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Workshop on Requirements for Aircraft Corrosion Control

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

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(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No.714

WORKSHOP ON REQUIREMENTS FOR AIRCRAFT CORROSION CONTROL

Edited by

W.M.Imrie

Papers presented at the 56th Meeting of the Structures and Materials Panel in London, UK on 10–15 April 1983.

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PREFACE

This Workshop was organized following a recommendation agreed at the Specialists' Meeting on Aircraft Corrosion held in Cesme, Turkey in April 1981 and described in AGARD Conference Proceedings CP-315. It was arranged as part of the continuing effort of maintaining the communication link between the designers, manufacturers and users of both military and civil aircraft.

Some 50 people attended the Workshop. Relatively short presentations were made by specialists in the areas of procurement and design specifications, manufacturing and maintenance practices, costs and future efforts; each series of papers was followed by a discussion period.

There were differing opinions on the continued use of magnesium alloy castings by the UK. However, the relatively complex protection procedures for successfully combating corrosion and damage were described by the British in some detail.

On the question of the prohibition of chromates and cadmium, the general consensus of opinion was that no overall satisfactory alternatives have been forthcoming. Whilst research was continuing, no member indicated a move away from these established protectives in the foreseeable future.

Several speakers referred to the difficulty of getting good feedback on corrosion problems. Efforts to combat this difficulty appear to have been achieved with some success in the US Navy by the introduction of a system whereby trained maintenance personnel at three levels are required to report back to a data collection system. The cost of corrosion prevention and maintenance proved a difficult subject for discussion. No clear answer was available as to the extent procurement personnel would be prepared to pay for extra protection.

Summing up, the Workshop highlighted both the similarities and the differences in both corrosion control and design practice utilized in the NATO countries. Despite a very good interchange of information, the Workshop revealed the need for detailed and uniform specification requirements for corrosion control. Although many of the domestic specifications used by individual countries are referred to in general terms by the authors in their papers, it is proposed to publish this data in more detailed form, together with associated costs, in Volume II of the Corrosion Handbook.

R.SCHMIDT
Chairman,
Sub-Committee on Corrosion

CONTENTS

CORROSION CONTROL REQUIREMENTS FOR UK MILITARY AIRCRAFT

by

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SUMMARY

Within AvP 970, Design Requirements for Service Aircraft, the designer is given advice on the selection of materials based upon their resistance to corrosion, and mandatory requirements for processes and materials to be used in aircraft structures so as to minimise deterioration and corrosion. Details are given of these requirements and the various sequences of operations required for corrosion control purposes.

To achieve a satisfactory level of corrosion resistance in aircraft structures the designer must consider, not in isolation but in relation to each other, the detailed design of the structure, the selection of structural materials, and methods of protection. Mandatory requirements to ensure acceptable performance of military aircraft appear in various Chapters of Aviation Publication 970, Design Requirements for Service Aircraft. The relevant Chapters are:

Chapter 400 - General Detail Design (paragraph 4 requires approved specifications for all materials and processes used, and paragraph 9 requires MOD approval before magnesium alloy components are used).

Chapter 409 - Exfoliation Corrosion of Aluminium Alloys (requires MOD approval before certain susceptible alloys are used).

Chapter 410 - Stress Corrosion Cracking (requires MOD approval before certain susceptible alloys are used).

Chapter 801 - Precautions Against Corrosion and Deterioration (contains most of the mandatory requirements for corrosion control).

These Chapters, together with associated advisory leaflets, have all been written or revised in the past 3 years after detailed discussions with the UK aircraft industry, with the Royal Air Force and experts within the Ministry of Defence.

BASIC DESIGN CONSIDERATIONS

In Chapter 801 there are mandatory requirements which cover the following design aspects:-

The structure must be effectively sealed to prevent water and other liquids gaining access to the internal aircraft structure. An integral part of this requirement is that all static joints must be wet assembled.

The structure must be drained and vented, both in flight and on the ground so that any liquids generated within the aircraft are not trapped within the structure.

Any pockets in the structure must be filled with inert, low density materials so that water traps are eliminated.

Access for inspection must be provided so that all parts of the structure can be inspected for corrosion or loss of protective coatings, and can be accessible for reprotection.

Sharp corners and edges, places where paint is too easily lost, must be eliminated.

SELECTION OF MATERIALS

Airframe materials are chosen primarily to achieve a light, strong structure. Unfortunately, high strength alloys are often the ones that given rise to major corrosion problems. For example, severe exfoliation corrosion can occur within a few years on maritime aircraft. Chapter 409 provides the designer with information on the susceptibility to exfoliation of all of the aluminium alloys currently used in the UK aircraft industry. Alloys are classified from A to D:- A materials are very resistant to exfoliation, D materials are very susceptible and these alloys cannot be used without the agreement of the Aircraft Project Director. The philosophy is not to ban the use of susceptible alloys but to give the designer information which helps him to select more resistant alloys. Having considered possible alternatives the designer may still have overriding reasons for using a D classified alloy. He will then have to persuade the customer that there is an advantage in doing so. This same approach is taken with magnesium alloys and materials susceptible to stress corrosion - the designer must make a good case for using materials which are potential corrosion hazards.

Bimetallic or galvanic corrosion can be a problem in aircraft structures. For example, an aluminium alloy will have a more negative corrosion potential than a steel fastener, and an electrolyte, bridging the two materials, allows a galvanic cell to form - the light alloy forming the anode, the fastener the cathode. The rate of corrosion of the light alloy is increased, but the fastener is cathodically protected - just as steel is cathodically protected by cadmium plating or by galvanising.

APPROXIMATE CORROSION POTENTIALS IN CHLORIDE SOLUTIONS

Corrosion potential (mV *vc* SCE)	Element	Material or Alloy
+500		
	Gold, Carbon	Carbon Fibre Composite
ZERO	Silver	Titanium Alloys
		Corrosion Resisting Steels (18/8)
	Copper	Brass (70/30)
	Chromium	
-500		
		Low Alloy Steels
	Aluminium, Cadmium	Aluminium Alloys
-1000		Aluminium-1% Zinc
	Zinc	
-1500		
	Magnesium	Magnesium Alloys

Corrosion potentials indicate which of two metals will form the anode and therefore suffer galvanic corrosion. Thus, aluminium alloys will suffer galvanic corrosion in contact with steels, brass, corrosion resisting steels, titanium alloys, and carbon fibre composite. Conversely, aluminium alloys can be cathodically protected by cladding with aluminium or aluminium-1% zinc. But corrosion potentials only tell half the story and it is far better to give the designer information based on experience of bimetallic corrosion, and such information is available in the British Standards Institute publication PD 6864, commentary on Corrosion at Bimetallic Contacts and Its Alleviation.

BIMETALLIC CONTACTS - CORROSION HAZARDS IN A MARINE ATMOSPHERE

0	1	2	3
Al-Cd	Cd-Al	Zn-Steel	Al-Cu
Al-Zn	Zn-Al	Al-Ti	Al-Brass
Steel-Cd	Cd-Steel	Al-CRES	Al-Steel
Steel-Zn			

Bimetallic couples are classified from zero to 3; for those classified zero there is no additional corrosion of the first metal due to contact with the second metal; for those classified 3, the first metal can suffer severe galvanic corrosion in contact with the second metal and the designer must avoid such contacts. It is interesting to note that low alloy steels cause more severe galvanic corrosion of aluminium alloys than titanium or corrosion resisting steels do, even though the corrosion potentials would indicate otherwise. The information in PD 6864 also shows the designer how to convert dangerous couples (such as aluminium/steel or aluminium/copper) into relatively safe ones by cadmium or zinc plating the cathodic metal. However, the designer is warned that coatings of cadmium and zinc have a finite life and require further protection.

PROTECTION SCHEMES

Because corrosion is an electrochemical process it can be prevented by making sure that electrolytes do not come into contact with metal surfaces, and insulation of the airframe metals from the environment by painting is, therefore, the most important aspect of corrosion prevention. By incorporating corrosion inhibitors in the form of chromate pigments in the paint primer, corrosion can be controlled even at defects in the paint scheme. However, for paint schemes to fulfil their role they must not be readily detached from the metal surfaces; satisfactory paint adhesion can be ensured by control of metal pre-treatment and painting operations. For aluminium alloys the sequence is:

Initial cleaning by degreasing, abrading, chemical cleaning or a combination of such processes (which are specified in DEF STAN 03-2).

