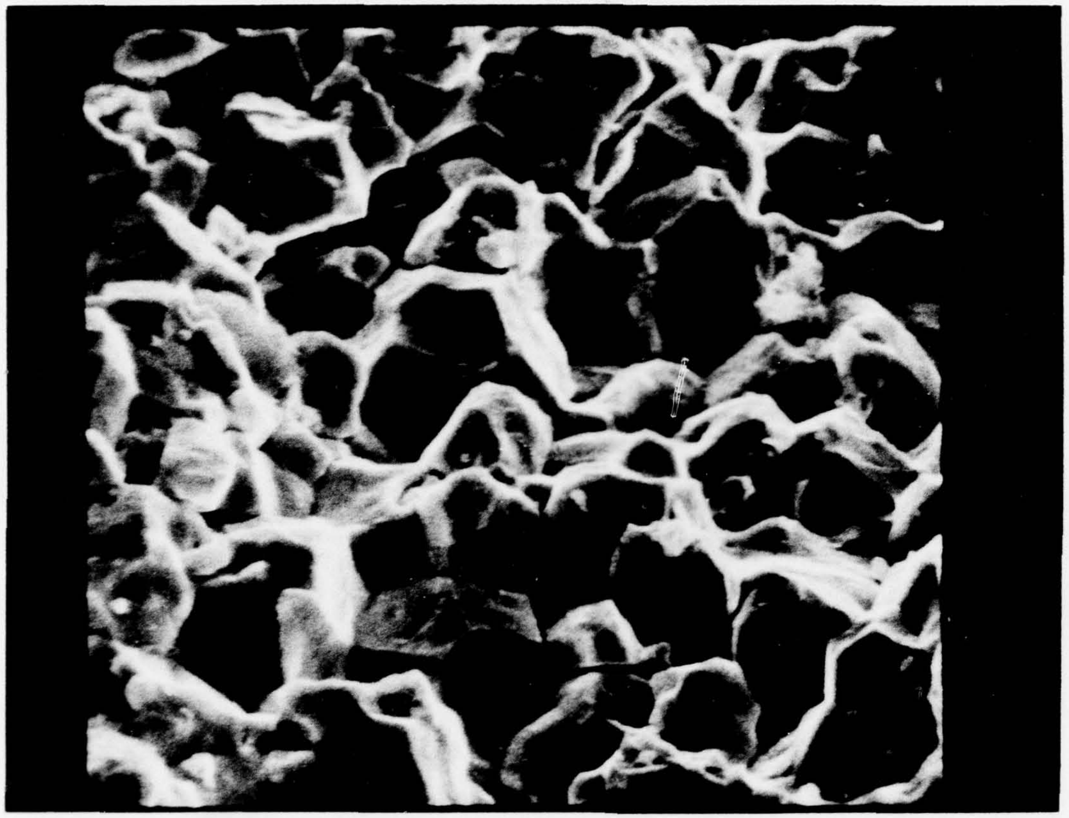


Figure 17. Transmission electron fractograph showing intergranular fracture mode

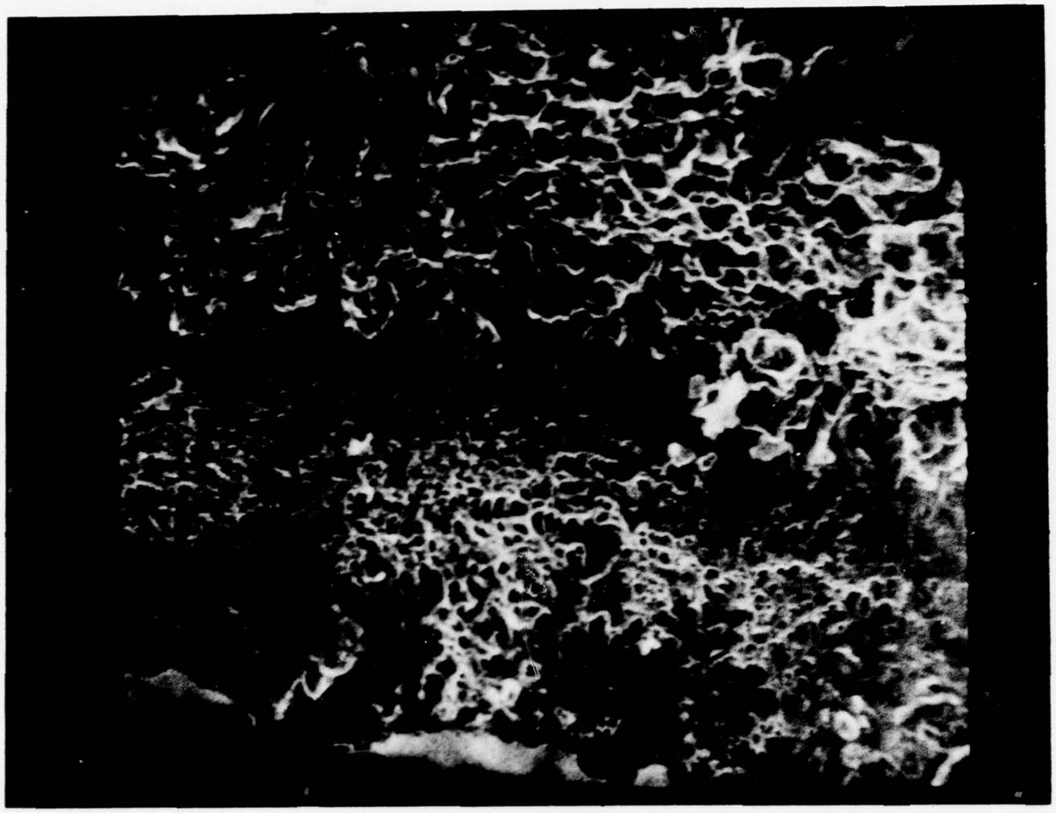


Figure 18. Scanning electron fractograph of the transition zone, showing intergranular cracking at the bottom and ductile dimpling at the top

Figure 19. Photomicrograph of a crack tip in the bottle wall. The secondary branch cracking is typical of stress corrosion cracking

ADVANCED METALLIC STRUCTURES TECHNOLOGY PROGRAMS

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Wright-Patterson AFB, Ohio 45433

I have been asked to give you a flavor for where we see ourselves going in Metal Structures in the Air Force over the next three to four years. My role, as compared to the AFOSR role, is in the Exploratory and Advanced Development areas. So I am more interested in the reduction-to-practice than in basic research. We look at our reduction-to-practice programs as "windows" wherein we can exploit some of the research activities that go on in the universities. I am going to try to quickly go over with you what our plans currently look like and during that process highlight the corrosion aspects that I think maybe this group can impact.

The AF has placed emphasis on various areas in the past ten years. In the 1960's, the emphasis was on minimum weight of systems and we paid a penalty for that as you saw from the horror pictures that Howard Zoeller just showed. In the early mid 70's, the emphasis was really on acquisition costs or on ideas for reducing the cost of buying new airplanes. With the escalating costs of airplanes, we Materials people had to do our share to reduce those costs. But now in the time period that we are in today, we can see more emphasis going into the maintenance question because that problem is now becoming overriding. The cost of ownership may in fact be overriding the acquisition cost problem.

If you look at what we do in metal structures, you will see that we divide the work into four major areas. These thrusts are shown in Figure 1. The structural integrity question really is the first order of magnitude; you must make sure that the basic integrity is there before you can start worrying about corrosion. The other three areas are, acquisition costs, ownership cost, and expanded performance. We have quite a bit going on in acquisition and ownership costs problems, but we have very little going on in the expanded performance area right now. Most of our money, in terms of funded research, is in the top three categories. Now that's not to say we aren't interested in the materials improvement area; it is just the fact that we in the Air Force don't see the need in the next 3 to 5 year time period for new airplanes to have materials to withstand significantly higher temperatures or loads.

I want to indicate for you some goals we have set for ourselves in these four basic areas. These are also given in Figure 1. The structural integrity area is one that you can spend a lot of money on. Our objective here is to get safety without having to spend a lot of money. In the ownership cost area, the objective is to try to achieve

FIGURE 1. METALLIC STRUCTURES TECHNOLOGY

MAJOR THRUST	GOAL
IMPROVED STRUCTURAL INTEGRITY	PROVIDE THE APPROACHES WHEREBY NEW REQUIREMENTS IN THE AREAS OF SAFETY, DURABILITY, AND LIFE MANAGEMENT CAN BE IMPLEMENTED WITH NO INCREASE IN COST
ACQUISITION COST REDUCTION	ACHIEVE A 20-30% REDUCTION IN THE ACQUISITION COST OF METALLIC AIRFRAMES
COST OF OWNERSHIP REDUCTION	ACHIEVE A 15-20% REDUCTION IN THE AMOUNT OF AFLC FUNDS EXPENDED IN MAINTENANCE OF METALLIC AIRFRAMES
EXPANDED PERFORMANCE	ASSURE AVAILABILITY OF THE METALS TECHNOLOGY REQUIRED FOR FUTURE HIGH PERFORMANCE AIRCRAFT

a 15 to 20% cost in the kind of dollars that Col. Setter talked about involving maintenance. Now you may ask where I got a number like 15 to 20%. I really don't know how valid that is, all I do know is that the numbers we could possibly affect are very high. You are talking about affecting 200 to 300 million dollars a year and a 1 or 2% reduction would be a substantial return for the small investment in research.

In Figure 2, you see listed on your right a series of programs by the same major thrust that we talked about. Each one of these little dots represents a program in itself. This is the way we have been organizing ourselves in order to concentrate on selected items. My intent in the next few minutes is to go down these lists of programs which are, as I said earlier, funded activities in the reduction-to-practice arena rather than the basic research. I want to do this in order to give you some flavor of where we see ourselves going.

In the structural integrity area, we see five major themes that we are concerned about. That's the five things you see listed down the center of Figure 3. Initial quality of the material has a direct effect on the basic structure integrity and pre-existing flaws, which you heard about earlier, have to be assumed. Also, we have to do all we can to assure that flaws are not there in the first place. The question of materials properties is the one I guess would be the most interesting to this group of people. Some of the questions that we have to concern ourselves with are the basic crack growth rate and the effect of the environment on that crack growth rate. We have to assume that a flaw is there, we have to assume that it's growing, and we have to decide when we are going to repair or quit using the airplane. This subject has a direct bearing in one of the workshops we are going to be attending today, i.e., "Environmental Effects on Crack Growth Rates". As you can see, we are very interested in today's and tomorrow's activities because this is a real problem for us and it is one that we are going to have to learn to account for. The other areas are of less interest to this group so I will just skip them in the interest of time.

Earlier, Dr. Burte talked about primary adhesive bond structures and the acronym we developed for that is PABST as indicated in Figure 4. The objective there was to reduce the number of fasteners and to do this by adhesive bonding. One of the critical problems we face in bonding is really corrosion and primarily corrosion of the bond line. One of the basic approaches we have to undertake is to assure ourselves that the long-term durability of the bondline can be handled because we are talking about building airplanes that last 30 years. Now the breakthrough we think that will allow us to do this is an understanding of the surface chemistry of aluminum anodizings. We think that finally we understand the importance of anodizing and what makes certain etchants of aluminum prior to bonding good and what makes others bad. We know when we trace back a failure in the adhesive bondline, that failure was usually in the metal/metal oxide interface. There was nothing wrong with the glue we used, it was fine; it was how we treated the aluminum that was the

FIGURE 2. METALLIC STRUCTURES TECHNOLOGY

SOURCE	THRUST
● ISSUANCE OF MIL-STD-1530, NEW ASD DESIGN PHILOSOPHY, MIL-A-83444, CONCEPT OF "ECONOMIC LIMIT"	● IMPROVED STRUCTURAL INTEGRITY ● INITIAL QUALITY ● MATERIAL PROPERTIES AND CONTROL ● ANALYSIS & STRUCTURAL PROPERTIES ● USAGE ● END POINT & PROOF OF CONFORMANCE
● LABORATORY GOALS, INDUSTRY MEETINGS, DESIGN STUDIES, SYSTEM STUDIES	● ACQUISITION COST REDUCTION ● PABST ● 10 Ni MODIFIED STEEL ● SLAS ● BLATS ● AMCOE ● TST ● CAM
● LABORATORY GOALS, AFLC INTERCHANGES, MIL-STD-1515	● COST OF OWNERSHIP REDUCTION ● CORROSION ● FASTENERS ● REPAIR ● LANDING GEAR
● NEW CAPABILITY REQUIREMENTS	● EXPANDED PERFORMANCE ● ATW

FIGURE 3. IMPROVED STRUCTURAL INTEGRITY

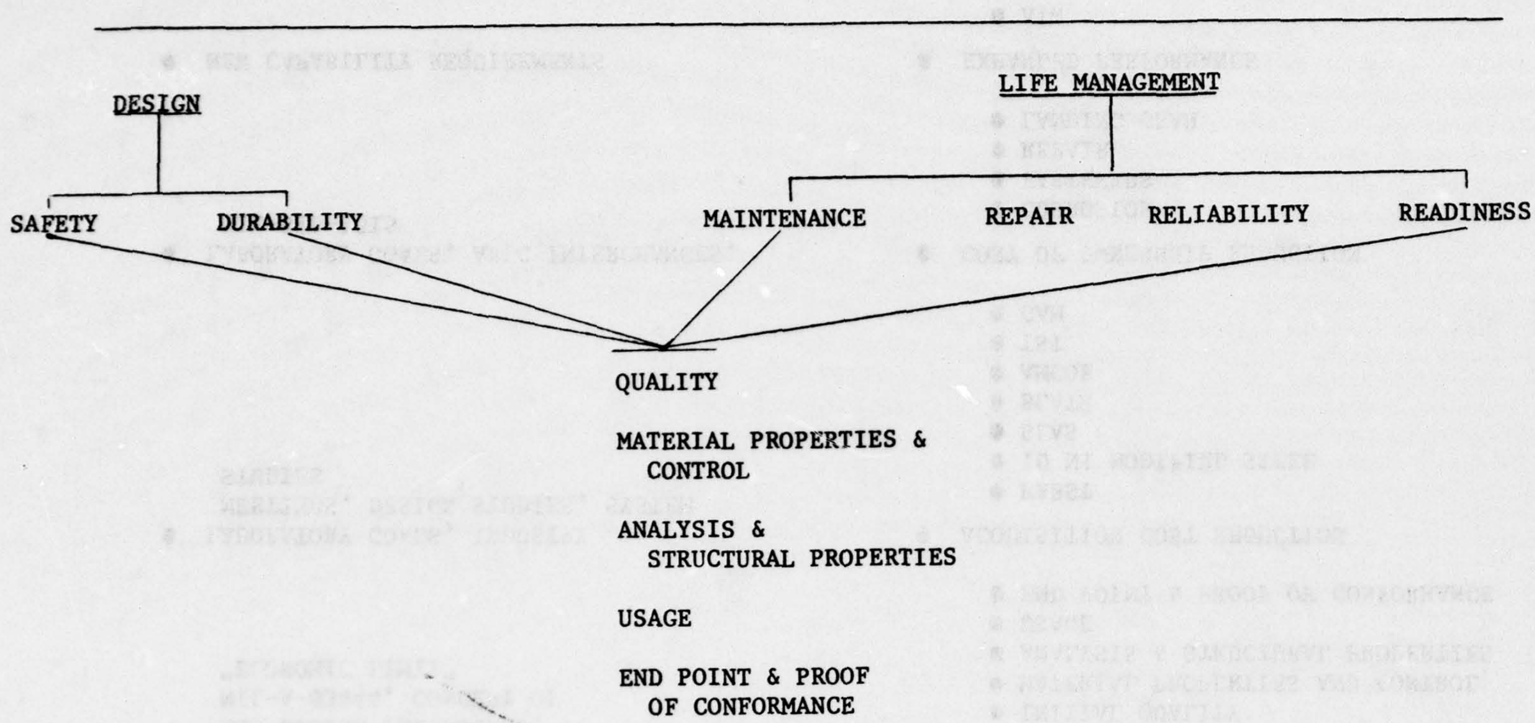

FIGURE 4. PRIMARY ADHESIVELY BONDED STRUCTURES TECHNOLOGY (PABST)

OBJECTIVE

- DEVELOP AND VALIDATE THE TECHNOLOGY REQUIRED FOR BROAD GENERIC APPLICATION OF ADHESIVE BONDING TO ALUMINUM PRIMARY STRUCTURE

APPROACH

- INVESTIGATE THE LONG TERM DURABILITY OF NEW SURFACE TREATMENTS FOR ADHESIVELY BONDED JOINTS
- DETERMINE THE EFFECTS OF BONDLINE DEFECTS
- VALIDATE THE STRUCTURAL INTEGRITY OF BONDED JOINTS IN FULL SCALE TESTS

problem. We think we understand the problem now, so we are taking on a major investment to literally build a full scale fuselage out of adhesively bonded aluminum. There is a big activity in corrosion in that area.