Pre-treating by anodising to the requirements of DEF 151 (usually Type 2 - chromic acid process), by chromate filming (to DEF STAN 03-18), or by etch priming (to DEF STAN 80-15 or approved alternatives).

Painting to the requirements of DEF STAN 03-7 with a chromate-pigmented epoxy primer (to DTD 5567) within 16 hours of pre-treatment. Finish coats will be epoxy (to DTD 5567) or, more usually, polyurethane (to DTD 5580) when high resistance to synthetic hydraulic fluids and lubricants is needed; for external surfaces of most military aircraft acrylic finishes (to DTD 5599) are currently specified.

For steel components approved pre-treatments are:

Cadmium, electroplated (to DEF STAN 03-19) or vapour deposited (to DTD 940).

Aluminium or aluminium-rich coatings (to BS 2569).

Zinc plating (to DEF STAN 03-20).

Phosphating (to DEF STAN 03-11).

Cadmium is the preferred pre-treatment, but the designer may specify one of the alternative treatments above when cadmium is not technically acceptable or feasible. After pre-treatment steel parts are painted using the same schemes applied to aluminium alloys, or using a stoving paint scheme (eg BS X 31).

Magnesium alloys depend on complete encapsulation with organic coatings to prevent corrosion. It is not possible to inhibit the corrosion of magnesium alloys at defects in the coating, nor is it possible to cathodically protect magnesium alloys which are anodic to all other structural materials and to the common plating metals, zinc and cadmium. The sequence of operations required in DTD 911, the UK Ministry of Defence specification for protection of magnesium alloys, includes:-

Fluoride anodising to remove impurities from sand castings.

Chromate filming or anodizing.

The impregnation of the chromate or anodic film with a stoving epoxy resin.

Painting, or application of nylon or other plastic coatings, to give a minimum of 100 m of organic coating.

Many corrosion problems have been encountered with magnesium alloys in both fixed wing aircraft and helicopters, and the designer is required to obtain approval from the Ministry of Defence before using magnesium alloy components. He is strongly advised not to use magnesium alloy in sheet form because of severe problems in the past. However, it is accepted that magnesium alloys have an important role to play in aerospace structures and in some applications their unique properties are invaluable.

Except for fasteners and fastener holes in aluminium alloys, Chapter 801 requires that metal surfaces are painted (at least with primer or, in the case of magnesium alloys, sealed with resin) at the detail stage before being assembled or built into the aircraft structure. During assembly a sealant or a jointing compound must be used on mating surfaces so that potential crevices are filled. The importance of wet assembly to prevent moisture getting into joints cannot be stressed too much. The vast majority of corrosion problems arise at interfaces between components, at fastener holes, or at the edges of panels. In many cases the corrosion occurs because wet assembly has been omitted or carried out poorly. Wet assembly can often be supplemented by caulking seams and any joints which leave ledges and traps where moisture and other contaminants can lodge. After assembly and before final painting, damage to the paint scheme must be repaired. Also, exposed parts of fasteners and exposed sealant or caulk must be primed. Areas which were only primed before assembly must be re-primed before finish coats (or any intermediate coats) are applied.

It is possible to obtain excellent protection when operating in the relatively controlled environment of aircraft manufacture and especially when protection schemes are applied to individual components. It is not always possible to restore protection to the same standard to aircraft in service when, for one reason or another, it is necessary to carry out 're-surface finishing' operations. In the UK the aircraft paint industry has developed improved epoxy primers, the major improvement being their excellent adhesion to metallic surfaces which have only been degreased. While the intention is to maintain the current requirements for surface pre-treatment, 're-surface finishing' should yield more durable and reliable protection.

Selective stripping of finish coats to leave the primer coat intact is one of the attractions of acrylic finishes currently used on the majority of UK service aircraft. However, the finish tends to craze and has only moderate resistance to some aircraft fluids. With recent paint developments it is technically possible to use paint schemes with polyurethane finishes which can be selectively stripped to leave the primer, or primer plus barrier coat, intact. These schemes appear to be almost as resistant to fluids as conventional polyurethane paint schemes. Other developments in polyurethane paint schemes are finishes with much increased flexibility. As well as greater resistance to chipping and cracking these paints have good erosion resistance. Service trials of these polyurethane paint schemes are underway. If successful, the paints will be added to the list of materials and processes (see Appendix) currently approved for use on military aircraft.

Finally, for internal areas of aircraft structures which require re-protection but cannot be repainted successfully (for example, when contamination with lubricants or hydraulic fluids cannot be removed completely) increasing use is being made of thin film, corrosion preventive compounds (DEF STAN 80-83). These materials are also used to supplement the paint schemes in areas where experience has shown that additional protection may be necessary. They are applied to give film thicknesses similar to those of paint schemes, dry to give a soft but non-tacky surface, and the coating is transparent. The same corrosion preventive compounds can be used for protection of parts in store and for semi-finished components during the complex process of aircraft manufacture.

APPENDIX

LIST OF PROTECTIVE MATERIALS AND PROCESSES APPROVED FOR USE ON UK MILITARY AIRCRAFT

Note: Specification DTD 900 includes appendices listing proprietary materials and processes approved under its terms for aerospace use.

Title	Specification number
PROCESSES	
Sprayed metal coatings	BS 2569
Cleaning and preparation of metal surfaces	DEF STAN 03-2
Protection of aluminium alloys by sprayed metal coatings	DEF STAN 03-3
The pretreatment and protection of steel parts of specified maximum tensile strength exceeding 1450 N/mm	DEF STAN 03-4
Electroless nickel coating of metals	DEF STAN 03-5
Painting of metal and wood	DEF STAN 03-7
Electrodeposition of tin	DEF STAN 03-8
Phosphate treatment of iron and steel	DEF STAN 03-11
Chromate conversion coatings for aluminium and aluminium alloys	DEF STAN 03-18
Electrodeposition of cadmium	DEF STAN 03-19 (previously DTD 904)
Electrodeposition of zinc	DEF STAN 03-20 (previously DTD 903)
Chromate passivation of cadmium and zinc surfaces	DEF-130
Anodizing of aluminium and aluminium alloys	DEF-151
Chromium plating for engineering purposes	DEF-160
Nickel plating (heavy)	DTD 905
Protection of magnesium rich alloys against corrosion	DTD 911
Identification colouring of rivets in aluminium and aluminium alloys	DTD 913
Process for the external finishing of radomes	DTD 926
Surface sealing of magnesium rich alloys	DTD 935
The cadmium coating of very strong steel parts by vacuum evaporation	DTD 940
Surface coating of parts by use of detonation, flame and plasma spraying processes	DTD 941
Anodizing of titanium and titanium alloys	DTD 942
Electrodeposited cobalt/chromium carbide composite coatings	DTD 943
STANDARD PAINT SCHEMES	
Interior and exterior protective finishing scheme (cold cured epoxy type)	DTD 5567
Exterior and interior finishing schemes - matt and glossy (cold curing polyurethane type) (Scheme I and Scheme II)	DTD 5580
Selectively strippable acrylic finishing scheme for use on aircraft	DTD 5599

Title	Specification number
OTHER PAINTS AND COATINGS	
Varnish for aeronautical purposes	BS 3X 17
Doping and finishing schemes for fabric covered aircraft	BX X 26
Low temperature stoving scheme for aeronautical purposes	BS X 31
Stoving enamel	DTD 56
Paint, pretreatment primer (etching primer)	DEF STAN 80-15
Corrosion preventative compound: aircraft structures. Joint Services designation PX 32	DEF STAN 80-83

AD-P003 628

CURRENT PROCUREMENT SPECIFICATION DESIGN
REQUIREMENTS FOR U.S. NAVY AIRCRAFT

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SUMMARY

An important step in the acquisition of a new naval aircraft is the review of detail specifications by materials and process specialists. The specifications are studied for compliance with SD-24, MIL-F-7179 and MIL-S-5002. In addition, reports on Adhesives, Lubricants, Finishes and Corrosion Control Plans are furnished as a contractural requirement. Some of the most important considerations are the materials to be used, designs incorporating dissimilar metals, and watertightness. Test programs may be necessary to validate a particular choice of material or design. In the final analysis, however, cost and performance are the overriding considerations so some compromises usually have to be made. The challenge is to obtain as corrosion-free a vehicle as possible within these constraints.

INTRODUCTION

It is only in the last ten years that materials engineers have been invited to take an active part in the weapons acquisition process. Documents such as SD-24, General Specification for Design and Construction of Aircraft Weapons Systems (Fixed and Rotary Wing Aircraft) was invoked as a contractural requirement, but the sections concerning materials selection were very general. Two other specifications were also usually called out, MIL-F-7179, General Specification for Finishes and Coatings for Protection of Aerospace Weapons Systems and MIL-S-5002, Surface Treatments and Inorganic Coatings for Metal Surfaces and of Weapons Systems. Adherence to these specifications was frequently perfunctory at best.

As higher performance aircraft evolved and the higher strength alloys used were by nature more susceptible to corrosion attack, an awareness began to develop that materials selection should receive more than passing attention. The situation has improved to the extent that materials reviews are included as part of all new Navy aircraft system acquisitions.

UPGRADING REQUIREMENTS

The documents mentioned previously have all been revised or are in the process of being revised to reflect state of the art developments in corrosion control. In SD-24 for example, the aluminum alloys approved for use are all of the exfoliation and/or stress corrosion resistant tempers. Use of magnesium alloys is severely restricted. A requirement for a corrosion control plan is imposed.

MIL-F-7179 and MIL-S-5002 are being revised to reflect the experience gained on operational aircraft over the last decade and the improved coating systems now available for use. Sealants are specified wherever dissimilar metals must be used and wherever moisture would have ingress. Coating systems are being standardized and those with marginal performance eliminated.

MIL-F-7179 originally specified different levels of protection depending on the severity of the environment to be encountered. These distinctions have been eliminated since they were arbitrary and with industrial pollution and acid rain no longer relate to any actual service environment.

The status of the revi ions mentioned above is as follows:

SD24L - Vol. I, Fixed Wing Aircraft - issued June 82

SD24L - Vol. II, Rotary Wing Aircraft - final review underway

MIL-F-7179 - undergoing industry and tri-service coordination

MIL-S-5002 - revision ready for industry and tri-service coordination

A new document is being developed to help combat the water intrusion problems being encountered with newer aircraft. This document is MIL-W-006729B(AS) entitled General Specification for Testing Watertightness of Aircraft (to be used in lieu of MIL-W-6729A).

FUTURE OUTLOOK

Although improved materials and procedures are being incorporated into contractural documents, manufacturers frequently claim their use will add to the cost of the aircraft, add weight, or change the aerodynamics in an unfavorable manner. In most cases performance and cost override all other considerations and waivers may be granted. The challenge to the materials engineer is to obtain as corrosion free a vehicle as possible within these constraints.

AD-P003 629

CURRENT DESIGN REQUIREMENTS FOR CORROSION CONTROL ON HELICOPTERS

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Aeronautical Design Standard ADS-13C embodies the general requirements for the materials and processes utilized in the design and construction of Army aircraft. The materials and processes are utilized in accordance with AMCP706-203, the Engineering Design Handbook Helicopter Engineering, part three, Qualification Assurance. The properties of materials are generally obtained from MIL-HDBK-5, MIL-HDBK-17 and MIL-HDBK-23, for metallic materials, plastics, and structural sandwich composites respectively. All of the system parts are finished to provide protection from corrosion and other forms of material deterioration in accordance with a contractor-prepared and Government-approved material deterioration prevention and control (MADPAC) plan which is detailed in the appendix to ADS-13. This appendix describes the managerial and technical responsibilities of Army contractors in the design, validation, development and production phases of Army aviation systems. It provides a mechanism for the implementation of sound materials selection practices and finish treatments during the life cycle of all Army aviation weapon systems and defines the organization and implementation of a MADPAC finish specification which complies with MIL-F-7179. ADS-13C represents the most recent revision of the standard which embodies some of the corrosion lessons learned from Army helicopters where weight reduction was the overriding concern in the design and construction of the aircraft.

Introduction

U.S. Army equipment has suffered enough out-of-service costs due to corrosion that today three principles on heading off corrosion can be said to be generally accepted. First, corrosion control must be built into original equipment design. Second, an awareness of the need for corrosion prevention must be maintained throughout manufacturing. Third, lessons learned on corrosion during design, development, production and fielding of equipment must be fed back to the start of any new designs. However, when a number of organizations not all under the same management are involved in the design-to-fielding process, creating the needed information flow is a problem by itself. It is the intent of this paper to describe the control mechanism now being used in support of future Army aircraft development. Within the controlling documents one can find details of current design requirements for corrosion control on helicopters.

Approach

Steps taken in establishing the needed control mechanism were to first recognize principle organizations or organizational sub-units in the information process and then to tie them together with appropriate regulations and contracts which assigned responsibilities. A schematic of the information flow loop for any type of Army equipment is shown in Figure 1. In this loop the command element responsible for development of all systems of a particular type is both an information collection and dissemination agency generally working closely with project managers and contractors on specific systems and with repair elements to get field experience. Project managers prepare contracts for new system development and assign responsibilities to the contractor.

Since there is no single approach, so far, to dealing with corrosion control on a wide variety of equipment, regulations allow a development command and subsequently a project manager to tighten controls, as necessary. To avoid misunderstandings, regulations also provide a statement of purpose. Developing commands and managers, in turn, provide contractors with specific guidelines.

Results

In September 1982, the U.S. Army Aviation Research and Development Command (AVRADCOM) released Aeronautical Design Standard 13C, covering general requirements for materials and processes involved in the design and construction of Army aircraft. A copy of the document is included with this paper. As noted in Figure 2 general requirements on materials and materials processes relate to Chapter 6 of the Engineering Design Handbook, Helicopter Engineering (Part Three-Qualification Assurance) while needs for engineering data are referred to the appropriate Military Handbooks for Metals, Plastics, and Structural Sandwich Composites. Most significantly, corrosion control is covered by a full appendix to ADS-13C itself.

Figure 3 shows that Appendix I to ADS-13C establishes contractual requirements for a Materiel Deterioration Prevention and Control (MADPAC) program for Army aviation weapon systems. The broader requirement on the development command is Regulation 702-24 from Headquarters U.S. Army Materiel Development and Readiness Command. A copy of this regulation is also included with this paper.

Project managers will now use ADS-13C in establishing contractual requirements for design, development and production of specific aircraft systems, thereby passing along the intent of minimizing life cycle cost due to corrosion. Figure 3 also shows that dialogue is intended between the contractor and the development command with the command having approval authority on a contractor's response to ADS-13C. A final important point in the figure is that contractual requirements are not limited to the new aircraft but are extended to cover spare parts and components.

With these two documents, responsibilities have been assigned to all principle organizations, the intent of the materiel deterioration prevention program has been established and specific guidelines on materials, processes, and practices have been publicized.

What then is required of the contractor? Figure 4 lists three basic requirements: the MADPAC Plan, a Finish Specification, and a System Technical Order for maintenance. Key parts of each requirement are also noted. It is important to note that both administrative and technical requirements are being detailed here for the contractor and that specific provision is made for the contractor and development command to work together in meeting these requirements. Thus, there is a continuing opportunity to introduce the most recent lessons learned.

It is also important to note that while corrosion prevention is the central theme of Appendix I to ADS-13C, the overall topic is materiel deterioration. There is sufficient room in these documents and their intent is to include all current and future organic base materials as well as metals.

Lessons Learned

Sufficient details on materials and materials processes are given in ADS-13C and Regulation 702-24 that they need not be repeated here. These details represent guidance to contractors based on past experience. More recent lessons learned are given in Figure 5. These lessons are similar to experiences gained by the U.S. Navy and U.S. Air Force on similar aircraft.