Another example of a program we are taking on is in steel alloys. This is illustrated in Figure 5. Although the major objective of the program was to develop an alloy that had high toughness and strength, its excellent stress corrosion resistance was certainly a big additional benefit. We learned from the Navy a lot about the high toughness steels that they had developed primarily for their submarines. These steels had fairly low properties when you talk about building airplanes. Through chemical and metallurgical manipulations we have now developed alloys in the 10Ni steel variety, AF 1410, which are now competitive with titanium on a strength/density basis. However, every time you talk about steel alloys, you worry about stress corrosion. We now have managed to develop an alloy which has a K_{Iscc} in excess of 100 at the same time carrying the yield strength of 220 to 230. Unless you are an aircraft designer those numbers may not mean much to you, but they are very significant because you are giving yourself a flexibility to go to a cheaper material like steel that keeps the stress corrosion and the strength properties of titanium. This is in the reduction-to-practice mode but it did grow out of some basic research which was funded by the Navy about 10 years ago.

We have a real interest still in aluminum structure because we believe that aluminum will be around for a long time. Currently most airplanes are aluminum and I think in the near future most airplanes will still be made of aluminum. We have several activities in aluminum, but I am going to highlight only one of them because I think this is the one from a research point of view that is the most interesting and intriguing to me. The one I want to talk about is powder aluminum. We see the use of powdered aluminum parts (compressed powders) as a major way to reduce cost. The other benefit we will gain is stress corrosion resistance. Initial data show that some of the new aluminum powder metallurgy hot pressed parts are virtually immune to stress corrosion cracking. That is a pretty strong statement to make about aluminum, but to date we have seen no failures under standard laboratory tests. The cost implication could be substantial, that is cost implication over and above the basic cost saving you would have making a powder part versus making a machine part. So this is an area in which we are very definitely interested. Also, we have found other properties of aluminum to be substantially greater in a powder part than in a forged part. That is why I think you may see some real interest in powder aluminum. It's a new area and an area in which we want to make sure that there is not some unknown in powdered aluminum that could come up and bite us ten years from now. Maybe it's an area that you have some thoughts in which we can invest more money from a research point of view.

We continue our interest in titanium because someday I think this country is going to have to build an airplane that can fly faster than Mach 2.5. We do not have any airplanes in a production mode that are

FIGURE 5. 10 Ni MODIFIED STEEL APPLICATIONS FOR COST REDUCTION

OBJECTIVE

- DEMONSTRATE THE COST SAVINGS POTENTIAL ACHIEVABLE BY THE SUBSTITUTION OF 10 Ni MOD STEEL (AF 14-10) FOR ANNEALED TITANIUM

APPROACH

- INVESTIGATE THE WELDABILITY OF 10 Ni MOD
- EVALUATE LOW COST MELTING TECHNIQUES (ESR 25% LESS THAN VIM/VAR)
- CONDUCT DESIGN AND FULL SCALE TESTING OF TYPICAL AIRCRAFT PARTS

principally made of titanium. The major obstacle in our mind is cost. The cost of titanium structure today may cost you six to seven times the cost of aluminum structure. There is a community of materials people in the Air Force whose major objective is to try to reduce the cost of titanium. There is minimal influence in the corrosion business because we think for the kind of environments we are worried about stress corrosion or hot salt corrosion isn't a problem since we are talking about airframes rather than the engines.

The bulk of titanium for airframes today is where stress is so high that you almost have to go titanium. The emphasis in our activities in titanium for the foreseeable future is probably going to be in powders. This is a parallel to aluminum, but we see the cost in this case, more than anything else, as the main driver. Current major activities in titanium are indicated in Figures 6 and 7.

For those of you who may not have had exposure to it, there is a lot of activity going on right now in the Government, and I say Government and not the Air Force alone because it is broader than just the Air Force, on the subject of computer aided manufacturing. I don't know what this has to do with corrosion, it may not have anything to do with it, but I think it is an interesting area. There is an awful lot of activity going on in trying to increase the producibility base of the whole country in the area of computer aided manufacturing and we in the Air Force are taking a key role in that business. This gets into how do you best use computers to schedule and actually do your manufacturing.

I will now go back to the discussion of the four major areas of structural integrity, acquisition costs, ownership costs and performance. I have talked so far about integrity and acquisition costs. I now want to show some things that we are doing in the cost of ownership or what we can do to reduce the cost of maintaining the existing fleet. The number one thing is the subject that we have met today to talk about, that is corrosion. We, in our area, consider corrosion the number one problem that we ought to try to address in the area of metallic structures. How do you reduce the cost of maintaining the fleet-in-being? This emphasis is indicated in Figure 8. Unfortunately, when you talk about the reduction-to-practice programs, remember that is versus the research programs; there are, as a matter of fact, only one or two programs that we have seen clear so far to fund in this area. I think this is one of the reasons for today's meeting: to see if we can identify more programs in the area. The only thing we are funding right now is a program to adapt ion vapor deposited aluminum to a production and field mode. This process consists of using an ion chamber to plate steel parts with aluminum rather than cadmium. We are funding this program because we see some clear evidence that the cost in corrosion maintenance will be significantly reduced. Ion vapor deposited aluminum is a lot cheaper than cadmium plating and baking. The other program we are funding is primarily under Ted Lynch's direction and is one to develop corrosion prediction models that people in AFLC can use

FIGURE 6. BUILT-UP LOW COST ADVANCED TITANIUM STRUCTURE (BLATS)

OBJECTIVE

- DEVELOP APPROACHES THAT ALLOW UTILIZATION OF BUILT-UP TITANIUM STRUCTURES AT A 25-30% ACQUISITION COST REDUCTION OVER CURRENT APPROACHES

APPROACH

- EVALUATE THE COST ADVANTAGES OF ADVANCED TITANIUM MANUFACTURING CAPABILITY
- OBTAIN AN UNDERSTANDING OF REQUIRED INSPECTION AND REPAIR PROCEDURES
- CONDUCT DESIGN AND FULL-SCALE STRUCTURAL VERIFICATION TESTING

FIGURE 7. THICK SECTION TITANIUM (TST)

OBJECTIVE

- DEMONSTRATE LOWER ACQUISITION COSTS, AT NO LOSS IN RELIABILITY, FOR THICK SECTION TITANIUM AIRFRAME APPLICATIONS

APPROACH

- BROADEN THE PRODUCTION BASE THROUGH VALIDATION OF HIP AND VHP POWDER METALLURGY PROCESSES
- ADAPT ISOTHERMAL FORGING TO BETA/NEAR BETA ALLOYS
- ADVANCE FUSION WELDING PROCESS FOR REDUCED ASSEMBLY COSTS
- EXAMINE Ti CASTINGS WITH YTTRIA ADDITIONS FOR IMPROVED PROPERTIES/CASTABILITY
- PRODUCT DEMONSTRATION

FIGURE 8. LOWER COST CORROSION CONTROL FOR AIRCRAFT MAINTENANCE

OBJECTIVE

- PROVIDE A CAPABILITY TO SIGNIFICANTLY REDUCE THE MAINTENANCE COST CURRENTLY BEING INCURRED BY AFLC FOR CORROSION CONTROL

APPROACH

- UP-DATE AFLC CAPABILITY FOR ADVANCED CORROSION CONTROL PROCEDURES
- REVISE/MODIFY RESTRICTIVE POLICIES
- EVALUATE ALTERNATE TECHNIQUES

to predict a maintenance schedule. As Col. Setter pointed out, if he had any idea when to schedule these airplanes it would be a great benefit to him instead of scheduling them all in the same time period. In effect, he could then selectively schedule airplanes.

Those are the only two programs in the whole corrosion business that are in the category of reduction-to-practice. Now these are certainly not the only ones that the Air Force is funding, there are a lot of others in the research business, but again I am talking about reduction-to-practice programs. We are trying to find more programs to work on in this area and I solicit as much help as you can provide in this area. I feel that when the programs are identified and justified, the resources to do them could be made available.

Another area, and one that Major Tom Moore spent some time on, is the one of mechanical fasteners. He was talking from an acquisition cost viewpoint, but the problem we also worry about is how to reduce the maintenance cost once the fastener is in service. There is a whole series of programs that are in this area and if anyone is interested in them I would be more than glad to talk to him about it. Some of our emphasis here is indicated in Figure 9.

The other big area is repair. This is summarized in Figure 10. I am not sure that we as a research community can do much in the area of repair. This is a fairly mundane business, but we are interested in seeing from a technology point of view if there is something we can do to reduce the cost of repairing structure as it sits out on the field or in the depot. It has been pointed out that the one area that gets a lot of attention now is honeycomb repair. The cost that we incur to repair honeycomb is phenomenal. We are trying to work that problem but I doubt that much research is involved.

After hearing all the problems about the expensive landing gear, we can state that we do have some activity going on in trying to reduce that cost, as shown in Figure 11. One of the ways we see of getting around the corrosion problem is to go to titanium or composites. The environment that the landing gear faces is very rough and maybe this is one of the few cases where we would be willing to pay the extra price for a titanium part because the overall life cycle cost would be substantially reduced.

To sum up, I was trying to give you a flavor for what we are doing in metal structures and where we are going in the very near term. Once again I emphasize we are looking for activities in the corrosion area in the reduction-to-practice mode.

FIGURE 9. MECHANICAL FASTENERS - ACQUISITION AND MAINTENANCE COST REDUCTION

OBJECTIVE

- DEVELOP LOW COST FASTENER SYSTEMS THAT CAN REDUCE BOTH ACQUISITION AND MAINTENANCE COST

APPROACH

- IMPROVE HOLE COLD WORKING TECHNIQUES
- REMOVAL & REPLACEMENT OF INTERFERENCE FIT FASTENERS
- INDEPENDENT EVALUATION OF FATIGUE RATES FASTENERS
- STANDARDIZATION/METRIFICATION

FIGURE 10. METALLIC STRUCTURAL REPAIR

OBJECTIVE

- DEVELOP LOW COST REPAIR PROCEDURES THAT CAN REDUCE THE MAINTENANCE COST CURRENTLY BEING INCURRED BY AFLC

APPROACH

- EXAMINE GENERIC REPAIR PROCEDURES
- IMPROVE TECHNIQUES FOR HONEYCOMB REBUILDING

FIGURE 11. REDUCED LIFE CYCLE COST LANDING GEAR

OBJECTIVE

- DEVELOP A MINIMUM LIFE CYCLE COST AIRCRAFT LANDING GEAR

APPROACH

- BUILD AND TEST ADVANCED LANDING GEAR DESIGN UTILIZING NEW MATERIALS AND PROCESSES TECHNOLOGY TO GAIN CONFIDENCE FOR APPLICATION TO NEW SYSTEMS

WORKSHOP I.

COATINGS AND INHIBITORS

Chairman: Phil Parrish, ARO

Recorder: Gary Stevenson, AFML

Participants: D.E. Prince, AFML/MBE
G. Stevenson, AFML/MXA
K.C. Frisch, University of Detroit
A. Dent, Carnegie-Mellon University
J. Hassell, Battelle-Columbus Labs
W. Thompson, WR/ALC/MMETC
P. Clarkin, OWR
G. Simmons, Lehigh University
M. Taylor, Wright State University
T. Beck, Electrochemical Tech Corp
B. Ives, McMaster University
C. Knauss, Kent State
S. Lee, AFIT/ENB
J. Wurst, University of Dayton Research Center
L. Weirick, Sandia Laboratories
P. Parrish, ARO

Introduction:

Opening remarks by Gary Stevenson, Dan Prince (both AFML), and W. Thompson (Warner-Robins AFB) discussed current coatings and their usage by the Air Force, current programs and near term interests at AFML in the coatings area, and field problems. The following requirements were specified as necessary attributes of any coating system:

Requirements of Coating Systems

1. Adequate flexibility
2. Ease of touch-up
3. Temperature stability (up to 350°F)
4. Good cleanability/maintainability
5. Low weight
6. Easy application techniques
7. Environmental stability
8. Ease of removability

Discussion: Specific Problem Areas in Coatings on Aircraft were Identified ("Hot Spots")

1. Fasteners - coatings are inevitably damaged during installation
2. Latrine areas
3. Internal areas (such as bilge areas) where condensation occurs

4. Faying surfaces
5. Battery compartments
6. Erosion of leading edges

Some Problem Environments were Identified:

1. Salt and salt spray
2. Humidity and heat
3. Industrial atmospheres
4. Temperature cycles

The current paint system contains either a zinc or a strontium chromate inhibitor to provide corrosion protection. However, it is known that chromium oxide films do not provide adequate protection against chloride environments. Why, then, is only single component inhibition used instead of multi-component (i.e., multi-functional) inhibition? Should we use a second component which attempts to alleviate the chloride-attack problem, for instance? Also, if you assume imperfections in coatings due to application variations, what can be made available to neutralize, passivate or provide cathodic protection of the imperfect area?

Another broad area of discussion was whether nondestructive techniques can be used to evaluate the state of a coating - whether it is cracked, separated from the base metal, whether filiform corrosion is occurring below the paint, etc. Also, can effective coating lifetime be predicted by utilization of NDE?

As a result of the discussions of maintenance techniques, paint systems, and nondestructive testing techniques, the following possible approaches to solve or mitigate coating problems were advanced:

Possible Approaches to Solve Problems:

1) Put inhibitors in rinse water used in washing aircraft, as currently done by National Airlines (W. Thompson cited reference paper). Possible windows for initiating this action are:

a. Include inhibitors in a test wash program being initiated at MacDill AFB in which aircraft will receive frequent (between mission) washings.

b. Perform a wash inhibitor survey in various environments (salt spray, industrial) on test panels of painted metals to determine optimum inhibitor chemical systems (compositions, concentrations, frequency of wash, etc.). Compare this to unwashed panels and also to panels which are washed according to the schedule prescribed for aircraft maintenance.

2) Multi-purpose, multi-component inhibitor systems should be incorporated in coatings. This is an area which the coatings groups, in conjunction with the environmental effects group, are addressing at AFML. Basic work on passivation kinetics, passivation effectiveness, and film compositions which actually give protection should be encouraged at AFML.