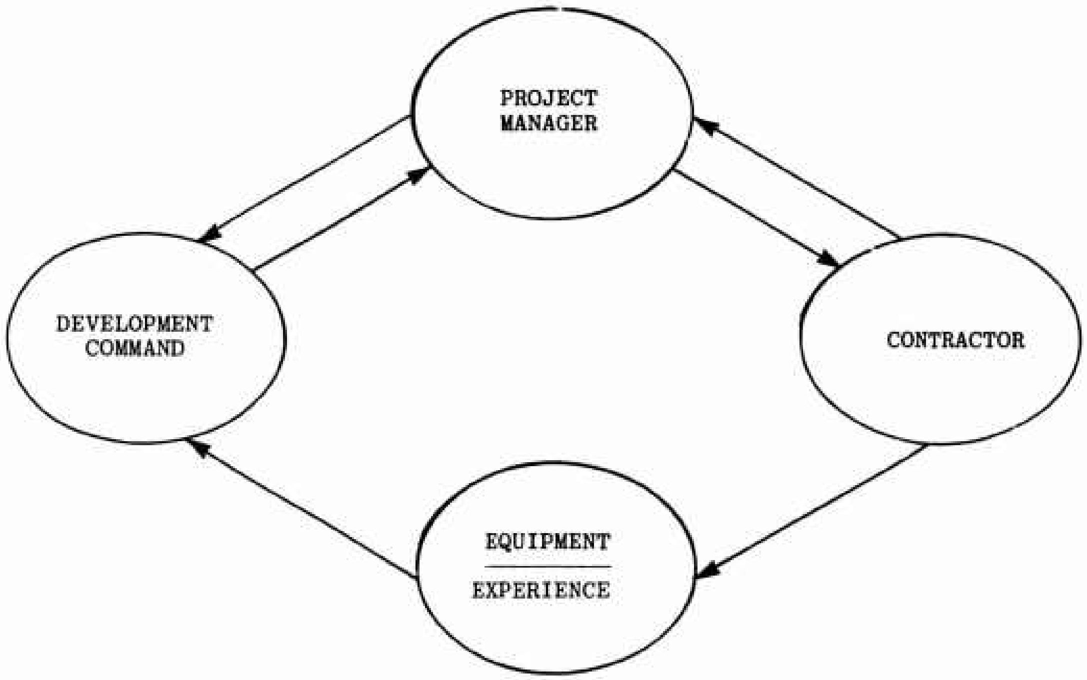

FIGURE 1

FROM
AERONAUTICAL DESIGN STANDARD
ADS-13C

- All Materials and Materials Processes in accordance with Ch. 6 of AMCP 706-203
- Materials Properties for Design Mil-Hdbk-5, -17, -23
- Corrosion Protection in accordance with Materiel Deterioration Prevention and Control Plan in Appendix I to ADS-13C

FIGURE 2

APPENDIX I TO ADS-13C

- PURPOSE: Specify contractual requirements for a Materiel Deterioration Prevention and Control Program for Army Aviation Weapon Systems.
- INTENT: Fulfill objective of minimizing Life Cycle Cost due to Corrosion.
- APPLICATION: Used in conjunction with ADS-13C by AVRADCOM and contractors in design and procurement. Includes spare parts and components.

FIGURE 3

MATERIEL DETERIORATION PREVENTION CONTRACTUAL REQUIREMENTS

I. MADPAC PLAN:

- Contractor establish Plan during Design, Development, Validation, Production
- Complete description of design efforts
- Selection of Materials and Production Processes
- Delineation of applicable finishes
- Test Program to establish effectiveness

II. PLAN INCLUDES:

- Designation of responsible organizational element
- Establishment of Materials Review effort between AVRADCOM and Contractor
- Evaluation of Manufacturing Processes and Materials Treatments

  Consider Hazards of:

  Stress Corrosion Cracking
  Hydrogen Embrittlement
  Galvanic Corrosion
  Corrosion Fatigue
  Fretting Corrosion
  Erosion Corrosion
  Pitting Corrosion
  Selective Leaching

- Review evaluation of protective finishes and coatings for specific system prior to use
- Provision for consultation between corrosion engineers and systems engineers - close liaison between Army and contractor professionals

III. FINISH SPECIFICATION:

- Prepared by Contractor in accordance with Mil-F-7179
- Referenced on drawings

IV. SYSTEM TECHNICAL ORDER:

- Explain procedures for corrosion control and maintenance
- Used by personnel in organizational intermediate and depot levels
- Prepared in accordance with Mil-M-38795

FIGURE 4

RECENT LESSONS LEARNED

- Exclude water from any interior space
- Drain all water traps and fill small cavities too small to drain properly
- Use wet assembly on all exterior fasteners
- Seal all mating surfaces
- Eliminate Nickel Plating on electrical connectors

FIGURE 5

THE INTERPRETATION OF DESIGN REQUIREMENTS FOR MULTI-MARKET HELICOPTERS

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Summary

To summarise the WHL approach to corrosion control in helicopters.

1. All drawings are vetted before issue to ensure that obvious corrosion sites, sharp edges, water traps are designed out and ~~of~~ course to obtain the most economical means of protecting components, we are after all commercially orientated and unit cost is important. A typical example of this ~~is~~ the ~~designers~~ misguided belief that the cost of the electro deposited material is significant compared with labour cost. ~~They therefore~~ believe that it is more economic to partially electroplate rather than electroplate all over the part.

2) Wherever possible apply a coat of paint before assembly.

3) Measures are taken to prevent ingress of water to joints and structures by the use of caulking materials, however, great care is taken to ensure structures are adequately drained.

1. There exists a number of design documents which cover the prevention of corrosion in aerospace applications.

For example:

AvP 970 Chap. 801 - Precautions against Corrosion and Deterioration
BCAR Sub Section G4 - Design and Construction
MIL-HDBK-132 - Protective Finishes
MIL-HDBK-721 - Corrosion and Protection of Metals
MIL-STD-1568 - Materials and Processes for corrosion protection and control in Aerospace Weapon systems.

Having examined the above documents Westland have concluded that provided we build an aircraft capable of withstanding the environment encountered by Naval helicopters then we are able to meet the requirements for multi-market helicopters. We have in fact adopted the design philosophy of AvP 970 Chap. 801. After all a helicopter hovering above the sea createsits very own salt spray test!

2. Aluminium

Chromic acid anodising to DEF. 151 Type 2 without sealing has been the preferred treatment for aluminium. Detailed parts are anodised and then painted with epoxy primer to DTD 5567 within 16 hours of anodising. Painted detail parts can be held in store which are fully protected. Rivetted assemblies are all wet assembled using either polysulphide or a polyurethane based material. Westland have used for many years a chromate leaching two part polyurethane as both a interfay and caulking material. However with the introduction of automatic drilling and rivetting techniques single part interfaying materials have shown considerable production advantages over two part materials. Being non-hardened, considerable savings in material are made, parts may be partly joined and left almost indefinitely before final rivetting. The combination of available chromate in interfay and primer in conjunction with an anodised film gives the maximum corrosion resistance to the majority of the airframe and components.

Chromate conversion coatings to DEF-STAN 03-18 are used but to a lesser extent than chromic anodising as the pretreatment prior to application of epoxy primer. We have noted from time to time adhesion failures, particularly on aircraft skins at the chromate to aluminium interface around rivets.

As well as providing excellent corrosion resistance when used in conjunction with epoxy primer chromic acid produced oxide films have been used for adhesive bonding purposes. Environmentally stable adhesive bonds have been produced using chromic acid anodising on structural parts such as aluminium rotor blades.

It would be wrong to give the impression that no corrosion problems exist with aluminium alloys on helicopters. The protection of skins and structure is satisfactorily achieved, however drilled holes are the weak points in the overall protection. We have recently seen after approximately 12 years service interlaminar corrosion in 7075-T6 alloy. Regular removal of bolts used to secure flooring had removed the protective treatment from the drilled hole, ingress of salt water had promoted corrosion from the hole, resulting in extensive corrosion of the T-sections. The use of 7075-T6 has been eliminated from new design and replaced by 7075-T73. This in service problem serves to illustrate the point that any protective scheme is only as good as the weakest point.

Components which require close tolerance dimensions and therefore cannot be protected with paint require more than the relatively thin oxide film obtained with chromic acid anodising. Service experience with the Lynx has demonstrated the considerable advantage of a dichromate sealed sulphuric acid anodised film to DEF 151 type 1 over chromic acid anodising on machined components used in undercarriage applications.

Welded tubular structures are notoriously difficult to protect internally and later comments on welded steel tubular assemblies can be read across to aluminium.

3. Magnesium

The use of magnesium is almost exclusively used at present for gearbox casing and ancillary gearbox components. The weight and fatigue properties are benefits which outweigh its susceptibility to corrosion. This susceptibility can be accepted provided certain basic design rules are followed.

Bimetallic contacts must be avoided, but when necessary must be recognised and catered for by wet assembly techniques and sacrificial coatings. Sharp edges must be eliminated and generous radii of at least 0.75 mm provided, areas which provide water traps must be eliminated.