3) NDI techniques should be applied to coatings. Some techniques which were specifically mentioned and dicussed were:

a. Methods of corrosion indication, such as pH indicators, could be incorporated into films.

b. Neutron radiography should be attempted in order to look for the onset of corrosion product formation under coatings. These sites should be candidates for quick cleanup before major damage occurs, or before the necessity for complete stripping and repainting of the aircraft has arisen.

c. Thermal imaging (IR) detection of areas which are corroding under paints.

d. Electrical potential monitoring and conductivity monitoring of corrosion "hot spots" should lead to determining when these "hot spots" become critical.

In all the NDI techniques discussed, it was agreed that they should realistically be attempted in the areas recognized as corrosion "hot spots".

4) New paint stripper research should be initiated. Currently, paint stripping is often very difficult and damaging to the metal surface. Research should be directed at specific model solvent solution to epoxy paint reactions, and also at the compatibility of the model solvents with the base metal.

5) Areas where plastic or other non-corroding materials should be employed should be systematically identified for each aircraft system - latrine areas, bilge areas, faying areas, etc., are obvious examples where retrofit of such materials could alleviate many current problems. Alternately, the same approach could be used in locating drainage ports for these aircraft.

WORKSHOP II.

ACCELERATED TESTING AND REALISTIC TEST ENVIRONMENTS

Chairman: R. Summitt, MSU

Recorder: F. Meyer, AFML

Participants: 1/Lt. Terry Bartel, AFML/LLS
John Hassell, Bettelle-Columbus Labs
Major Mahan, AFLC/MMEA
F. Meyer, AFML/MXA
R. Summitt, Michigan State Univ.
Thomas A. Torres, Technology Inc.
Walt Tripp, Systems Research Labs
T.O. Tiernan, Wright State Univ.
Dave Clouse, 4950/SUP
C.J. Knauss, Kent State Univ.
Harris Burte, AFML/LL
Brian Ives, McMaster Univ.
Larry Weirick, Sandia Labs

The topic was unusually difficult and we did not produce definite researchable ideas. The group did, however, develop a good definition of the problem.

The purposes of accelerated testing methods are threefold: materials selection, performance prediction and for contract specification. Existing test methods are in no way related directly to the service environment in which materials actually are used. In the case of relatively simple properties, e.g., ultimate tensile strength, hardness, notch toughness, the engineering community has been able to agree upon standard tests which do achieve those three purposes. These tests work pretty well, albeit rather imperfectly, but they do a job everybody is willing to agree to and to accept. The corrosion problem, however, is a vastly more complex situation, because the causative agents of corrosion and their effects are neither completely identified nor "well understood". Consequently the so-called standard tests for corrosion resistance, even those which have been agreed upon, e.g., the salt spray test, are not predictive of actual field experience. The current situation is simply that corrosion tests are costly and are regarded with suspicion at best and no one claims that they will predict service experience over a 20-year, 10-year, even a 5-year period. Hence, the problem briefly is: We have simply no knowledge, or rather very little knowledge of what are the corrosive agents in the service environment that materials will see nor do we know what is their mode of action. Without that knowledge we simply are not able to design accelerated tests which can provide data in reasonably short periods of time and which achieve the purposes of accelerated corrosion test methods.

We don't know what they are, that is if you are talking about trace effects, trace component effects, things like that. Consequently the so-called standard tests of corrosion resistance, even when they have been agreed upon, for example, the salt spray kind of test exposure, they are not predictive of actual field experiènce at all. The current situation is simply that corrosion tests are costly and at best are regarded with suspicion and nobody claims that they're going to tell you what will be the service experience over a 20 year, 10 year, even a 5 year period. You simply can't use these tests for that kind of thing. So the problem, and that is all we were really able to define, the problem very briefly is: We have simply no knowledge, or rather very little knowledge of what are the corrosive agents in the service environment that materials see nor do we know what is their mode of action, how they act upon materials to produce corrosion. Without that knowledge we are simply not able to design accelerated tests which can provide data over reasonably short periods of time that will achieve the purposes of accelerated corrosion test methods. That't it. We defined the problem, now those of you who were in the discussion, if I have left something out, jump up and say so. If I haven't, if there are arguments or discussion that want to go on, we'll take off from there.

Question: Are you saying that until we understand a species by species cause and effect relationship, there is no hope of developing an accelerated test?

Answer: You have to be very, very careful, I think, to avoid the idea that you are aiming for a complete and thorough understanding of cause and effect. We went round and round about that particular point. That is, that we feel that we must identify what are the elements in a particular service environment but you don't go backwards to find the hard science, the basic research, you don't spend years and years trying to find out why, but the important thing is to define what are these particular elements. We won't go into the particular example that we spent all that time talking about, but it's a problem I think of correlation. Once you have correlated, for example, if we knew about a particular element in a service environment that it was a corrosive causative agent, then could we go a step farther and perhaps double the concentration. Would that lead to an accelerated test? Suppose we increased the temperature or something of that sort? There must be some way then, once you have identified the causative agent, to go ahead and develop an accelerated kind of test that would then be useful for these purposes of selection, performance, prediction and specifications. But we are not at that stage, we are talking about exposures over a very long period of time and we haven't identified them. I don't think we know how to yet.

Question: Does anybody, and we take the easiest one which might be materials selection, rank materials the right way which might be a lot easier than trying to give a quantitative prediction? Did anyone feel, to take it a step further, that there was some research that one might undertake to shed some light on some these to better define at some future time accelerated tests? Research that wasn't, as you put it, continued for the next ten years and take a look then.

Answer: I think if there were, they were within the minds of individual people at the meeting. I have probably an idea or two wherein one might look at a specific material and try to examine the kind of environment that it sees. There is another possibility that the prediction program that we are involved with might help one to identify causative variables or causative agents. But, frankly, I didn't and I guess I have to say to anybody in that session did you have any reactions of that kind?

Response from someone in the audience: Maybe I missed a point here, but I think we all agreed that you could design a screen test that would evaluate a series of materials for this particular test. But what that means as far as the application of this material, I don't know. Does anyone know?

Answer Continued: I think what you have here is two different viewpoints: One is in the case of the chemical manufacturing industry, who know pretty well what the environment is going to be over a 20 or 30 year period - they have a pipeline self-contained and they know what is going to be inside of it. Whereas an aircraft can fly through on a landing approach to Dayton, Ohio, and experience certain kinds of atmospheric pollutants that it won't experience over Columbus, Ohio. We feel that the major problem is that we do not know what specific agents are important, sulfur dioxide, nitrogen oxide, ozone, hydrochloric acid, etc.

Question: Can we design a test where we can anticipate the actual field results?

Answer: We see this in terms of two different kinds of concepts. The prediction aspect is really one that is statistical in nature whereas the features of accelerated testing are more of the type to be applied to individual materials over short periods of time to get a picture of what is going to happen over the long exposure. That is precisely what our AF people on this panel pointed out. They can't afford the eight year tests. They can't wait even one year. Is that right, Major Mahan?

Speaker: Maj Mahan

Yes, a lot of times you say, "Before we can tell you what we can do about corrosion, we have to define the environment", but we would like for you folks to tell us that if we are going to fly in a certain environment, we need certain protection. If we are flying in a cold environment where corrosion isn't prevalent, we don't need much protection; but if we are flying in the Southeast Asia environment, we need you to say, "if you are going to fly in this type of environment you will need this type of protection, etc." You can't really define a typical environment because our airplanes are going to be deployed worldwide and you can take any twelve airplanes at any time and in a deployment concept put them anywhere in 24 hours. Thus, a lot of times we don't know what the environment will be. We can't afford to wait for the eight years or so to really define what we have to do to a material for corrosion protection. We need an all-purpose material to protect our airplanes now. If we run into a problem we need the solution within six weeks. The main idea is that when we deploy, we have got to be there ready to go within 24 hours and we need to be able to prepare our airplanes within that time limit.

Speaker in the audience responding to Major Mahan:

I think you are assuming that we don't know something about what environmental species are responsible, but we have been conducting atmospheric corrosion tests for more than 50 years. ASTM has 50 years of data on coatings, etc. which they have correlated with what's going on, what the atmospheric conditions have been from a moisture standpoint, from pollutants and everything else. I think you are saying we don't have them. I think we do have them and we can identify some of them. I don't agree that you will ever find an accelerated test, I think your tests are going to have to be more sophisticated to define subtle changes and which you can then measure. But I only know of one accelerated test that has been developed and it took a long time that correlates anywhere near with anything that has ever gone in actual service and that is the Katz test that was developed for the bumpers on automobiles. I don't know of any other one that has ever done it. I've been in the coating business for over 30 years, and I don't.

Dr. Summitt: I think the problem is that you want more than indications if you are going to do anything with this kind of thing at all. But you are absolutely right and I think we saw the same thing, tests simply are not indicative of the real world. But the difference between the relatively simple property tests which are indicative of performance like hardness, tensile strength, etc. are good enough probably for what you are trying to do, but the corrosion situation is one that is simply far more complex.

WORKSHOP III.

ENVIRONMENTAL EFFECTS ON CRACK GROWTH RATES

Chairman: Ellis Verink, Univ. of Florida

Recorder: Kirit Bhansali, AFML

Participants: E.D. Verink, Jr., Univ. of Florida
P.J. Bania, AFML/LLS
J.H. Hoke, Penn State Univ
C.J. Dinkeloo, Technology, Inc.
W.K. Boyd, Battelle-Columbus Labs
B.F. Brown, American University
P. Ficalora, Syracuse University
D. Walters, Wright State University
S. Feuerstein, Aerospace Corp
N. Pugh, University of Illinois
M. Bernstein, Carnegie-Mellon Univ
R.P. Wei, Lehigh University
W.B. Lisagor, NASA Langley Research Center
K.J. Bhansali, AFML/LLN
V. Russo, AFML/LLN
T. Beck, Electrochemical Tech Corp

Introduction

It was recognized that a certain amount of overlap is inevitable between this session and a later session on Stress Corrosion Cracking and with the Session on Coatings and Inhibitors. In order to focus the discussion, emphasis was directed first to aluminum alloys which comprise the major metallic constructional materials in the present force and in most designs currently being drawn. However, the comments and recommendations enumerated below apply generally to all metal structural systems useful to the Air Force. The problems, hence the suggested approaches to their solution, were categorized as "short range" and "long range". Short range problems were those which were particularly associated with the present (existing) operating force. Long range problems are those particularly associated with new designs. There are several suggestions which are equally applicable to both long and short range problems.

Summary of Discussion and Recommendations

A. Short Range Problems

b. Incorporate inhibitors in

1) coatings
2) cleaning and flushing solutions
3) stripping solutions

2. Continue and extend as necessary present Air Force program of Corrosion Prediction to improve basis for scheduling of depot maintenance and to assess effectiveness of maintenance procedures.

B. Long range problems.

Purpose: To Develop Fundamental Knowledge which will lead to more cost-effective design and permit longer service life with lower maintenance cost.

1. Philosophy - Develop data, as necessary, on crack growth rate vs. stress intensity factor (V vs K) for all alloys of interest. The aim would be to develop alloys and/or environments which would displace the V vs K curve to lower values of V (in Stage II) and give higher values of K_{Iscc}. Extend knowledge from well characterized systems to alloys of interest.

2. Specific Types of Tests

a. Determine the effect of metallurgical variables (e.g., microstructure, texture, distribution of precipitate, etc.) on V vs K curve.

b. Determine the rate controlling processes separately for Stage I and Stage II.

c. Assess the influence of environmental variables on V vs K curves for alloys of interest by determining:

1) chemical behavior
2) electrochemical behavior
3) kinetics
4) influence of temperature
5) effects of inhibitors

d. Assess the combined effects of spectrum loading and chemical environments on V vs K.

C. Communications.

Purpose: To acquaint as broad an audience as possible with the practices and procedures which have been shown to be effective in aircraft design, construction and maintenance. The audience should include designers, technicians, shop personnel, military personnel, contractors and subcontractors, educators and students. Media should be selected for broad readership. Special efforts should be made to interact with NACE, ASM, AIME, SAMPE, etc.

WORKSHOP IV.

STRESS CORROSION CRACKING AND HYDROGEN EMBRITTLEMENT

Chairman: I.M. Bernstein, Carnegie-Mellon University

Recorder: Kirit Bhansali, AFML/LLN

Participants: N. Pugh, University of Illinois
Paul Bania, AFML/LLS
W.K. Boyd, Battelle-Columbus Labs
B.F. Brown, American University
B. Lisagor, NASA Langley Research Center
Thomas A. Torres, Technology Inc.
John Hoke, Pennsylvania State Univ.
R.P. Wei, Lehigh Univ.
P. Clarkin, Office of Naval Research
P. Ficalora, Syracuse Univ.
Walt Tripp, SRL
T.O. Tiernan, Wright State Univ.
Syl Lee, AFIT/ENB
R. Summitt, Michigan State Univ.
K. Bhansali, AFML/LLN
Phil Parrish, U.S. Army Research Office
E.D. Verink, Jr., Univ. of Florida

Introduction

Due to obvious and useful overlap between this session and the previous session on Environmental Effects on Crack Growth Rates, the discussion was initiated as an extension of the previous session. The stress corrosion cracking and hydrogen embrittlement of aircraft structural materials was recognized as a severe problem in the existing systems useful to the Air Force. The behavior in high strength steels and aluminum alloys were specifically identified.

The approaches to the solution of this problem were categorized as "short range" and "long range". Short range solutions are those which are applicable to existing alloys of aircraft structures susceptible to the stress corrosion cracking and hydrogen embrittlement. Long range solutions are those which are associated with the more fundamental studies of the mechanicsms of inhibition of stress corrosion cracking and hydrogen embrittlement, either by control of the metallurgical structure, the nature of the surface, or by modification of the environment.

Summary of Discussion and Recommendations

A. Short Range Solutions

Purpose: To decrease the susceptibility of the current systems to stress corrosion cracking and hydrogen embrittlement and minimize related failures.

1. Develop inhibitive systems to be applied on the structure to specifically minimize the problem. Fundamental studies should be carried out in order to develop inhibitors that will shift the plateau region crack growth rate curves to a lower value and threshold stress intensity factor (K_{Iscc} or K_{Ihz}) to a higher value. An ideal inhibitive system should then be designed for use under the service conditions and should include these inhibitors.

2. Replacement of structural parts, when needed, should employ alloys with higher resistance to SCC and HE.

B. Long Range Solutions

Purpose: To suggest approaches leading to a better understanding of the mechanism of inhibition of stress corrosion cracking and hydrogen embrittlement.

1. Conduct systematic studies existing or on potential embrittling systems. This phase would include development of analytical techniques to determine concentrations and distribution of embrittling species at the "dangerous" levels, e.g., determination of very low level hydrogen concentrations in hydrogen-steel embrittling systems. Of equal importance is the characterization of hydrogen distribution within the alloy.

   Study other embrittling systems where determination of distribution and concentration of embrittling species may be easier than in the case of hydrogen as embrittling species, e.g., oxygen embrittlement of niobium.

2. Categorize interactions between surface chemistry and metallurgical techniques to develop understanding of the roles of anodic dissolution and hydrogen embrittlement. This study might also include an investigation of surface catalysts in order to inhibit entry into the metal.

3. A re-examination of hydrogen interactions with metal structures and subsequent effects on physical and mechanical properties is needed from a fundamental and theoretical point of view.

WORKSHOPS III & IV

ENVIRONMENTAL EFFECTS ON CRACK GROWTH RATES AND STRESS CORROSION CRACKING AND HYDROGEN EMBRITTLEMENT

Speaker: Ellis Verink

There was considerable commanlity of interest and overlap between Sessions III and IV so I will start out with the report we put together on Session III and amplify it with additional things that came out of IV.

In order to focus the discussions we had in Session III, we emphasized first the aluminum material system with the full understanding that many if not all of the comments would be applicable in some degree to other major metallic structural systems. The problems and suggested solutions to the problems (or approaches to finding solutions) were categorized into two general categories: "short range" and "long range". The short range problems were those that were particularly associated with the present or existing operating force; whereas the long range problems were those that were particularly associated with new designs, new aircraft, etc. There are a number of the suggestions that could well be applicable in both categories.

First, the goal of short range solutions is to reduce the cost and increase the effectiveness of maintenance procedures. Among these there are a certain number of field procedures one of which involves, as Mel was saying, "operation of the hose," i.e., flushing the exterior of the aircraft after patrol and after extended exposure in corrosive environments. If possible flushing of aircraft should be done at advanced bases rather than waiting for aircraft to return to the depot. Also the matter of the incorporation of inhibitors into coatings, in cleaning solutions, in flushing solutions, and so on, seemed logical. Perhaps inhibitors, should be incorporated into stripping solutions also. This, of course, is consistent with Dr. Parrish's recommendations.

A second aspect of both the short range and long range considerations is the Air Force should continue and extend as necessary the present AF program on corrosion prediction, to improve the basis for scheduling depot maintenance, and to assess the effectiveness of maintenance procedure changes.

The purpose of long range research would be to develop fundamental knowledge which would lead to more cost-effective design and would presumably permit longer service life with lower maintenance cost. The philosophy which this Panel felt might be most productive would be to develop data as necessary on crack growth rate vs. stress intensity factor, V vs. K curves, for all the alloys of interest. Some of those are already in hand, others we feel could be advantageously developed. The aim would be to develop alloys and/or environments which would displace this V vs. K curve down and to the right. In other words, to lower values of crack growth rate and to increased values of K_{Iscc}. This would have a number of important advantages from a standpoint of the ability to nondestructively test with a more reasonable chance of picking up a flaw before it became of critical size. Extension of existing knowledge on well characterized systems could provide a basis for moving into these areas. Now in regard to specific tests, determination of the effect of metallurgical variables (i.e., microstructure, texture, distribution of precipitate, all these kinds of things) on the V vs. K curve, would be an area of investigation that we feel would be fruitful. Determination should be made of the rate controlling processes which would apply individually to stage 1 (where the rapid increase in rate (V) vs. K takes place) as contrasted to the 2nd stage, or "plateau" region (in which rate is independent of K). A real understanding of the rate controlling processes should provide a basis for devising a useful strategy in materials development and selection.

The assessment of the influence of the environmental variables on V vs. K curve encompassing studies of chemical behavior, electrochemical behavior, kinetics, influence of temperature, the effects of inhibitors, the interference with these processes by the opportunities which would attend the use of inhibitors, and finally combined effects between spectrum loading and the chemical environments on the V vs. K curve. All of these we feel would provide useful background information aimed at the long range purpose of such long range programs.

Finally, in Session III, a strong case was made for better communications. A meeting such as this is one facet of such a program, but we are thinking more broadly than this. The purpose would be to acquaint as broad an audience as possible with the practices and procedures which have been shown to be effective on aircraft design, construction and maintenance. The audience should include not only the designers, but technicians, shop personnel, military personnel, contractors, subcontractors, educators, students, so that they will really have some appreciation for the problems. This isn't a one shot proposition as we are all aware because the audience is constantly changing and new generations need to understand why it is important to do certain things in terms of what can happen if you don't. Special efforts should be made to interact with the National Association of Corrosion Engineers, for example, who publish standards for selection of materials for particular kinds of services. ASM, AIME, SAMPE also should be included.

Many of the same recommendations also came from Session IV, plus three or four additional points which I felt were particularly germane. One is that there is a need for a better, more accurate, more dependable means for determination of hydrogen level and distribution, ...the "instrumentation question". Secondly, because of the couples problems involved in hydrogen determination, other more easily studied embrittling systems should be studied since many of the embrittlement processes seem to have many similar features. One such system is the oxygen-niobium system whose embrittlement can be studied readily by hardness measurements. In this way it is hoped that models can be developed which might better be helpful in explaining mechanisms of hydrogen embrittlement. Thirdly, there was a reaffirmation of the need for establishing the role of metallurgical variables and environmental variables on V vs. K behavior, and fourthly, there also was a reaffirmation of the need to explore and verify prospects of aluminum powder metallurgy products which are alleged to be immune or free from stress-corrosion cracking types of problems. Finally, there was a comment that in many respects catalysis technology impinges directly on the study of the effect of inhibitors..that inhibitors are in a sense "poisons for catalysis".

COMMENTS

The comment was made that the remarks made with respect to hydrogen embrittlement or stress corrosion cracking might just as reasonably be made with respect to corrosion fatigue. Investigation of environmental versus loading affects that the effect of cyclic conditions, both as to load and as to environment, may well be important. Experimental potential pH diagrams over a range of potential should be helpful in selecting of experimental conditions and in assessing the influence of metallurgical and environmental variables.

WORKSHOP V.

ENVIRONMENTAL DEGRADATION OF ELECTRONIC MATERIALS

Chairman: L.J. Weirick, Sandia Labs

Recorder: F. Meyer, Jr., AFML/MXA

Participants: Carl Krauss, Kent State
Walt Haas, AFML/MBM
Mike Mahan, AFLC/MMEA
Mike Taylor, Wright State
Dave Clouse, Aeronautical Systems Division
S. Feuerstein, Aerospace Corp
Ted Beck, Electrochemical Research
Fred Meyer, AFML
Larry Weirick, Sandia Labs

Introduction

Session began with round table introduction of participants. They stated their names, affiliation, materials responsibilities, and interest in this session.

Carl Krauss, Kent State - is involved in mobility measurements of molecules (e.g., water) and ions (e.g., Cl^-) in organic films (e.g., paint). He is also associated with the "Institute of Paint Technology". He is interested in doing research along these lines.

Walt Haas, AFML - investigates surface interactions using Auger and ESCA techniques. He is currently investigating lead-wire problem (Kovar-aluminum-silicon). Envisions field problem with no obvious fix.

Mike Mahan, AFLC - is responsible for immediate "fixes" of aircraft corrosion problems. He came to listen and contribute AFLC interface to the workshop.

Mike Taylor, Wright State - investigates gaseous environments using gas chromatography and mass spectrometry. Desperately looking for Air Force support, possibly in the area of analyzing vapor phase inhibitors.

Dave Clouse, ASD - concerned with acquisition of new vapor systems, performance of electronics in aircraft such as the C-5A.

Seymour Feuerstein, Aerospace Corporation - is another analytical chemist with access to a number of analytical tools, not least of which is an ion microprobe. Aerospace has some experience with failure analysis of electronic hardware. Interested in any analytical applications.

Ted Beck, Electrochemical Research - is well known for his work on the SCC of titanium. Is interested in applying electrochemical techniques to corrosion problems of avionic hardware. No immediate mutual interest resulted from this session. Unfortunate.

Fred Meyer, AFML - responsible for Air Force programs on failure analysis research for electronic hardware and specifications for corrosion resistant electronic components.

Larry Weirick, Sandia Laboratories - was residing authority on research directed at solving corrosion problems on electronic hardware by fact that he had written two articles on subject. He is interested in failure analysis and development work on electronics, particularly involving hybrid and integrated circuit leads.

Following these introductions, Fred Meyer gave a lengthy briefing on general corrosion problems in avionics. Emphasized two major causes of long time corrosion degradation of electronic hardware: 1) atmospheric rain and 2) internal "rain" due to temperature and humidity cycling of aircraft. Most likely can do nothing about either environment, thus must concentrate on material condition of componentry. In investigating this area, AFML has identified two major materials conditions which lead to corrosion. The first is dissimilar metals. However, by nature of the product these are unavoidable. Second, during the soldering process, aggressive fluxes must be used to clean leads. Unfortunately, flux often remains after the processing if thorough cleaning is not practiced. This problem is part of the second general condition which is contamination.

Fred believes the major need for research as applied to avionics corrosion is the development of a quality control technique, including instrumentation, to more accurately identify the cleanliness of a surface than the currently used "water-break" test and water rinse and conductivity test.

However, there is one significant road block which is the need to first know the level of contamination allowable before corrosion becomes a nuisance. Thus, sophisticated analytical tools that participants in this session operate may be useful if problems are more specifically detailed.

Vapor phase inhibitors discussed. Air Force has small program but should be expanded in our opinion.

WORKSHOP V.

ENVIRONMENTAL DEGRADATION OF ELECTRONIC MATERIALS

Dr. Weirick - Speaker

I was happy Session VI came before V because the comment from Professor Firsch about a cocoon for aircraft protection was close to my thoughts that one solution to the problems of corrosion of electronic materials was for the AF to develop the technique of seeding clouds such that it would rain everywhere except on the airplane. Rainfall and leakage into the aircraft seemed to be the major avionics problem. Also, due to the temperature and humidity cycling caused by a grounded and then flying plane, a rain environment is produced within the aircraft. This also produces condensation on the electronic components.

The two components that appear to be the most susceptible as a result of temperature and humidity cycling are dissimilar metal couples and lead materials. The only suggestion on a possible way to control the problem is coating or encasement systems for the electronic gear.

The other area that appears to be a problem is lead materials where there is a solder joint and you have residues from the flux. This is a specific example of the general category of contaminants; thus contaminants not only from solder fluxes but from the manufacturing and handling steps as well. A program should be started on this problem area but unfortunately we were unable to define such a program. The program needed is a nondestructive testing, quality control program, a nondestructive testing technique, for determining levels of contamination on electronic parts. However, the difficulty in forming such a program is that there is only sporadic data available at the present time on what level of contamination on a printed circuit board or particular lead on a specific part is allowable without a subsequent corrosion problem.

As I mentioned earlier, we weren't really able to define any specific programs. We were left with an overall feeling that perhaps as much effort is needed on a people reorientation and education program within the AF and AF contractors as much as technical application by the scientific community to solve what appeared to be general corrosion problems due to contamination.

Fred Meyer - Speaker

As Dr. Weirick brought out in his talk, a lot of the problems of corrosion were built in during the manufacturing period. We have to use a corrosive flux to get a good solder joint and if you go to less corrosive flux, you wind up with poor solderability. If, after you finish the soldering, you don't remove the solder flux and it has to be removed completely, you have a built-in corrodant. Especially if you coat or surface treat it, this later on with moisture condensation will contaminate the lead if you don't get a good seal with fumble coating and the lead. You get practically an asmodic condition where any condensate can get down into the board and contact with the flux residue and you wind up with an acid solution which then causes problems with the circuitry because of the dissimilar metals. You can't do much metals selection with electronics because of the very nature of the various components. Transistors are made of certain materials and as far as you go that's it, you can't substitute too much. The great majority of the failures we run into are generally related to these basic violations to corrosion prevention.

When we get into the field, we find that the electronics people are generally not that well oriented to how to identify corrosion on their systems. They are trained to evaluate performances aboard, for instance, and for some reason most of the circuitry we have now can be field repaired. Their feeling is if it works use it,if it doesn't discard it. One area that we like to mention is plug-in circuitry. If we have connector corrosion it's a simple matter to clean that connector, but if the electronics man isn't aware of this, he may dump a valuable part because it doesn't work when it may simply be dirt or corrosion contamination on the leads in the connectors. The AF has published TO T01-6-89 entitled "Corrosion Prevention and Control on Electronics" which is being sent out to all avionic shops to help them become aware of this problem.

Question: What is new in vapor phase inhibitors?

Answer: I brought that up to the group to see if anybody had any specific information on the utility of vapor phase inhibitors. In our particular group, nobody had any direct results of any of the recent ones. There was some data input about looking at some a number of years back but no real studies in recent times as to just how useful they are, particularly with electronic gear. Perhaps I could throw that same question back out to this group.

You might talk to the AF Package Evaluation Agency people who are studying ways of improving packaging and techniques. They began to have certain problems with the various plastic packaging materials available. You would figure they would be impervious to vapor but they are not. The reason this technique has rather limited utility in electronics is that unless it is a sealed assembly, you get an eventual depletion of the vapor phase inhibitor. Unfortunately vapor phase inhibitors do not work well in open systems design and many of the electronic systems are open to the atmosphere. Dr. Lynch brought up the point of the horizontal design, rather than vertical, of many of these electronic systems. This horizontal design unfortunately permits condensation of water vapor to set on the components and not drain off as it would in the vertical design. This causes a great corrosion problem. Dr. Lynch also brought out the fact that many of the old radar systems, for example, in the older planes were enclosed but now in the newer designs are open and thus exposed to the atmosphere.

There has been a lot of work at Rome AF Base on breakdown inside the package and the results they found with corrosion and subsequent failure caused by heat up and cool down with water condensing inside the package and causing corrosion.

WORKSHOP VI.

NEW APPROACHES TO CORROSION PROBLEM SOLVING

Chairman: W.A. Thompson, ALC/MMETC

Recorder: F. Vahldiek, AFML

Participants: T. Bartel, AFML/LLS
F. Mullins, AFML/LLP
A. Dent, Carnegie-Mellon Univ
W. Thompson, WR/ALC/MMETC
D. Walters, Wright State Univ
C. Dinkeloo, Technology Inc.
G. Simmons, Lehigh Univ.
B. Ives, McMaster Univ.
S. Lee, AFIT/ENB
J. Wurst, Univ. of Dayton Research Center
J. Hassell, Battelle-Columbus Labs
K. Frisch, University of Detroit
Maj. Tom Moore/ASD/ENFSS
D. Montgomery, Michigan State Univ.
F. Vahldiek, AFML/LLN

Introduction

Considerable time was spent in introducing AF corrosion problems to representatives of universities and industrial organizations. In this briefing by AF personnel, it was pointed out that new ideas which are easy to use and are cheap and rapidly applied are of interest. Then using a typical corrosion problem, a Cd-plated steel fastener lead in a wing structure was used as a model for consideration of corrosion inspection, detection, and prevention methods.

Discussion and Summary

In the course of the discussion it came out that a galvanic cell mechanism is the important factor in the corrosion process at hand in the fastener situation. Most of the "corrosion problem solving session dealt with inspection and detection methods with some emphasis also placed on preventive measures. It was felt that, besides the usual visual inspection on known "corrosion hot spots" as well as overall inspection of the airplanes, the following methods should be looked into in greater detail than has been the case in the past.

a) Corrosion sensitive coatings - color changes by pH changes
b) Liquid crystals - thermally activated color changes
c) Electrically conductive material - <u>in</u> topcoat as dispersed phase or <u>on</u> topcoat
d) Xerography

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PROCEEDINGS OF AFOSR/AFML CORROSION WORKSHOP.(U)
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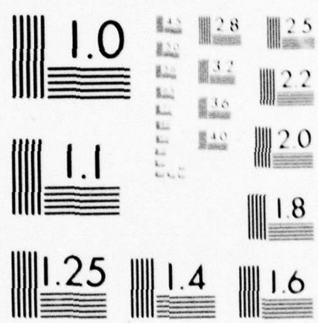

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

e) Acoustic emission
f) Infrared techniques
g) Spark and ion source mass spectroscopy
h) Neutron radiography

The rest of the session was spent discussing corrosion prevention techniques. Emphasis was placed on usage of inhibited sealants on aircraft problems and on crack inhibition in general. It was mentioned that the ion vapor deposited Al process should be used to plate the steel fasteners in the future. Finally, it was mentioned that when the 7049, 7050 Al alloys are being applied for airframe structures, then overall corrosion should be substantially decreased on airplanes.

Fred Vahldiek -Speaker

First of all I would like to emphasize the recently raised comment as to getting a good communication between the people of the Air Force, industry, and the university, that is pretty obvious because our session this morning had to spend quite a bit of time introducing the other side - industry and university - to the Air Force problems. I would like to emphasize that this should be continued on a deeper basis, there is a need for this communication.