The guide lines given in DTD 911C are the basis for the protection of magnesium. The strict sequence of protection from casting manufacturer to finished component is followed to ensure corrosion protection. Briefly this consists of:-

Cleaning after casting by fluoride anodising or chemically pickling and protecting with a chromate conversion coating and a supplementary oil. On receipt the casting is stripped of conversion coating and a fresh coating applied and the whole casting impregnated with an epoxy resin.

After machining all machined surfaces are re-chromated and painted with DTD 5567 epoxy primer.

Bimetallic contacts can occur with threaded inserts, studs, liners and bearings. Even when totally immersed in lubricating oil, it is paramount that wet assembly techniques are used. This is achieved by assembly with "wet paint", again DTD 5567 primer is used or single part chromated compounds. Mating faces must be wet assembled and sealed to prevent ingress of water by capillary action. Experience has shown the polysulphide sealant such as PR 1221-B to be most suitable for such applications.

Gearbox attachment points represent classical examples of potential corrosion sites.

There exists Bimetallic
Possible water entrappment

High risk of mechanical damage during servicing.

The need for regular inspection of these highly stressed areas has meant that an easily removable protective material was necessary which gave good corrosion resistance. The brushable material PX-28 has proved most beneficial in such applications. The thick film has resistance to mechanical damage, is non-permeable to water and can be readily removed by swabbing with kerosene. The need to be continually removing paint and re-applying has been eliminated in this instance when regular inspection is required.

Despite all the measures which are taken eventually magnesium components have to be rejected for corrosion and therefore the need to investigate alternative treatments and materials needs to continue. Composite materials have been tried and evaluated, even an adhesively bonded structure has been proposed as a gearbox casing.

4. Steel

Cadmium plating to DEF-STAN 03-19 with a supplementary chromate film and epoxy primer to DTD 5567 is the preferred scheme for non corrosion resisting steel. Steel components which can be electroplated all over cause little problems, however components with bores below 25 mm in diameter and blind bores, cannot be satisfactorily coated and a duplex treatment of cadmium and phosphating needs to be used in conjunction with epoxy primer.

Tubular steel structures have always presented difficulty in providing a satisfactory protection scheme. Too often designers have created welded assemblies totally sealed except for gas vent holes. The only means of internal protection was to attempt to introduce primer or lanolin based protectives. Latterly parts have been designed with easier access and whenever possible phosphated and then protected with a combination of paint and the waxy protective PX-28. Much as been said and written about the replacement of cadmium for environmental reasons. The ramifications of such action, whilst not affecting new design would be immense on existing designs. The suggested replacement IVD Aluminium would need to be twice as thick to give equivalent protection to cadmium this would affect the fit of parts, the fastener being a prime example.

5. Non-Metallic

Non-Metallic materials such as GRP, CFRP, Kevlar and reinforced thermoplastics are increasingly used in helicopter and fixed wing applications. Design requirements are that such parts are given an appropriate pretreatment followed by painting with an approved scheme. Because surface finishes do not match those of metallic components it has been necessary to use fillers to improve the as moulded surfaces. This has lead to unnecessary over application in an attempt to match metallic finishes. The resulting increase in weight partially negates the advantage gained in using non-metallics. Over application often leads to in-service cracking of the finish. To overcome these problems realistic standards have been set and typical components used as standards.

Galvanic corrosion between CFRP and metals is recognised as a potential problem and care is taken to have a layer of woven glass as facing on the carbon, standard techniques of sealing using polysulphide are used to prevent water reaching the bi-material contact.

CURRENT REQUIREMENTS ON SPECIFICATIONS FOR CORROSION PREVENTION

by

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SUMMARY

The SAAB-SCANIA Company has been making military aircraft for more than fourty years. Recently we have started manufacturing of civil aircraft.

We have therefore long experience in production of military aircraft. Most of those aircraft have been or are used by the Royal Air Force, some have been exported. The requirements for corrosion protection are partly based on past service experiences, partly on requirements in foreign specifications where we consider MIL-F-7179 and MIL-STD-1568 to be the leading ones.

As a subcontractor for other aircraft manufacturers, we follow their requirements with some minor changes which have been agreed between us and the manufacturer. For one aircraft, called SF 340, made by SAAB-SCANIA in cooperation with Fairchild, we have adopted a protective scheme which basicly follows IATA doc gen/2637.

2 SELECTION OF BASE MATERIALS

2.1 Aluminium

Like other aircraft manufacturers we have had problems with stress corrosion cracking and exfoliation of the 7000-series aluminium alloys. Despite that we have never used 7079 in the T6-condition but in a condition silimar to T76 giving a resistance to stress corrosion in short transverse direction of 120-150 MPa several failures have been observed. Figure 4 illustrates one example. Ten years ago forgings of 7079-T76 were replaced by 7009-T736. Plate and extrusion of 7075-T6 were completely avoided for all critical parts. No case of stress corrosion cracking has been reported since then.

Our use of the 2000-series alloys is limited to 2024 for sheet and extrusion and 2117 and 2017 for fasteners. We do not use artificial aging of 2024, mainly because of the slower fatigue crack growth in the natural aged condition. Another reason is that the main applicability is sheet with a thickness less than 3 mm. The resistance against exfoliation is fairly good for such material and there is little risk of stress corrosion cracking.

Specified materials are summarized in table 1.

2.2 Magnesium

There is now an international trend to completely avoid using magnesium alloys in aircraft constructions, see IATA doc 2637. Our current requirements do not go that far but they support the policy of MIL-STD-1568A. This policy is to avoid using magnesium in corrosion prone areas, e.g. the bilge area or in areas where the metal could be damaged by foreign objects. Magnesium parts shall also be installed in a manner that easy provide inspection and replacement. Magnesium was earlier used unrestrictively. Some cases of corrosion damages were reported, especially on aircraft in Denmark. Because of restrictive use in the latest Swedish aircraft 37 "Viggen" no corrosion failures have been reported.

Magnesium usage is limited to a cast alloy called ZE 41 A.

2.3 Low alloy steel

As shown in figure 2 there are several reports on corrosion failures of low alloy steel. The main part of them deal with rusting and pitting corrosion. In some cases this type of corrosion has resulted in serious problems:

a Wing bolts of Hy-Tuf were broken after being severely pitted. The material was changed to H-11 with substantially better resistance against pitting corrosion.

b A landing gear of a small aircraft cracked because to fatigue initiated by pitting corrosion at areas were a protective paint coating had flaked off. Recent models of these gears received a more flexible coating applied by fluidized bed.

Only a few cases of hydrogen stress cracking have been reported. One case was solved by reducing the hardness of the steel another by replacing an electrolytic process by an aprotic one.

Our policy is that it is better to temper harden to a low hardness and stress high than vice versa. No cases of HSC or SCC have been observed for steel with Rm < 1230 MPa. We also avoid using steel like Hy Tuf which corrode very easily.

2.4 Corrosion resistant steel

Our experiences and requirements may be summarized as follows:

a Stabilized austenitic steel AISI 321 and 347 is used for welded constructions. We have therefore had no problems with intercrystalline attack of welded parts.

b Corrosions has been observed in brazed assemblies. We require careful cleaning and chloride check similar to that per MIL-S-5002 to avoid this problem.

c Superficial corrosion has appeared on unprotected 400-series alloys. We intend to improve the protection.

d The 400-series alloys are not used in the 1080-1250 MPa range because of risk of intercrystalline attack.

e Custom 455 and 17-4PH and similar steel must not be used unprotected under stress in the H 900 condition if in contact with aluminium. The H 900-condition should preferably be avoided.

d Preferred materials are shown in table 1.

2.5 Titanium

Laboratory tests indicate that resistance against hot salt cracking is better for Ti6Al4V than for Ti5Al2,5 Sn, which have been used by my company for many years without any service failures. Materials lists now specify Ti6Al4V.

2.6 Composites

The service experience with graphite composites is very limited. Laboratory tests indicate that this material requires special considerations regarding absorption of humidity, galvanic compatibility with metals and thermal expansion.

3 SELECTION OF PROTECTIVE MATERIALS

3.1 Sacrificial coatings

- Cadmium coatins are expected to be used on steel fasteners in the future despite of its toxicity. The reasons for this are that no other coating gives better sacrificial protection in confined spaces, the torque characteristics make it difficult to replace cadmium, the throwing power of cadmium electroplate is slightly better than for other coatings. Bright cadmium plating is permitted for steel with Rm ≤ 1230 MPa and porous cadmium plating up to Rm = 1640 MPa. Vacuum plating is required over 1640 MPa and in special cases.

- Zinc coatings must not be used in humid environment over 60°C. To my knowledge my company is the only one who uses zinc electroplating on steel fasteners in aircraft manufacturing. There have been more reports on pitting corrosion and rusting on zinc electroplate than on cadmium. One example is shown in figure 5, which illustrates a zinc electroplated wing bolt.

- Aluminium coatings are approved as a substitute for cadmium plating in civil and future military aircraft. The aluminium coating gives better protection than cadmium in environment heavily contaminated with sulphur dioxide. The aluminium coating has also better temperature stability.

Foreign specifications now require aluminium coatings on titanium fasteners because of improved protection against galvanic corrosion. Cadmium can not be used for this application. Since we do not have any bad experience with galvanic corrosion caused by titanium fasteners we do not require this coating.

3.2 Coatings for protection against wear and fretting

- Chromium plating is used mainly on steel parts. Because of the very bad throwing power of the electrolyte, chromium is normally applied to the outer surfaces of parts having symmetrical configuration. Chromium plating reduces the fatigue strength and increases risk of hydrogen embrittlement. Grinding of plated surfaces may introduce cracks transverse to the grinding directions. These cracks, are difficult to detect with the normal NDT-methods. To get rid of these problems which are specially pronounced on high strength steel (Rm > 1230 MPa), we avoid chromium plating over sharp notches, we specify either cold working prior to plating or special high temperature baking after plating to restore the fatigue strength, we use micro cracked chromium and very long time baking to eliminate embrittling effects of hydrogen and we prefer plating to final dimension to avoid cracking caused by grinding. Special precautions similar to those outlined in MIL-STD-866A must be observed for any post grinding operation.

- Nitriding of steel can be carrid out on parts having a complex configuration. For nitriding in gas special steels are required. Nitriding in hot salt bath, tufftriding, may be performed on a much broader range of different alloys. The fatigue strength of low alloy steel is improved by tufftriding while the improvement may be insignificant for corrosion resistant steel. Selective tufftriding may be performed but the masking procedure is complicated. Unless the tufftrided surface is continuously exposed in oil surface protection is required.

- Solid film lubricants may be applied to all metal surfaces but a suitable kind of pretreatment is required in order to achieve best results. Unfortunately the lubricants and the pretreatment which provide the best antifretting properties seem to create general corrosion. Thus phosphating plus solid film lubricant results in better sliding properties than cadmium plating plus the very same lubricant but the protection against general corrosion is inferior of the phosphated surface. For our new aircraft we prescribe a heat curing lubricant per MIL-L-46010 and a room temperature curing lubricant per MIL-L-46147 for touch-up purposes.

- Teflon coatings have successfully replaced teflon tape around doors. The tape did not adhere well and peeled off in service which created fretting around doors.

3.3 Anodic coatings

We have heard about many problems with delamination in adhesively bonded structure abroad but we have had very few problems ourselves. Service performance of the bonded joints is often determined by the surface pretreatment. We have always used etching plus unsealed chromic acid anodizing while manufacturers having problems have used just etching. Anodizing is now required per MIL-A-83377B. In our civil aircraft we have introduced phosphoric acid anodizing.

In MIL-STD-1568 bonding to clad surfaces is prohibited. We have not had any serious problems with bonding to such surfaces which previously have been chromic acid anodized but we avoid cladding of surfaces prior to phosphoric acid anodizing and bonding. The philosophy is here that the chromic acid anodize acts as a more effecient barrier against "clad dissolution" than the very thin anodic coatings produced in phosphoric acid does.

To improve corrosion protection of nonclad 7000-series alloys sulphuric acid anodizing is required per MIL-STD-1568. This requirement is a little bit confusing to me because the corrosion resistance requirements for sulphuric acid anodizing and chromic acid anodizing are exactly equal in MIL-A-8625. Anyhow we have not adopted this requirement and we still use chromic acid anodizing mainly because of fatigue considerations but also because we believe that the chromic acid anodize is a better method for indicating material defects than the sulphuric acid anodize.

3.4 Paint schemes

The selection of paint scheme must be carried out with regard to erosion, effect of chemicals during service and maintenance and the need for regular inspection of the surface.

We have always used hydraulic fluids based on mineral oil and therefore avoided the paint stripping problems known to be caused by phosphate esters.

For our civil aircraft we have adopted a paint scheme on exterior surfaces which consists of a bonding primer applied in detail stage a wash primer, an inhibited primer and a polyurethane top coat. The reasons for this selection are that:

a The polyurethane top coat has outstanding gloss retention properties in UV-light and is flexible enough to suppress paint cracking around fastener heads. The paint is also fluid resistant.

b The inhibited primer will improve the corrosion protection value and suppress filiform corrosion.

c The wash primer will make it possible to strip the paint by use of non-phenolic non-corrosive paint stripping material down to the bonding primer. The wash primer is filiform corrosion resistant.

d The transparent bonding primer makes it possible to inspect the metal surface and it simplifies cleaning of the surface before repainting.

The policy has been to minimize the need for mechanical stripping which may result in unacceptable dimensional thinning of the skin material.

Internal areas are painted with inhibited primer. Adhesively bonded structure is painted with bonding primer in detail stage before application of the inhibited primer. Areas exposed to a corrosive environment also receive a polyurethane top-coat.

Primers are often pigmented with chromates to improve the corrosion protection value. However, paints are sometimes found to be loaded with pigments which have an adverse effect, se fig 6.

3.5 Adhesives

As earlier described we think that the pretreatment is very important for the environmental stability of adhesively bonded joints. Another factor is the adhesive itself. The modern epoxy adhesives seem to be more critical regarding the pretreatment than the older phenolic adhesives which have been successfully used for fourty years.

Our policy can be summarized as follows:

a Adhesives with carrier cloth of glassfibre or nylon must be avoided since such cloth permit wicking of water along the fibres.

b Nylon-epoxy adhesives shall be avoided because of high environmental susceptability.

c Room temperature curing adhesives shall be applied only to anodized and preferably primed surfaces and their use should be restricted to a minimum.

d Adhesives used for sandwish structures must be without volatile release.

3.6 Sealants

The most common sealants are based on polysulphide and are either cured by reaction with chromate or manganesedioxide. The chromate cured polysulphides have better fluid resistance than the manganese dioxide cured ones. The chromate sealants are generally preferred. In integral fuel tanks the manganese dioxide cured sealant is still preferred because of very long experience without severe problems.

For removable parts a chromate pigmented jointing compound is generally preferred. At tank doors MIL-S-8784 low adhesion sealant is used.

For wet assembly sealants are considered to be more effective than paint coatings simply because they contain very small amounts of volatile constituents. Enclosed solvents tend to form channels through the wet coating.

4 DESIGN CONSIDERATIONS

The design is a determining factor for corrosion resistance as examplified by figures 7 and 8. These figures indicate that cutting of the materials flow direction in critical areas is dangerous. The example is taken from an old aircraft not used any more. Thus the 7075 T6-material which has a stress corrosion resistant threshold value (K_{ISCC}) only 100 MPa in short transverse grain direction is not used any longer for similar applications. The current specification requires machining to be minimized after final heat treatment in non-stress relieved condition. The depth of cut over 3,8 mm should be avoided unless the material has demonstrated to have threshold value $K_{ISCC} > 175$ MPa.

In order to get adequate protection our specification requires corners and edges on metals used in exterior locations or corrosion prone areas to be broken prior to protection. This requirement also applies to metals prior to shot peening.

Designated items made of forgings and plate are protected as follows:

- Cold working by shot peening or blasting and sleeve cold working in holes.
- Polishing of critical radii.
- Chromic acid anodizing using a process with good reproducibility and painting.
- Installation of interference fit bushings using a solid film lubricant.

The minimum distance between edge and hole is of course very carefully specified as well as actions which must be taken against any undercutting of a radius.

The design should permit free drainage especially inside the outer skin and in the ventilation system where considerable condensation takes place. Provisions should be made for adequately sized drainage paths. Contact between porous materials and metals must be avoided. Thus, it is important that e.g. insulating blankets are not installed taut and wrapped around stringers or in contact with the skin. Figure 9 illustrates corrosion of metal part after being in contact with a porous material.

All faying surfaces in exterior locations and corrosion prone areas must be sealed unless not adhesively bonded. Special consideration is required for contact between dissimilar materials. Figure 10 illustrates a door exposed in a severe marine environment. The main reason why this door has failed is the choice of the material. Interesting is also to observe the design with drilled countersunk holes at places for fastener installation. Within such countersunk holes the short transverse grain direction of the basis material become uncovered and corrosive fluid entrapped. Such design is unacceptable near critical radii of machined forgings and plates.