Now as to the actual detection and prevention aspects, we arrived at new methods on problem solving in corrosion, essentially in two areas: 1) in inspection and detection and 2) prevention. Now a number of these ideas have already been mentioned by earlier speakers, but I would like to summarize just briefly what we talked about this morning. This again will emphasize new and old methods which have resurfaced and particularly the use of corrosive sensitive coatings which can be put into materials to detect certain types of corrosion. Conductive materials, for example, can be put into top coats and by electrical methods can be measured if corrosion is present. Another method mentioned briefly was liquid crystals which caused quite a stir. Another technique that was brought up in the discussion was inhibited sealants. There again we have an inhibitor-type process which has been studied for a number of years and now is being used in sealants. Professor Montgomery brought up a new method, Xerography, as a possibility. In the area of chemo-electrical methods, spark and ion source mass spectroscopy and infrared, which was mentioned earlier, were discussed.

In the area of prevention, the example discussed was the cad plated fastener, a typical aluminum-type structure, and it was mentioned that aluminum will eventually be available for coatings rather than cadmium because of the galvanic cell problem that we have in the structure at the present. Professor Frisch brought up another interesting point that since the military airplanes spend most of their time on the ground, would it be possible to develop a simple cocoon-type thing which could be put up very cheaply and quickly and would help in corrosion prevention.

FINAL SESSION

CORROSION WORKSHOP

Dr. C.T. Lynch - Speaker and Discussion Leader

There are several items of a general nature I would like to cover and then we will open up the session for general discussion, particularly on the points that have been raised as to where we go from here.

First of all, Dr. Hoch and I will get out to the participants a report including the Air Force presentations, reflecting the inputs from the different workshop committees as to what was done here, and a list of attendees, as well as possible action items, etc.; and we will also try to include in it the new AF COP-CON or Corrosion Prevention and Control document which is being issued as MIL-STO 1568 later this fall. This report will be followed later by a Government Technical Report available for general distribution. Secondly, if you have any questions pertaining to the meeting or comments, please direct them to Mrs. Jean A. Gwinn in care of the University of Cincinnati Office, AFML/LLM-1, W-PAFB, OH 45433.

We have the representatives here of the Air Force Office of Scientific Research, the Office of Naval Research, and the Army Research Office. It seems appropriate that they might talk briefly on this question on where you go from here, after having attended this meeting, and got some thoughts together pertaining to the topics discussed. Hopefully, they will present some needs as I have had some criticisms directed to me that we haven't been specific enough with the needs. I will say that we have tried to be specific within the confines of the time available but we still may not have done the job from your standpoint. We perhaps have not been nearly specific enough to give you the ideas that you feel you need to work on to develop concrete proposals. You may feel that you have to return and talk further with people such as myself, people in the Logistics Centers, etc. about some of these problems we have in more detail than we could do at this meeting together. We would encourage and hope to foster such further response. So without going further with this, I have asked our co-sponsors from AFOSR, and our sister service representatives to comment at this time.

Lt Col R. W. Haffner - Speaker

Because of the limited time available this week, neither Dr. Lynch nor I expected to have detailed plans drawn up as to the results of this Workshop, especially to the point where one would be ready to apply funds and head off in the direction that the Group had decided. I think that would have been asking too much; but let met go back to what we said was our original objective. First we wanted to stimulate a little thinking about corrosion prevention and certainly we have done that. Secondly, we have done a little communicating. I know, for example, that you people from industry and universities have had a chance to listen to Air Force people describe their problems firsthand. You have listened to them and you have heard a good deal about how we have tried to control the problem to date. Some of the things that have been tried did not work out very well, some of the limitations we are up against, i.e., cost, weight and time considerations prevent an easy solution. Now I think what we would like to have you do -- the other half of the exercise -- would be to continue thinking about these problems that we have discussed when you go back home. Continue to think about them, discuss them with colleagues. I do not know how creative ideas are born, but when they are please share them with us. Your proposals may apply to the field of metallurgy or they may relate to surface chemistry. They may involve improved design concepts or suggest new maintenance procedures. Whatever they are we welcome your proposals. We will consider and evaluate, to the very best of our ability, any ideas that you care to submit. In my organization, AFOSR, we operate entirely on the basis of unsolicited proposals sent to us by the scientific community.

My surface chemistry program includes the study of corrosion reactions; however, others at AFOSR also sponsor surface studies in physics and solid state sciences. They are equally interested in surface phenomena and some of their research is closely related to our corrosion work. I can not promise to fund every idea that comes in, that obviously is a fiscal impossibility due to the limited funds we have to apply in the basic research area. But we will thoroughly evaluate each proposal, first to determine its scientific merit, and secondly, to consider its relevance to the Air Force.

Phil Clarkin - Speaker

I thought I would tell you about the directions we are taking in our corrosion research program at the Office of Naval Research with respect to stress corrosion cracking and hydrogen embrittlement.

In high strength aluminum alloys, we feel that there is still enough confusion concerning the mechanism(s) of stress corrosion cracking that we are continuing our mechanistic studies. We feel--and this relates to Dr. Russo's earlier question about the potential for improving the stress corrosion resistance of these alloys--that improvements are possible; the development of alloys such as 7050 point to this. However, we need to know much more about the stress corrosion cracking mechanism in these alloys in order to make these improvements effectively.

With respect to steels, we feel that stress corrosion cracking has been reasonably well established as a hydrogen embrittlement problem and, although it would be of interest to determine how hydrogen actually works to degrade the mechanical properties of steels, we are not pursuing this in our research program. The reason for this is our feeling that the physics of solids and our understanding of cohesion in solids has not advanced to the point where research on hydrogen effects may be fruitfully pursued. This assessment has been further reinforced by the many discussions of hydrogen effects on crystal plasticity at a recent meeting on Surface Effects in Crystal Plasticity in Germany that offered no new research approaches to resolve the hydrogen problem. On the other hand, we have taken the view that if hydrogen is in a steel, it is always potentially harmful; thus, we must keep hydrogen out or render it innocuous should it be absorbed. Our research program reflects this viewpoint by emphasizing research on surface additions aimed at preventing or minimizing hydrogen adsorption and entry, and research on alloying to provide hydrogen trapping.

While I am on the subject of hydrogen embrittlement I might add one further observation. We spend a lot of time worrying about the hydrogen absorption that may occur during the many fabrication steps to which a steel part may be subjected or when the part is in service, but we have little, if any, quantitative definition of the absorption at each point in a parts history. I think it might be both practical and worthwhile to establish this, even if only for a few representative components. For if we had information of this type, we might be able to take more effective steps to prevent hydrogen entry in practice, and it may point out areas where further research on this problem is needed.

Dr. Phil Parrish - Speaker

As most of you know I am relatively new at the Army Research Office and that is probably good from a nonindoctrination standpoint. As far as the Army problems are concerned, I am trying to get attuned to them as rapidly as possible in the area of corrosion. Many of our problems are quite similar to those voiced by the Air Force speakers these last two days, and I have spent four years working on some of them at the Air Force Materials Laboratory with Dr. Lynch and others of their staff. We have not discussed much of the problems associated with ground equipment maintenance but this certainly is another problem area where tight budgets and high maintenance costs require a heightened research interest for all of the armed services.

In terms of proposals we are definitely looking for some imagination in programs that are proposed; some good ideas and new techniques or new applications of existing methods. One thing that does concern me is that we do not encourage everyone to work on hydrogen problems to a degree that other equally important topics are neglected or given inadequate attention. We are always open to good proposals and we encourage obtaining these proposals from you for consideration in our research efforts.

Dr. Lynch - Speaker

I think we should keep in mind that corrosion programs are often difficult to sell to management. They are not glamorous like new missile or laser weapon programs. Some of this is due simply to the fact that the corrosion problem is an old one that seems uninteresting to management people who buy the programs. Another fact we have alluded to and hope to have progressed on here is that many research proposals seem to be quite removed from the engineering solutions that they are supposed to be advancing. A further hurdle is the prevalent attitude even among scientists who have lived through a tremendous scientific revolution in this century, that you simply can't stop it since it's mother nature, and we just have to live with it. On your car that may be all right when your fenders rusts off and falls apart. On an aircraft wing, it may not be so ignored.

The importance of meetings like this workshop is to draw attention to these problems and the necessity to work on their solution. Regardless of how we establish a definite need, the Air Force is still spending many hundreds of millions of dollars per year on maintenance of the existing fleet. Somehow we need to significantly reduce these costs. Despite the difficulties we must find a way to define and sell programs that will have this desired impact. We feel that this workshop constitutes a reasonable starting point for this effort.

NOTE: The workshop open discussion which was taped at this closing session was unfortunately such an unsatisfactory tape that the results could not be reproduced here. We would encourage participants, who made remarks that they feel should be annotated to this report, to prepare them and forward them to Dr. C.T. Lynch, AFML/LLN, etc. These remarks will then be included in the subsequent Government Technical Report to be published on this Workshop Proceedings.

NEW DIRECTIONS FOR CORROSION RESEARCH AND DEVELOPMENT

Dr. H.M. Burte and Dr. C.T. Lynch

In the "Opening Remarks" one of us challenged this Corrosion Workshop to "identify and define new and promising specific directions for corrosion research, or approaches where development might be attempted" and to attempt to match these to specific "windows". There are several ways in which we might assess our progress towards these, and the value of the Workshop. One is simply to see what new proposals of significant merit have been received by a granting agency for basic research such as AFOSR during the 6 to 9 months subsequent to the meeting, which appear to directly arise from the new approaches discussed. We might define significant merit for this purpose as proposals which have been received and found acceptable during the review of independent evaluators who assist AFOSR. Another method would be to look for those programs in the AFML which came from an identification of reduction to practice possibilities. Finally, one can look for changes in the direction of academic or industrial fundamental research programs as the result of this meeting, or subsequent to publication of this report.

In the past six months or so, at least five specific proposals which appear to relate to attendance at this meeting and to the conclusions reached on directions for future research to solve Air Force problems, have been received by AFOSR in the fields of metallurgy and chemistry. Of these proposals, four or 80%, have received sufficiently high ratings and will probably be funded in the FY77-78 time period. From the point of view of AFOSR this is both a significant number of good, relevant proposals, and a higher than expected degree of submission of successful proposals than usually realized. In this context, then, an impact has been made to bring the best equipped academic minds we can find to bear on problems of reducing maintenance costs due to corrosion and to prevent and/or control corrosion problems.

In the area of defining application "windows" which can serve as outlets for fundamental research, one outstanding opportunity was identified. It was mentioned that the Air Force is currently building an automated rinse facility for F-4 fighter aircraft at MacDill AFB, FL., to establish the advantages/disadvantages of rinsing of aircraft after every mission. The application of soluble inhibitors of a multifunctional, nontoxic type, as recommended in the Coatings and Inhibitors Workshop was coupled to this "window" providing an opportunity to research and apply inhibitor concepts in an operational framework and assess the results from service data on actual maintenance cost data on the aircraft. Within less than one year this program has been planned and resources obtained to support it. This is a good example of how the coupling of research capabilities to applied problems and specific windows -- as we have attempted to stimulate in the Corrosion Workshop -- can not only guide research but can lead to new program efforts which are readily sold to management and hence receive adequate support. The suggestion for R&D on new stripping compounds will also probably result in new program efforts in FY78. Other suggestions such as for new primers are still under consideration.

In this particular meeting the coupling was between fundamental research scientists and acquisition and logistics engineers. We may need to broaden the interchange to include field level maintenance personnel and their view of operational problems. If it is difficult for logistics engineers and research scientists to speak and exchange useful information in a manner that will lead to defining new research efforts to meet applied problems, it may be almost impossible to quickly integrate the operational field personnel and research scientists into a workshop mode. We did not try it, here, but probably should in a subsequent meeting. Along a similar vein, the Air Force does bring together operational personnel and logistics engineers (and a few inhouse scientists with a more fundamental background) at a Corrosion Managers Conference held every 12-18 months. There has been a tendency for such meetings to concentrate on procedure and supply problems such as the variability in different batches of a centrally processed washing compound or paint, but it might be possible to direct more attention to consideration of where research efforts might be fruitful.

The example given of a research opportunity to apply new inhibitor systems to reducing maintenance costs can be expanded from automated rinsing of aircraft to washing aircraft at fixed intervals, or to using soluble inhibitors in bilge, latrine, and galley areas which virtually always show serious corrosion problems on all types of aircraft, or to the possible development of improved inhibitors incorporated into paints. All of these approaches might lead quickly to reduction to practice possibilities. On the other hand, many corrosion engineers who must "fire-fight" existing problems often feel that many new approaches have no merit when compared with the advantages that could be gained if current corrosion prevention and control measures as outlined in the new MIL-STD 1568 (which is included in this report) were assiduously followed. They may often be right. The communication and feedback mechanisms between the research and the user communities must thus be of sufficient depth to define the problems, propose the solutions, find the windows, and meet the objections. In this process we have at least made a beginning. An encouraging note in this regard has been the positive and helpful response of maintenance personnel and logistics engineers when they see that the scientists are actually interested in their applied problems. They become willing partners in formulating new program efforts to solve existing problems.

We have attempted to summarize the discussions of the panels at the Corrosion Workshop in the Tables which follow. The format used is designed to provide some perspective on how well it was possible to define either the nature of general problems and/or reduction to practice windows or possible avenues for future research. There is one table for each Workshop.

The comparisons between Panel results are indeed marked. The Workshops on Coatings and Inhibitors, Crack Growth Phenomena, Stress Corrosion Cracking and Hydrogen Embrittlement, and New Approaches, were able to define general problems/needs, find at least a few windows, and suggest areas of research or development. The Workshop on Electronic Materials did not actually complete problem definition, and consequently could not specify much in the way of specific research efforts or define windows for reduction to practice. The Panel on Accelerated Testing spent all of its time defining the problem without defining any specifics in the way of research programs. In this area possibilities for windows appear to be straightforward providing a strategy for reseach efforts can be devised. Also on the subject of accelerated testing a further problem was considered without reaching any conclusions. Several panel members felt that much useful data are available from thirty years of prior research that relate actual service response of experimental panels to atmospheric conditions. They feel that the relevance of these data to current needs is not recognized nor are they adequately utilized. For general atmospheric conditions (humidity, temperature, rainfall, wind velocity, etc.) this may be the case; for some pollutants data on potential environmental accelerators such as SO_2 were not widely available until a few years ago.

The Tables which follow summarize our perception of the results and suggest some directions for Corrosion R&D. We felt that the Workshop was a good start at improving the coupling between the corrosion research community and the real needs of the acquisition and logistics community. We thank all the participants for their contributions.