Magnesium castings are protected by surface sealing with a stoved epoxy resin prior to painting. Whenever possible we apply this resin even to tolerance surfaces in order to avoid direct metal-to-metal contact. By extensive use of wet assembly practice, aluminium washers and sacrificial coatings on dissimilar metal to be installed we protect magnesium from galvanic corrosion. The rather new carbon fibre composite material poses new potential risks of galvanic effects especially for fasteners installed perpendicular to the fibre direction. Metal fasteners of titanum or corrosion resistant steels ought to be used in these cases. In adhesively bonded structures the adhesive itself may be used as a barrier between carbon fibre composite and metal provided the glue line is free from penetrating pores. In areas where galvanic corrosion may occur attention should be paid to the fact that it is better to arrange for drainage from the less nobel metal to the more nobel one than reverse and that the anode area should be large relative to the cathode area.

In highly corrosive areas such as under the lavatory the use of plastic materials, corrosion resistant steel or titanium should be considered and the area enclosed from other structure. Areas highly susceptible to corrosion should also be easily accessible to permit cleaning and inspection.

For metal sandwich structure it is important to restrict transportation of humidity within the panel. The core material should therefore be of the non-perforated type and the adhesive consequently of the non-volatile type. All edges and holes must be adequately sealed. Figure 11 shows a rudder damaged by corrosion due to humidity which had penetreted the construction through an insufficiently sealed small hole. Adequate sealing of holes is of utmost importance for sandwich constructions. Figure 12 illustrates a design with minimum risk of humidity ingress.

Special protection is required in some area such as the integral fuel tank and the bilge area. Severe pitting and exfoliation corrosion caused by fungus has been reported in aircraft operating in tropic countries. The damages have appeared within a period of a few months. The use of additions to the fuel in order to suppress the fungi growth has been considered insufficient as a single mean of avoiding the corrosion. The integral fuel tanks are therefore protected by a fungi resistant coating per MIL-C-27725 in our civil aircraft. Our military aircraft are not protected by this coating since we have had no problem with fungi in the fuel tanks of aircraft operating in Scandinavia. According to the IATA recommendation and other information we have got the use of an additional protective oil on top of the paint coatings has been very effective in reducing maintenance cost for corrosion. We therefore require application of such an oil in corrosion prone areas taking into consideration all risk of fatigue strength reduction, risk of fire, compatibility with rubber seals and inspectibility.

5 MANUFACTURING CONSIDERATIONS

Speidel reported 1976 that the main reasons for stress corrosion cracking of aluminium alloys are residual stresses from heat treatment and assembly stresses (1). Thus the cooling rate from solution temperature is a determining factor for residual stresses and forgings. Lack of proper shimming can result in stresses as high as 350 Mpa. We think that the problem of stress corrosion cracking now is under control by the use of new materials in suitable tempers and by application of specific rules for heat treatment, machining, forming, joggling and swaging operations.
Proper control of machining operation is essential. Excessive heat may result in untempered martensite on steel surfaces. This surface layer is very brittle and is extremely likely to crack. The defect is discovered by temper etch inspection. Machining of radii is another important factor. Unsuitable machining may result in stress raisers. The cutting fluid must not produce serious corrosion damages as exemplified in figure 13.

Our specifications require closely defined parameters through all stages of surface treatment of designated items and adhesively bonded parts. To meet these requirements we have installed a fully automated line for pretreatment prior to adhesive bonding which gives adequate guarantee for reproducible times of treatment and voltage cycle during anodizing and also eliminates all handling of parts prior to application of bonding primer. Contamination of surfaces is a problem which may cause e.g. bond delamination, bad adhesion of sealants and protective paint coatings. Our specifications require several actions to eliminate these problems such as adequate short time intervals between different operations, adequate time for adhesive film to attain room temperature prior to application, approved release agents and other materials used for manufacturing and storage and handling within controlled contamination area. Rigid control of the vacuum pressure during adhesive bonding of sandwich structure to avoid entrapment of air and subsequent node bond failure is another requirement which is important for the corrosion resistance of manufactured parts. Another factor is proper back up during mechanical operations such as trimming and drilling. Removal of adhesive bleedout should be limited to a minimum.

In order to get proper protection of fay surface sealing our specification require application of sealant to both mating surfaces before assembly. In order to check that the sealant fills the space between the faying surfaces adequate volume of sealant must be applied so that the material forces its way out and forms a fillet along all edges after assembly. It is important not to clog drainage paths with sealant.

Another problem of importance is mechanical damages of protective coatings during assembly operations, see figure 14.

6 REFERENCE

1) Speidel Metallurgical Transactions, 6A April 1976, pp 631 - 651.

TABLE 1. SELECTION OF BASE MATERIALS

FORM	ALUMINIUM	TITANIUM	LOW ALLOY STEEL	CRES STEEL	MAGNESIUM
FORGING	7010-T736, 7050-T73652 7175-T736-T73652	Ti-6Al-4V	4130 4330 M VAR	17-4 PH H1100 H1025 A 286	
EXTRUSION	2024-T42-T3511 7075-T76-T76511 7075-T73-T73511	Ti-6Al-4V Ti 50 A			
PLATE	7475-T7351-T761-T7651 7010-T736-T73651 7050-T73652		4130		
SHEET	2024-T3-T4	Ti-6Al-4V	4130	321, 347 Ann	
CASTING	A356-T6				ZE 41 A
FASTENER	5056-H32, 2117-T4, 2017-T4	Ti-6Al-4V	30 NCD 16, 4340 H-11 Mod, 4140	Custom 455, PH 13-8 Mo A 286	
TUBING	6061-T4-T6	Ti-3-2,5 Ann CW/SR			

REPRESENTATION

- DESIGN
- STRESS
- MANUFACTURING
- QUALITY ASS.
- MATERIALS LAB
- MAINTENANCE
- DESIGN REVIEWER

REVIEW TASKS

- CONTROL COMPLIANCE FAR/JAR 25.609.
- REVIEW IATA GUIDANCE MATERIAL
- REVIEW USERS' INFORMATION
- REVIEW SAAB SPECIFICATIONS
- REVIEW APPLICATIONS
- REVIEW MAINTENANCE PLANS
- INSPECT HARDWARE
- SUGGEST IMPROVEMENTS
- INITIATE ADDITIONAL TESTING
- COORDINATION WITH FRC

Figure 1. SF340 Corrosion Protection Review Board, SAAB

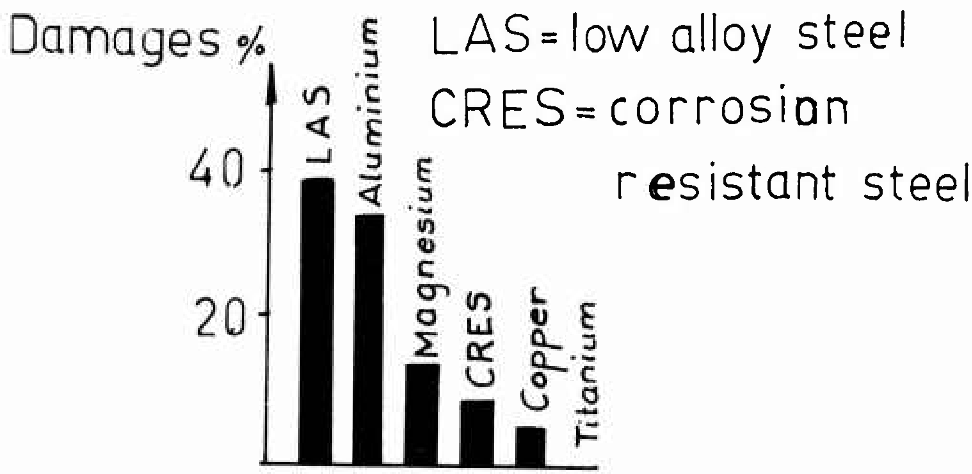

Figure 2. Eighty reports on corrosion damages distributed on different metals

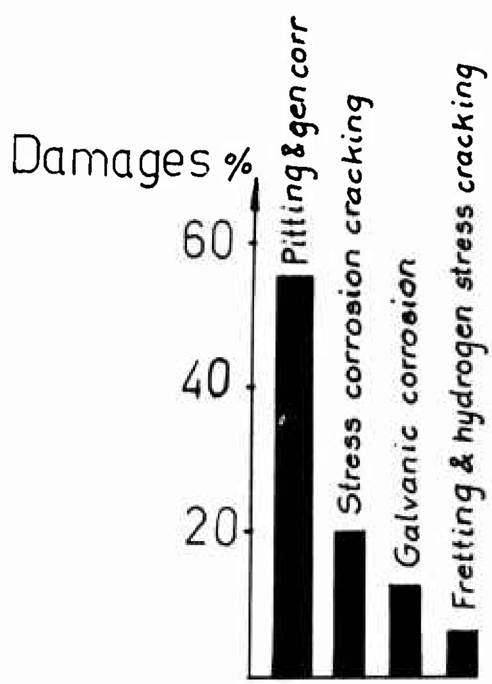

Figure 3. Eighty reports on corrosion distributed on different types of corrosion