WORKSHOP I

COATINGS AND INHIBITORS

GENERAL PROBLEMS/NEEDS	WINDOWS	REDUCTION TO PRACTICE/ DEVELOPMENT	RESEARCH
More Durable Primer	C-141A and B-52 Upper Wings, AF Program Depot Maintenance (PDM) Inspections	Evaluation of Polysulfide Primer	Methods for Quantifying Corrosion Hot Spots and Problem Environments
Corrosion Detection and Coating Condition Evaluation	NDI of Coatings	New NDI Methods Development 1) Neutron Radiography	Develop new NDI Methods 1) Corrosion Sensitive Coatings (pH indicator) 2) Electrical Potential and Conductivity Monitoring of Hot Spots 3) IR Thermal Imaging
Reduce General Corrosion	Fighter Automated Rinse Facility at MacDill AFB, FL	Use of Inhibited Rinse Water in Automated Systems	Multipurpose, Multicomponent, Nontoxic Inhibitor Development-Research on Aℓ Alloy Corrosion Inhibitors Particularly
Reduce General Corrosion	Computerized Automated Wash Racks for Aircraft	Wash Inhibitors for Aircraft	Wash Inhibitor Studies in Various Environments/Painted Panels, Determination of Optimum Conditions, Types of Inhibitors, Concentration, Wash Frequency, etc.
Reduce General Corrosion	Bilges, Galleys, and Latrines of Aircraft, Particularly Cargo Planes Such as C-130, C-141A and C-5A	Bilge Inhibitors Development and Evaluation	Multipurpose, Nontoxic Inhibitor Development With Controlled Solubility Release and no SCC or Corrosion-Fatigue Problem
Reduce General Corrosion	Galleys and Latrines	Use of Plastics in in Galley and Latrine Design. AMST Aircraft Cost Effectiveness Proposals. Quantify Corrosion Hot Spots and Estimate Life Cycle Cost Savings.	Durability of Plastics in Very Corrosive Environments

WORKSHOP I (Cont'd)

COATINGS AND INHIBITORS

GENERAL PROBLEMS/NEEDS	WINDOWS	REDUCTION TO PRACTICE/ DEVELOPMENT	RESEARCH
Comply with New EPA Regulations	Evaluation thru a Maintenance Evaluation Program with WRALC on Specific Aircraft	Non-Corrosive Biodegradable Paint Strippers	Mechanisms for Suitable Paint Stripping by Non-Corrosive or Inhibited Corrosive Paint Strippers. Solvent-Paint Reaction Studies, Non-Corrosive Degradation of Paints with Mild Chemicals. Synthesis of Water Base Polymeric Coatings.

CONCLUSION: A substantial number of research efforts outlined and specific windows appear available. Several NDI techniques suggested identical to some from Workshop VI.

WORKSHOP II

ACCELERATED TESTING AND REALISTIC TEST ENVIRONMENTS

GENERAL PROBLEMS/NEEDS	WINDOWS	REDUCTION TO PRACTICE/ DEVELOPMENT	RESEARCH
Materials Selection Screen and Rank Materials/Short Term	AFLC Request for 6 Week Turn Around on Materials Evaluation by Accelerated Testing Could Provide Window With Selection of Specific Materials or Components for Test	Not Defined - Possibility: Accelerated Testing New Alloys Such as Powder Metallurgy Aluminum on Comparative Basis (provides no service life estimate in current state of the art, however).	Not Defined: Need to Determine Causative Mechanisms, Realistic Environments, Corrosion Accelerators. Determine Mechanisms and Reaction Products for Realistic Accelerated testing. Need Sophisticated Service Failure Analysis to Compare Candidate Tests with Service Experience.
Performance Prediction Life Cycle Cost Models for Evaluation of Materials Behavior in Corrosion Environments.	WRALC Request for Life Cycle Cost Models for Total Aircraft Systems and Specific Preventative Measures for an Aircraft. Pac r Lime Project Provides an Entry Step for Atmospheric Corrosion Severity Index for Aircraft. Scheduling Aircraft into Program Depot Maintenance.	Not Defined - Possibility: C-141A Corrosion Tracking and Prediction Program.	
Contract Specification Standard Tests for Accelerated Corrosion and Utilizable Quantitative Results. Life Cycle Cost Models for New Systems.	Tests Would Have to be Demonstrated for Materials Selection and Prediction First.	Not Defined - Possibility: Realistic Environmental Testing Under New Mil-Specs for Specific Aircraft Components.	

CONCLUSION: Problem definition in this case did not lead to any group conclusions as to specific research programs.

WORKSHOP III

ENVIRONMENTAL EFFECTS ON CRACK GROWTH RATES

GENERAL PROBLEMS/NEEDS	WINDOWS	REDUCTION TO PRACTICE/ DEVELOPMENT	RESEARCH
Reduce General Corrosion	F-4 Automated Rinse Facility at MacDill AFB, FL, Extend to Other Aircraft.	Use Exterior Rinse After Each Mission	Develop Effective Inhibitor Systems
Reduce General Corrosion	Specification of New Paints and Inhibitor Systems	Not Defined - Possibility: Extend Inhibitor Use in Coatings, Cleaning and Flushing Solutions, and Stripping Solutions.	Not Defined But Requires Substantial Efforts to Incorporate Effective Nontoxic Inhibitor Systems. Soluble Inhibitors cannot be Directly Incorporated into Coatings, Requires R&D. Encapsulation of Soluble Inhibitors into Coatings.
Prediction of Maintenance Needs	Program Depot Maintenance Scheduling	AFLC-AFML Corrosion Prediction Study on the C-141A. Analysis of 66-1 Maintenance Data Bank and Procedures. Determine Data Reduction Techniques and Correlation Methods to Establish Corrosion Prediction Models for Given Aircraft Forces.	Not Defined. May Require New Data Analysis and Modeling Methods.
Selection of Optimum Materials for New Systems	Damage Tolerant Design Procedures	Not Specifically Defined - Provides Effect of Environment on Crack Growth, for Failure Anticipation, Wider Range of Choice, Avoid Future Surprises, Establish Material. Limitations and Lower Cost Improved Materials.	Fundamental Studies of V vs K Curves, Including Metallurgical Variables, Rate Controlling Processes, Aim for Lower Plateau V, and Higher K_{Iscc}. Assess Environmental Variables, Temperature, and Effects of Inhibitors, Combined Chemical-Mechanical Effects Including Spectrum Loading.

WORKSHOP III (Cont'd)

ENVIRONMENTAL EFFECTS ON CRACK GROWTH RATES

GENERAL PROBLEMS/NEEDS	WINDOWS	REDUCTION TO PRACTICE/ DEVELOPMENT	RESEARCH
Continuing Education of Both Maintenance Personnel and the Research Community		Continually Itemize and Delineate Useful Practices and Procedures for Effective Corrosion Prevention and Control in Aircraft Design, Construction, and Maintenance	

CONCLUSION: An extensive research program outlined, some windows available, for longer range work need some window definition, overlap with conclusions of Workshop I, subject overlaps Workshop IV, and reports were issued by the panels with this in mind.

WORKSHOP IV

STRESS CORROSION CRACKING AND HYDROGEN EMBRITTLEMENT

GENERAL PROBLEMS/NEEDS	WINDOWS	REDUCTION TO PRACTICE/ DEVELOPMENT	RESEARCH
Development of Optimum Materials for New Systems	Not Specifically Defined in Many Instances but Examples of SCC and HE Failures Such as Recent C-141A Landing Gear Failure Due To HE Always Coming up to Provide Windows for Failure Anticipation/ Failure Avoidance Efforts. Decrease Susceptibility of Current Systems to SCC and HE.	Production and Evaluation of a Variety of New Aluminum Alloys Including Powder Metallurgy Products	Develop Inhibitive Systems Specifically for SCC and HE (vs. general corrosion inhibitors). Fundamental Studies to Shift V vs. K Curves, Lowering Plateau V, Raising K_{Iscc}.
Selection of Optimum Materials and Processes for New Systems	Specific Windows for Longer Range Research Hard to Define. Limited On-Line Analysis of Plating Solutions for HE Problems.	Hydrogen Probe Development and Evaluation for Steels and Other High Strength Alloys (sensitivity and reproducibility problems, however).	Develop Hydrogen Detection Techniques for Low ppm Analysis, Characterize Hydrogen Distribution and Effects, $Nb-O_2$ as a Model System, Interaction of Surface/ Environment, Catalysts vs. Catalyst Poisons for Degradative Reactions, Reexamine H Interaction with Metals, Verify Aℓ powder Metallurgy Prospects in Terms of Excellent Reported SCC Resistance of These Alloys, Study Reasons for SCC Resistance if Verified, and Possible Extension to Other Alloy Systems.

CONCLUSION: An extensive research program outlined, some windows available but hard to define for longer range programs, overlaps with Workshop III.

WORKSHOP V

ENVIRONMENTAL DEGRADATION OF ELECTRONIC MATERIALS

GENERAL PROBLEMS/NEEDS	WINDOWS	REDUCTION TO PRACTICE/ DEVELOPMENT	RESEARCH
Longer Life Electronic Components	Procurement Specifications. The Lack of Specific Window for Failure Anticipation Studies Evident. Need Component and Integrated Systems Performance Analysis Both to Indicate Research Needs and Provide Guidance for Reduction to Practice Demonstrations.	Not Defined - No Specific Developments Noted	Not Well Defined - 1) Solve Existing Problems of Contamination, Cyclic Humidity and Temperature, Dissimilar Metals, and Atmospheric Rain, All Leading to Premature Component Failure. 2) Allowable Contaminant Levels for Given Components Should be Determined. 3) Investigation of Vapor Phase Inhibitors for Encased Electronic Systems Needed.

CONCLUSION: Problem definition not completed. Very little in the way of specific new research programs suggested.

WORKSHOP VI

NEW APPROACHES TO CORROSION PROBLEM SOLVING

GENERAL PROBLEMS/NEEDS	WINDOWS	REDUCTION TO PRACTICE/ DEVELOPMENT	RESEARCH
Corrosion Detection and Coating Condition Evaluation	NDI of Coatings and Adjacent Structure, Fasteners, Honeycomb, and Other Complex Structures. PDM or Other Inspection.	New NDI Methods Development: 1) Acoustic Emission 2) Neutron Radiography	Application/Detection Limits and Reproducibility of New NDI Methods, e.g., 1) Corrosion Sensitive Coatings (pH indicator) 2) Liquid Crystals (thermally activated color changes) 3) Electrically Conductive Topcoats 4) Xerography 5) IR Imaging 6) Spark and Ion MS
Simplify Corrosion Detection NDI Methods	NDI of Coatings, Fasteners, Honeycomb Structure, Etc.	Not Specifically Defined	
Reduce Cost of Maintenance	Not Defined	Wider Application of IVD Aℓ. Wider Use of New Aℓ Alloys. Inhibited Sealants (multiphase inhibitor protection). Cocoon Storage of Aircraft.	

CONCLUSION: A substantial number of NDI techniques directly applied to corrosion detection suggested for further research and development. A potpourri of other possible windows to apply technology suggested which appear to require little research.

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MILITARY STANDARD

MATERIALS AND PROCESSES FOR CORROSION PREVENTION AND CONTROL IN AEROSPACE WEAPONS SYSTEMS

FSC MFFP

DEPARTMENT OF THE AIR FORCE

1. This Military Standard has been approved by the Department of the Air Force and is published to provide requirements for effective corrosion prevention and control programs.

2. Recommended corrections, additions, or deletions should be addressed to Air Force Materials Laboratory, Attn: MXA, Wright-Patterson Air Force Base, Ohio 45433.

CONTENTS

CONTENTS (CONT'D)

CONTENTS (CONT'D)

FOREWORD

The purpose of this standard is to establish the requirements for materials, processes and techniques, and to identify the tasks required to implement an effective corrosion prevention and control program during the conceptual, validation, development and production phases of aerospace weapons systems.

1. Scope.

1.1 Scope. This standard establishes the requirements for materials, processes and techniques, and to identify the tasks required to implement an effective corrosion prevention and control program during the conceptual, validation, development and production phases of aerospace weapon systems. The intent is to minimize the cost of upkeep due to corrosion during the operational life of aerospace weapon systems.

1.2 Intended use. This standard is to provide a mechanism for implementation of sound materials selection practices and finish treatments during the design, development, production and operational cycles of the aerospace weapon systems. This standard defines requirements to insure establishment and implementation of a corrosion prevention advisory board (where applicable), a corrosion prevention and control plan and its accompanying finish specification as directed in Section 4. The corrosion prevention and control plans will dictate the organization of the boards, their basic duties, operating procedures, and the finish philosophies used in the systems. The finish specification will require the contractor design engineers to designate the appropriate treatments, in organic finishes and organic finishes on the applicable production drawings. The finish specification will therefore be required to specify the detailed finish systems to be used on the respective aerospace weapons system in accordance with the finish philosophies as approved in the corrosion prevention and control plan. The information contained in Section 4 thru 9 of this standard is derived from experience gained on protection of aerospace weapons systems against corrosion by the military services and industry. It represents technical guidance and requirements for incorporation in the Corrosion Prevention and Control Plan and finish specification.

1.3 Applicability. This standard is applicable for use by all Air Force procuring activities and their respective contractors involved in the design and procurement of aerospace weapon systems. The detailed corrosion prevention and control plan and the finish specification applies to all elements of aerospace weapon system and its support equipment except electronic and propulsion sub systems. The requirement for the establishment of a corrosion prevention advisory board shall pertain only to major aerospace systems approved for Air Force use as defined by AFR 800-2, Program Management.

2. REFERENCED DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this standard to the extent specified herein:

SPECIFICATIONS

FEDERAL

QQ-P-416	Plating, Cadmium (Electrodeposited)
TT-P-1757	Primer Coating, Zinc Chromate, Low Moisture Sensitivity

MILITARY

MIL-S-5002	Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems
MIL-F-7179	Finishes and Coatings: Protection of Aerospace Weapons Systems, Structures and Parts, General Specification For
MIL-C-7438	Core Material, Aluminum, For Sandwich
MIL-M-7866	Molybdenum Disulfide
MIL-A-8625	Anodic Coatings, For Aluminum and Aluminum Alloys
MIL-S-8784	Sealing Compound Aluminum Integral Fuel Tanks and Fuel Cells, Cavities, Low Adhesion, Accelerator Required
MIL-S-8802	Sealing Compound, Temperature Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion
MIL-C-8837	Coating, Cadmium (Vacuum Deposited)
MIL-F-18264	Finishes: Organic, Aircraft: Application and Control Of

MIL-P-23377	Primer Coating; Epoxy-Polyamide, Chemical and Solvent Resistant
MIL-M-25047	Marking and Exterior Finish Colors For Airplane, Airplane Parts and Missiles (Ballistic Missiles Excluded)
MIL-C-27725	Coatings, Corrosion Preventive, For Aircraft Integral Fuel Tanks
MIL-S-38249	Sealing Compound, Firewall
MIL-M-38795	Manual, Technical: System Peculiar Corrosion Control
MIL-M-45202	Magnesium Alloys, Anodic Treatment Of
MIL-M-46080	Magnesium Castings; Process for Anodic Cleaning and Surface Sealing Of
MIL-A-46106A	Adhesive Sealants, Silicone, RTV, General Purpose
MIL-A-46146	Adhesive Sealants, Silicone, RTV, Noncorrosive (For Use With Sensitive Metals and Equipment)
MIL-S-81733	Sealing and Coating Compound, Corrosion Inhibitive
MIL-C-83231	Coatings, Polyurethane Rain Erosion Resistant for Exterior Aircraft and Missile Plastic Parts
MIL-C-83286	Coating, Urethane, Aliphatic, Isocyanate, for Aerospace Applications
MIL-A-83377	Adhesive Bonding for Aerospace Systems, Guidelines for

MIL-S-83430	Sealing Compound, Integral Fuel Tanks and Fuel Cell Cavities, Intermittent Use to 360°F
MIL-C-83445	Coating Systems, Polyurethane, Non-Yellowing, White, Rain Erosion Resistant, Thermally Reflective
MIL-C-83982	Compound, Sealing, Fluid Resistant

STANDARDS

FEDERAL

FED-STD-151	Metal, Test Methods

MILITARY

MIL-STD-810	Environmental Test Methods
MIL-STD-889	Dissimilar Metals
MIL-STD-1500	Cadmium-Titanium Plating, Low Embrittlement, Electrodeposition

(Copies of documents required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

3. DEFINITION NOT APPLICABLE

4. GENERAL REQUIREMENTS. The Contractor shall prepare a Corrosion Prevention and Control Plan and shall apply corrosion prevention and control requirements and considerations during systems definition, design, engineering development, production and deployment phases, which are consistent with the design life of the aerospace weapon system.

5. DETAIL REQUIREMENTS

5.1 Documentation. The following documents shall result from the implementation of the Corrosion Prevention and Control Program.

5.1.1 Corrosion prevention and control plan. The contractor shall prepare a Corrosion Prevention and Control Plan which describes the contractor's approach to corrosion prevention and control measures which shall be implemented for the purpose of minimizing or eliminating potential corrosion developments in the aerospace weapons system being procured. This includes government furnished equipment installations and contractor designed associated ground equipment. Guidelines for preparing this document are provided in Data Item, DI-S/3598/S-138-1.

5.1.2 Finish specification. The contractor shall prepare a finish specification which identifies the specific finish or techniques to be used on the various substrates of all parts components and assemblies to protect them against corrosion in the applicable operating and nonoperating environments to which they will be exposed. The items to be included shall be in accordance with DI-S-3598/S-138-1 and the systems procurement specification. After the document has been approved by the responsible Air Force procuring activity, the requirements contained therein shall be included in all applicable production drawings.

5.1.3 System peculiar corrosion control technical order. The contractor shall prepare a system peculiar corrosion control technical order which details the procedures for corrosion control and maintenance to be utilized by personnel in the organizational, intermediate and depot levels. This document shall be prepared in accordance with MIL-M-38795. In addition maximum use of General Technical Orders 1-1-1, 1-1-2, 1-1-4, 1-1-689 and 1-1-8 will be made. Through Field Surveys and Air Force technical order change requests, this technical order shall be updated as required.

5.2 Schedule for submission

5.2.1 Corrosion prevention and control plans. The initial draft of the corrosion prevention and control plan shall be submitted to the procuring activity as a part of the proposal package. The corrosion prevention plan and finish specification shall be submitted for approval sixty days subsequent to contract award. Revision of this document shall be accomplished as required to properly record a change to materials and/or processes being used for corrosion prevention and control. Through design studies, analysis of failure reports, and weapons systems inspections, data shall be collected which shall be analyzed for required revisions to this document.

5.2.2 System peculiar corrosion control technical order. The system peculiar corrosion control technical order shall be submitted as required by the procuring activity.

5.3 Implementation of corrosion prevention and control program

5.3.1 Establishment of corrosion prevention advisory board. The contractor shall participate in a corrosion prevention advisory board which shall have responsibility for assuring that all the functions of the corrosion prevention and control program are carried out. The board shall be chaired by the representative of the procuring activity and include an engineering team from the contractor. The panel shall include members from the contractor's organization and from the Air Force as follows:

a. Contractor Members: The contractor team shall be led by an engineer with experience in corrosion prevention and control and will serve in this capacity on a full time basis. The team leader shall report directly to program management. The remaining team members shall be authoritative representatives of the contractor's organizations which are necessary to insure that proper materials, processes, and treatments are selected and subsequently properly applied and maintained from the initial design stage to the final deliverable hardware.

b. Air Force members: The Air Force team will be as designated by the applicable Systems Program Office in accordance with the provisions of AFR 400-44.

5.3.2 Duties of corrosion prevention advisory board. The primary function of the board is to insure that adequate corrosion prevention and control requirements are being implemented during all phases of the aerospace weapons system being procured. Specific duties of the board shall include:

a. The contractor shall be responsible for assuring that the documents outlined under section 5.1 are prepared and submitted in accordance with the required schedule.

b. The chairman shall obtain the necessary reviews, clarification, resolutions of any differences in technical position and final approval of the documentation on a timely basis. In particular, the final approval of the finish specification shall be secured prior to release of the production drawings.

c. The chairman shall establish monthly meetings or as required to resolve design problems as they occur. Other meetings shall be convened should a critical or major problem arise which requires action by the board.

d. The chairman will notify all Air Force and contractor members of each meeting date, the topics to be discussed, and any decisions resulting from the previous meeting. Written reports of each meeting shall be submitted to all members.

e. The Air Force member(s) shall attend those meeting deemed appropriate, based on the agenda items to be discussed, and, if necessary, to present the Air Force position on controversial technical decisions made at the previous meeting.

f. The contractor team leader and his group representative shall sign off on all production drawings after review of materials selection, treatments and finishes.

g. The chairman and team leader will maintain a running log of all action items and their resolutions.

h. The contractor team leader shall prepare and obtain panel members agreement on the principal tasks to be accomplished to implement corrosion prevention and control procedures in the contractor and subcontractor facilities.

i. Both the chairman and contractor team leader shall maintain authority to conduct periodic reviews, on a scheduled and nonscheduled basis, of the contractor and subcontractor facilities where critical parts and assemblies are being fabricated, processed, assembled and readied for shipment to evaluate the adequacy of the efforts in corrosion prevention and control. Discrepancies will be documented and submitted for review and resolution by the board. The reviews shall be scheduled as frequently as deemed necessary by the chairman and/or contractor team leader.

5.4 Materials and process considerations in design

5.4.1 Selection considerations. The primary consideration in the design and construction of aerospace weapons systems is the ability of the design to comply with structural and operational requirements. In addition, the aerospace weapons are expected to perform reliably and require minimum maintenance over a specified lifetime, which includes minimizing the rate of deterioration. Therefore, in the selection of suitable materials and appropriate processing methods to satisfy structural requirements, consideration must also be given to those materials, processing methods and protective treatments which reduce service failures due to deterioration of parts and assemblies in service. Deterioration modes which contribute to service failures include but are not limited to pitting corrosion, galvanic corrosion, exfoliation corrosion, stress corrosion, corrosion fatigue, thermal embrittlement, fretting fatigue, oxidation, hydrogen embrittlement, weathering and fungus growth. In the entire design phase attention shall be given to precautionary measures to minimize deterioration of individual parts and assemblies as well as the entire system.

Precautionary measures include proper selection of materials, limitations of design operating stresses, relief of residual stress levels, shot peening, heat treatments which reduce corrosion susceptibility and protective coatings and finishes.

5.4.2 General design requirements for corrosion prevention

5.4.2.1 Exclusion of rain and airborne spray. The design of the system shall be such as to prevent water leaking into, or being driven into, any part of the system either on the ground or in flight. All windows, doors, panels, canopies, etc, shall be provided with sealing arrangements such that the entry of water is prevented when these items are correctly closed. Particular care shall be taken to prevent the wetting of equipment, and heat and sound proofing materials. Sharp corners and recesses should be avoided so that moisture and solid matter cannot accumulate to initiate localized attack. Sealed floors with suitable drainage shall be provided for galleys, toilets, and cockpits.

5.4.2.2 Ventilation. Adequate ventilation shall be provided in all areas to prevent moisture retention and buildup.

5.4.2.3 Drainage. Drain holes shall be provided in the system to prevent collection or entrapment of water or other unwanted fluids which can enter by various methods. All designs shall include considerations for the prevention of water or fluid entrapment and insure that drain holes are located to effect maximum drainage of accumulated fluids. Actual aircraft configuration and attitude shall be considered in addition to component design.

5.4.2.4 Dissimilar metals. Use of dissimilar metals (as defined by MIL-STD-889) in contact shall be limited to applications where similar metals cannot be used due to peculiar design requirements. When it is necessary to use dissimilar metals in contact, the metals shall be adequately protected against galvanic corrosion. Galvanic corrosion can be prevented by interposition of a material which will reduce the overall electrochemical potential of the joint or by interposition of an insulating or corrosion inhibiting material.

5.4.3 Metallic materials

5.4.3.1 Aluminum

5.4.3.1.1 Alloy selection. Whenever the design requires the selection of aluminum for structural components, maximum use shall be made of alloys, heat treatments, and claddings which minimize susceptibility to pitting, intergranular and stress corrosion. The following are alloy temper recommendations for resistance to exfoliation or stress corrosion.

Exfoliation resistance

Alloy	Temper
2124	
2219	
2024	All Artificially Aged
2014	
7075	T76XX, T736XX
7175	T76XX, T736XX
7049	T76XX, T73XX
7475	T76XX, T73XX
7050	T76XX, T736XX

Stress corrosion resistance

Alloy	Temper
2024	All Artificially Aged
2124	
2219	
7049	T73XXX
7050	T73XXX
7075	T73XXX
7175	T73XXX
7475	T73XXX

In the event these alloys and tempers, or other approved alloys, are not used, the susceptibility to stress corrosion cracking of the selected alloy will be established for each application in accordance with paragraph 5.4.3.1.5.

All aluminum sheets used in external environments and interior corrosive environments shall be clad on both sides except where the design requires surface metal removal by machining or chemical milling or where the design requires adhesive bonding or where the design uses alloys of the 5000 or 6000 series type. Surfaces from which cladding has been removed shall be protected in accordance with MIL-S-5002 and MIL-F-7179 which require a chemical or anodic film followed by an organic finish, except that bonded parts shall be finished in accordance with paragraph 5.6.1.1.1.

5.4.3.1.2 Aluminum alloy selection limitations. Mill product forms of aluminum alloys 2020, 7079, and 7178 in all temper conditions shall not be used for structural applications. The use of 7075-T6 shall be limited to thicknesses not to exceed 0.125 inch.

5.4.3.1.3 Maximum metal removal. Maximum metal removal from surfaces of non-stress relieved structural parts after final heat treatment shall not exceed 0.150 inch unless the final temper or condition has been demonstrated to have a stress-corrosion resistance of 25 ksi or higher in the short transverse grain direction as determined by a 20 day alternate immersion test given in FED-STD-151, Method 823. This requirement is applicable to 2000 and 7000 series alloys, but 30 days shall be used on 2000 series alloys. Stretch stress-relieved or compression stress-relieved aluminum products shall be used wherever possible. Maximum metal removal requirements are not intended to apply to mechanically stress-relieved products because of the low level of internal stresses resulting from mechanical stress-relieving.

5.4.3.1.4 Shot peening for stress corrosion resistance. All surfaces of all structural forgings, where accessible after final machining and heat treatment, must be completely shot peened using a minimum of two coverage passes or placed in compression by other suitable means, except for forgings having a demonstrated stress corrosion resistance of 25 ksi or higher in the short transverse direction and web areas under 0.080 inch thick where no short-transverse grain is exposed by machining. Those areas of forgings requiring lapped, honed, or polished surface finishes for functional engineering requirements shall be shot peened prior to such subsequent surface finish operations. Aluminum forgings used in corrosive environments shall have essentially no residual surface tensile stresses in the final heat treated and machined condition. Surface finish clean-up of shot peened surfaces such as landing gear bores, as required for fit up will not exceed 0.003 inch of surface material removal for aluminum alloys or 0.0015 inch for steels.

5.4.3.1.5 Test for stress corrosion susceptibility. Primary structure aluminum forgings, extrusions, and parts machined from plate used in corrosive environments shall have essentially no residual surface tensile stresses in the final heat treated and machined condition. To demonstrate that stress corrosion susceptiblity is within acceptable limits, the second production forging of all critical aluminum forgings and one sample part of each configuration machined from extruded stock or plate, except those in paragraph 4.3.1.1, shall be subjected to a standard 3.5 percent salt solution alternate immersion test for 2000 cycles. This test shall consist of 10 minutes total immersion followed by 50 minutes in air under conditions that result in complete drying of the part in the first 5-10 minutes of the drying cycle. Inspection for cracks shall be accomplished after 250, 500, 750, 1000, 1500 and 2000 cycles. These inspections shall be fully documented and the results made available for review by the procuring activity. The occurrence of any crack within the first 1000 hours of testing shall be cause for rejection of the design and for the contractor to modify his forging or machining techniques to eliminate such cracking. Retest shall be accomplished to verify that the modifications result in a part that will not crack for 1000 hours of testing. Every practical effort shall be made when cracking occurs during the second 1000 hours of testing, to relieve the residual stresses which resulted in cracking during the second 1000 hours of testing. The part used for this test shall have been machined and heat treated in accordance with the processes to be used for the production part. No protective finishes or anodizing shall be used and no external loads shall be applied. This test shall be conducted prior to committal of the part to production.

5.4.3.1.6 Stress corrosion factors. High strength aluminum alloy parts shall be designed, manufactured, assembled, and installed so that sustained residual tensile stresses are minimized to prevent premature failures due to stress corrosion cracking. In cases where such stresses cannot be avoided, corrective practices such as use of stress corrosion resistant alloys and tempers, optimum grain-flow orientation, shot peening or similar surface working shall be employed.

5.4.3.2 Low alloy, high strength steels. All low alloy, high strength steel parts including fasteners require corrosion protective metallic coatings by a process proven to be nonembrittling to the alloy/heat treatment combination. Applicable metallic coatings and finishes are described in subsequent sections of this document.

5.4.3.2.1 Limitation on use of protective metallic coatings. Soft surface coatings such as cadmium, nickel-cadmium, and aluminum shall not be used for sliding or wear applications. Cadmium plated surfaces shall not be used in applications where surface temperature exceed 450°F. Cadmium shall not be used in contact with fuel, hydraulic fluid or lubricating oil. The use of chrome plating for corrosion protection of alloy steel wear surfaces in interior environments is acceptable. For applications involving exposure to the exterior environment, chrome plating shall be considered an acceptable corrosion protection of alloy steel wear surfaces only when the chrome plating is periodically lubricated (fluid or grease types only) or a 0.0015 inch minimum layer of nickel plating is applied under the chrome. All chrome plated steel surfaces shall be shot peened prior to plating. Chrome plated surfaces shall not be used in applications where service temperatures exceed 700°F.

5.4.3.2.2 Stress corrosion factors. Alloy steel parts heat treated to 200,000 psi and above shall be designed, manufactured, assembled and installed such that sustained residual surface tensile stresses shall be minimized to prevent premature failures due to stress corrosion cracking. Whenever practicable, the use of press or shrink fits, tape pins, clevis joints in which tightening of the bolt imposes a bending load on the female lugs, and straightening or assembly operations that result in sustained residual surface tensile stresses in these materials shall be avoided. In cases where such practices cannot be avoided, apply protective treatment such as stress relief heat treatments, optimum grain-flow orientation, wet installed (with a protective material) inserts and pins, and shot peening or similar surface working to minimize the hazard of stress-corrosion cracking or hydrogen embrittlement damage.

5.4.3.3 Corrosion resistant steels. Except for the 400 Series Martensitic steels, corrosion resistant steels generally exhibit excellent corrosion resistance and do not require protective coatings for general protection against corrosion. Corrosion resistant steels shall be passivated. Table I should be used as a guide in the selection of corrosion resistant steels for structural applications.

5.4.3.3.1 No corrosion resistant precipitation hardening steels shall be used in the H900 condition. Corrosion resistant maraging, Almar series, Custom series, etc. steels shall not be heat treated to their highest strength condition. Corrosion resistant 19-9DL and 431 steels shall not be used for any application. Series 400 martensitic grade corrosion resistant steels shall not be used in the 150,000 to 180,000 psi strength range. Unstabilized austenitic steels may be used up to 700°F. Welded assemblies thereof shall not be used unless they have been given a solution heat treatment after welding (except for the stabilized grades 321 and 347, ELC 304 and ELC 316).

TABLE I. CORROSION CHARACTERISTICS OF CORROSION RESISTANT STEELS

Class	Alloy	General Corrosion Resistance	Stress Corrosion Resistance
Austenitic	316	Excellent	Excellent
	347	Excellent	Excellent
	A286	High	Excellent
	321	High	Moderate
	304(ELC)	Moderate to High	Moderate
	302	Moderate	Low
	303	Low to Moderate	Low
Martensitic	440C	Moderate-Sensitive To Hydrogen Embrittlement	All Grades Susceptible To Stress Corrosion Cracking
	420 410 416	Low To Moderate-Will Develop Superficial Rust Film With Atmospheric Exposure	
Precipitation Hardening	PH13-8Mo	High	Susceptibility Varies Significantly With Composition, Heat Treatment, and Product Form
	PH15-7Mo	High	
	PH14-8Mo	High	
	17-4PH	High	
	15-5PH	High	
	AM355	High	
	AM350	High	

5.4.3.4 Surface considerations. The surfaces of titanium mill products (sheet, plate, bar, forging, and extrusion) shall be 100% machined or chemically milled to remove all contaminated zones and layers formed while the material was at elevated temperature. This includes contamination as a result of mill processing, heat treating and elevated temperature forming operations.

5.4.3.4.1 Fretting. Titanium alloys are peculiarly susceptible to the reduction of fatigue life by interaction with fretting at interfaces between titanium alloys or titanium and other base metal parts. In any design where fretting is suspected, tests shall be made to determine whether such a condition will exist. Design considerations shall be applied to minimize fretting in structural applications.

5.4.3.4.2 Special precautions. Titanium parts shall not be cadmium plated and shall not be used in direct contact with cadmium plated parts or tools, Silver brazing of titanium parts and silver plated fasteners for elevated temperature applications shall be avoided. All applications of titanium above 600°F should include consideration of the hot salt cracking phenomenon.

5.4.3.5 Magnesium. Magnesium alloys shall not be used unless they are in areas where low exposure to corrosive environments can be expected and adequate protection systems can be maintained with ease and high reliability. Specific approval of the procuring activity shall be required. Magnesium alloys shall not be used in primary flight control system; for landing gear wheels; for primary structure; or other areas subject to abuse, foreign object damage, or to abrasion; or to any location where fluid or moisture entrapment is possible. Only aluminum alloy 5056 rivets shall be used for riveting magnesium alloy parts. Magnesium surfaces shall not be used for electrical bonding or grounding purposes.

5.4.3.6 Beryllium. In applications where beryllium is an approved material, consideration shall be given to suitable protective coatings to protect parts against corrosion. Tests shall be conducted to determine suitability of the protective coating under conditions simulating the expected corrosive environments.

5.4.3.7 Mercury. Mercury and many compounds containing mercury can cause accelerated stress cracking of aluminum and titanium alloys.

Devices containing mercury shall not be used on installed equipment or during production where spillage can contact these metals.

5.4.3.8 Adhesively bonded assemblies. Design of adhesively bonded assemblies shall preclude the accumulation and trapment of water or other contaminants within the structure. Post assembly edge sealing shall be used in addition to design techniques to preclude water entry. Perforated or other core configurations which allow moisture transfer shall not be used. All adhesively bonded assemblies shall be constructed in accordance with MIL-A-83377. Adhesively bonded assemblies shall be designed so that normal handling and other minor damage will not result in edge or other delamination which could lead to moisture entry.

5.4.4 Non-metallic materials

5.4.4.1 Foam plastics. Foamed plastics shall not be used for metal skin stabilization or as a sandwich core material in structural components, other than all-plastic sandwich parts, low density filler putties, or hollow glass bead (syntactic) foam. Use of these components shall be avoided unless rigorous vibration, sonic fatigue, and all life and environmental exposure tests can amply demonstrate a durable product. All components shall be completely sealed to preclude contact of fluids with core.

5.4.4.2 Lubricants. Silicone oils and greases shall be prohibited as lubricants but may be used for vibration damping, in gyros, and as heat transfer media when enclosed in hermetically sealed assemblies. Grease or heavy oils should not be used in applications where sand, dirt or similar contamination may be agglomerated into the lubricant. Solid film lubricants shall be entirely free of powdered carbon and graphite. Graphite shall not be used as a lubricant for any component. Graphite is cathodic to all structural metals and will establish the basis for galvanic corrosion under proper conditions, i.e., when exposed to heat and moisture. This is especially true if the graphite is applied in dry form. Lubricants containing graphite shall not be used.

5.4.4.3 Electrical insulation. Vinyl and polyvinylchloride, as insulation on wiring or as sleeving shall not be used because of their well known fungus nutrient characteristics and the dangers of outgassing during storage. These organics give off corrosive vapors which are active in attacking metals, plastics, elastomers, and insulation. Outgassing proceeds under normal room temperature conditions but is accelerated by high temperature or low pressure, and is most serious in closed containers. Satisfactory insulation includes Polytetrafluorethylene, FEP Teflon, Kel-F, H-film, Polyamide, Nylon, Polyurethane, Polycarbonate, Polyethylene, Polyalkene, Polyethylene Terephthalate, Polyolefin, Polysulfone, and Silicone sleeving in all grades. Where materials other than these are required, fungus resistant classes shall be specified and established by test per MIL-STD-810. Caution must be exercised in the use of Teflon covered silver plated copper wire because of possible corrosion at pin holes. Another problem associated with Teflon insulated wire is the difficulty of obtaining adhesion when potting or encapsulating. Polyamide insulation is considered to be the best for elevated temperature wire.

5.4.4.4 Tape. Tapes shall be selected which are non-corrosive, do not outgas, absorb moisture nor support fungus.

5.4.4.5 Hygroscopic materials. Non-wicking, non-hygroscopic gaskets shall be used to prevent moisture intrusion. Felt, leather, cork asbestos or glycol impregnated gaskets shall be avoided as well as cotton core material in electrical cables. The outer edges of laminated assemblies shall be sealed to prevent moisture intrusion.

5.4.4.6 Water displacing compounds. Water displacing compounds may be used to coat metal surfaces against moisture, fingerprints and corrosion. On plated surfaces of electrical devices including leads, contacts, and terminal posts, the soft film types of such compounds have been found to be effective protection against corrosion at pores or pinholes in the protective plating, a defect frequently found with standard commercial items. The water displacing compounds shall be in accordance with applicable military specifications. Other corrosion preventive compounds must be approved by the procuring activity.

5.4.4.7 Moisture and fungus resistance. Parts and equipment shall be designed so that the materials are not nutrients for fungi except when used in permanent hermetically sealed assemblies and other accepted and qualified parts such as treated transformers. Other necessary fungi nutrient material applications shall require treatment by a method which will render the resulting exposed surface fungi resistant.

The criteria for the determination of fungi and moisture resistance shall be that contained in MIL-STD-810.

5.4.4.8 Insulating blankets. Where thermal-accoustical insulating blankets are required, they shall be either procured with a permanent baked on water repellant binder system or suitably protected with sealant to prevent any moisture absorbed by the blanket from contacting the metal structure. The blankets shall be attached to the aircraft structure by means of adhesive.

5.5.0 Corrosion prevention during manufacturing operations. Adequate precaution shall be taken during manufacturing operations to maintain the integrity of corrosion preventative design requirements and to prevent the introduction of corrosion or corrosive elements.

5.5.1 Cleaning. Cleaning of the various types of metallic surfaces, prior to application of the surface treatments and coatings, shall be as specified in MIL-S-5002, using materials and processes which have no damaging effect on the metal, including freedom from pits, intergranular attack and significant etching. Appropriate inspection procedures shall be established. After cleaning, all parts shall be completely free of corrosion products, scale, paint, grease, oil, flux, and other foreign materials including other metals, and shall be given the specific treatment as soon as practicable after cleaning. Particular care shall be exercised in the handling of parts to assure that foreign metals are not inadvertently transferred, as may occur when steel is allowed to come into contact with zinc surfaces.

5.5.1.1 Titanium contamination. Care shall be taken to ensure that cleaning fluids and other chemicals used on titanium alloys are not detrimental to their performance. Substances which are known to be contaminants and can produce stress corrosion cracking include:

a. Hydrochloric acid
b. Trichlorethylene
c. Carbon tetracholoride
d. All chlorides
e. Chlorinated cutting oils
f. Freons
g. Methyl alcohol

5.5.2 Surface damage. Damage to any previously applied surface treatment or protective finish shall be repaired. Damage to surfaces which will become inaccessible because of mating with other parts shall be touched up prior to mating. Organic coatings used for repair shall be the same as those on the undamaged areas.

5.5.3 Marking pencils. Ordinary lead pencils containing graphite shall not be used to mark metal parts. Nongraphitic marking pencils covered by MIL-P-83953 shall be used.

5.5.4 Cleaning after assembly. All closed compartments shall be cleaned after assembly to remove all debris such as metal chips, broken fasteners, and dust. Particular attention shall be given to insure that drain holes are not blocked.

5.5.5 Protection of parts during storage and shipment. All parts and assemblies shall be given adequate protection to prevent corrosion and physical damage during temporary or long term storage and shipment.

5.6.0 Inorganic finishes

5.6.1 Detail requirements. Cleaning, surface treatments and inorganic finishes for metallic surfaces of aerospace weapons systems parts shall be in accordance with MIL-S-5002. Those parts or surfaces of parts located in corrosion susceptible areas or which form exterior surfaces of the system shall require chemical finishing to provide maximum corrosion resistance.

5.6.1.1 Aluminum. All unclad parts made from 7000 series aluminum alloys and located in an interior corrosive, exterior, or abrasive environment shall be sulfuric acid anodized in accordance with MIL-A-8625, Type II. 2000 series aluminum alloys may be anodized in accordance with MIL-A-8625, Type I or Type II, or chemical film treated in accordance with MIL-C-81706. Shot peening of aluminum alloy parts shall be accomplished prior to anodic coating. The detrimental effect of anodic coatings on fatigue life shall be considered in design.

5.6.1.1.1 Adhesive bonding. Face sheets used for adhesive bonding shall not be clad in the bond line. All bond line surfaces shall be protected against corrosion by the use of MIL-A-8625, Type I, chromic acid anodizing or FPL etch. The treated surfaces shall subsequently be coated with a corrosion inhibiting adhesive primer compatible with the adhesive. Other surface treatments may be used with the approval of the procuring activity. Sandwich construction core shall have a corrosion resistant finish in accordance with MIL-C-7438.

5.6.1.2 Cadmium coatings. Cadmium coatings for all steel parts including fasteners shall have a minimum thickness of 0.0003 inch and shall be subsequently treated with a chromate conversion coating. High strength steels having an ultimate tensile strength of 200,000 psi and above shall be plated with the titanium-cadmium process in accordance with MIL-STD-1500, the vacuum deposition process in accordance with MIL-C-8837, or a similar non-embrittling process except as noted in paragraph 4.3.2.1.

5.6.1.3 Magnesium. Magnesium alloys shall be treated in accordance with MIL-M-45202 or MIL-M-46080 prior to painting. Hole drilling after finishes have been applied shall not be permitted. Any operation which might remove previously applied finishes shall not be permitted.

5.7.0 Organic finishes

5.7.1 Detail requirements. All finishes and coatings shall be consistent with the requirements of MIL-F-7179.

5.7.1.1 Organic finishes. The organic finishes or finish systems used shall provide the necessary protection against corrosion for all materials used in areas subjected to corrosive environments. All exterior paints and colors shall be consistent with thermal design requirements. Marking and color schemes shall be in accordance with MIL-M-25047 and T.O. 1-1-4, or as otherwise specified by the procuring activity. The exterior organic finish system shall be MIL-C-83286 aliphatic polyurethane over MIL-P-23377 epoxy polyamide primer. This organic finish system is suitable for temperature requirements to 350°F. Interior primer shall conform to MIL-P-23377 except in high temperature areas such as engine bays. Where primers are required in high temperature areas, the selected material shall be approved by the procuring activity. Integral fuel tank coatings shall meet the requirements of MIL-C-27725. All exterior plastic parts which are subject to rain or solid particle erosion shall be protected by coatings conforming to specifications MIL-C-83231 or MIL-C-83445. Justification data, including both laboratory and service experience, shall be submitted for approval by the procuring activity whenever materials other than those given above are proposed.

5.7.1.2 Organic finish application. The MIL-C-83286 aliphatic polyurethane coating shall be applied in two coats to a thickness of 0.0018 to 0.0023 inch, for an overall average total topcoat thickness of 0.0020 inch. The MIL-P-23377 primer shall be applied to a thickness of 0.0006 to 0.0009 inch, for an overall average primer thickness of 0.0008 inch organic finishes shall be applied in accordance with MIL-F-18264.

5.7.1.3 Magnesium surfaces. Magnesium surfaces shall receive pretreatment, two coats of primer and two top coats prior to assembly. Magnesium components shall be installed without undergoing any operation such as hole drilling or fit-up, which would damage this finish. All faying surfaces shall be sealed with and all fasteners must be installed wet with a corrosion inhibiting sealant conforming to MIL-S-81733.

5.8 Environmental sealing

5.8.1 General requirements. Environmental sealing is utilized to provide protection from corrosion by excluding moisture and other corrodants from joints. It is important that the areas to be coated with sealant be adequately cleaned before sealant is applied.

5.8.2 Detail requirements. All joints and seams located in exterior or internal corrosive environments, including those in landing gear wells, control surface wells, attachment wells and structure under fairings shall be faying surface sealed with sealant conforming to MIL-S-81733, MIL-C-83982, MIL-S-8802 or MIL-S-83430. The MIL-S-81733 specification covers a sealant which contains a soluble chromate content of 3 to 6 percent for corrosion inhibition. For sealing high temperature areas, MIL-S-38249, firewall sealant, shall be used. The use of sealants not covered by a Military Specification must be approved by the procuring activity. Removable panels and access doors shall be sealed, either by mechanical seals or separable fay surface sealant MIL-S-8784.

5.8.3 RTV silicone adhesive sealants are occasionally required for specialized applications in aerospace equipment. Sealants conforming to MIL-A-46106 or MIL-A-46146 shall be used for these applications. Caution must be exercised when using MIL-A-46106 material since it may cause corrosion due to liberation of acetic acid during curing. The application precautions given in MIL-A-46106 shall be followed.

5.9.0 Fastener installation

5.9.1 Detail requirements. All permanently installed fasteners (all fasteners not normally removed for regular access or servicing) shall be installed with a corrosion inhibiting sealant conforming to MIL-S-81733 where temperature limitations permit. In high temperature areas, up to 350°F, MIL-P-23377, epoxy primer, or a sealant which is suitable for the thermal environment shall be used. Fasteners in integral fuel tanks shall be installed with wet sealant as specified in MIL-S-8802 or MIL-S-83430. The use of sealants not covered by a military specification must be approved by the procuring activity.

5.9.2 Special considerations. Quick release fasteners and removable fasteners penetrating exterior surfaces shall be designed and installed so as to provide a seal to prevent moisture or fluids from entering. Holes for these fasteners shall be primed and allowed to dry prior to installing the fastener.

5.9.2.1 Titanium rivets installed in titanium structures may be installed dry, unless sealing is required for liquid tightness.

5.9.2.2 Cadmium plated fasteners are prohibited in applications which would bring them into contact with titanium, and titanium fasteners are prohibited in applications which would bring them into contact with cadmium plated components. Cadmium plated fasteners shall not be used in contact with graphite composites.

5.9.2.3 Monel fasteners or copper plated fasteners shall not be used in contact with aluminum components.

5.9.2.4 All permanently torqued fasteners shall be lubricated with a mixture of 50 percent (by weight) petrolatum and 50 percent (by weight) molybdenum disulfide MIL-M-7866.

5.9.2.5 Only 5056 aluminum fasteners shall be used to fasten magnesium components.

5.9.2.6 The use of aluminum coated fasteners is the preferred method for preventing exfoliation in the countersink area of aluminum skins.

Custodians:

Air Force - 11

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