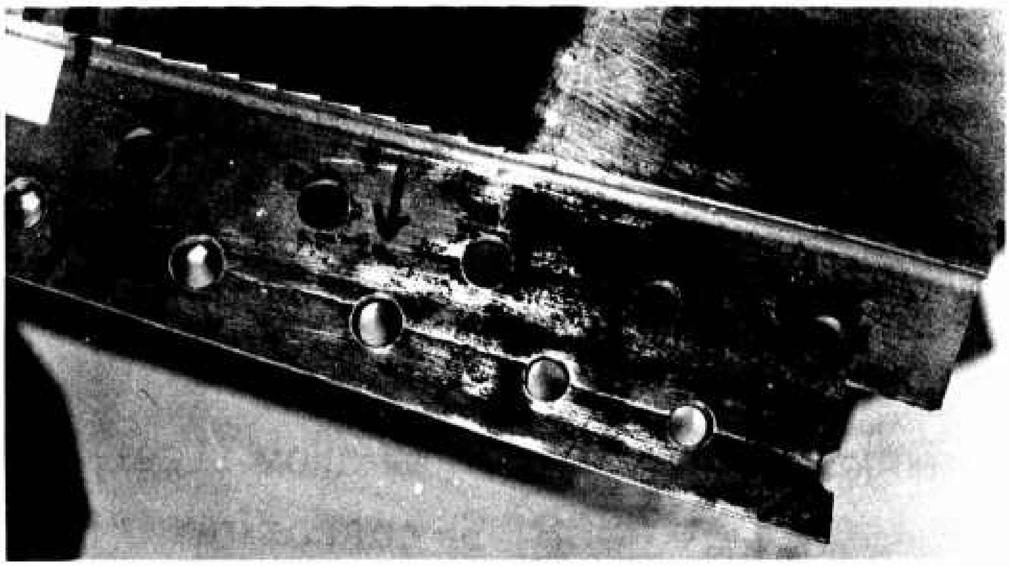

Figure 4. SCC of 7079 T 76 forging

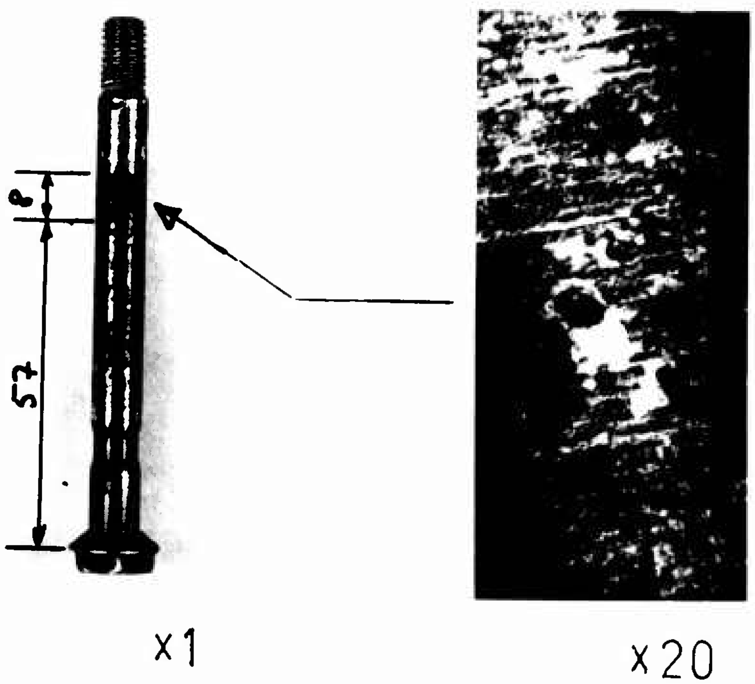

Figure 5. Pitting corrosion of a zinc electroplated wing bolt

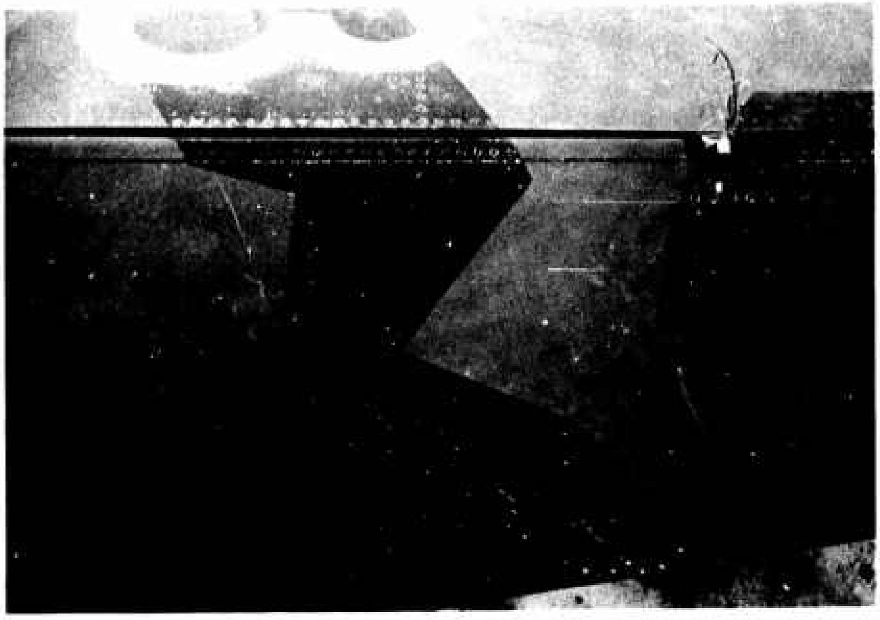

Figure 6. Corrosion of black painted areas

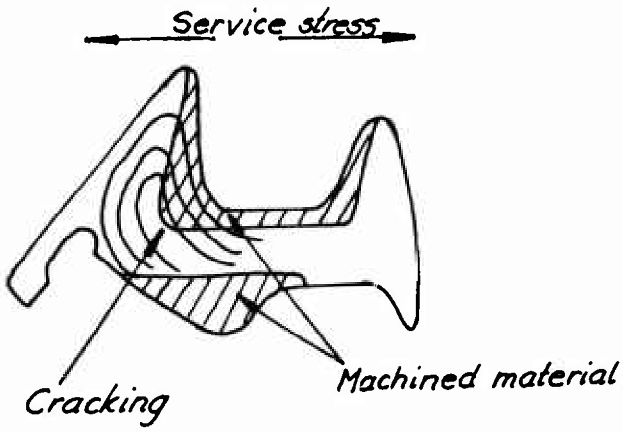

Figure 7. 7075 T 6 extrusion which failed through SCC

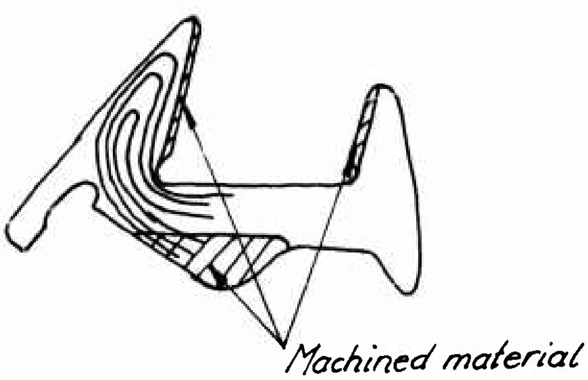

Figure 8. Improved design

Figure 9. Corrosion of a metal surface which had been exposed to a porous moistured material

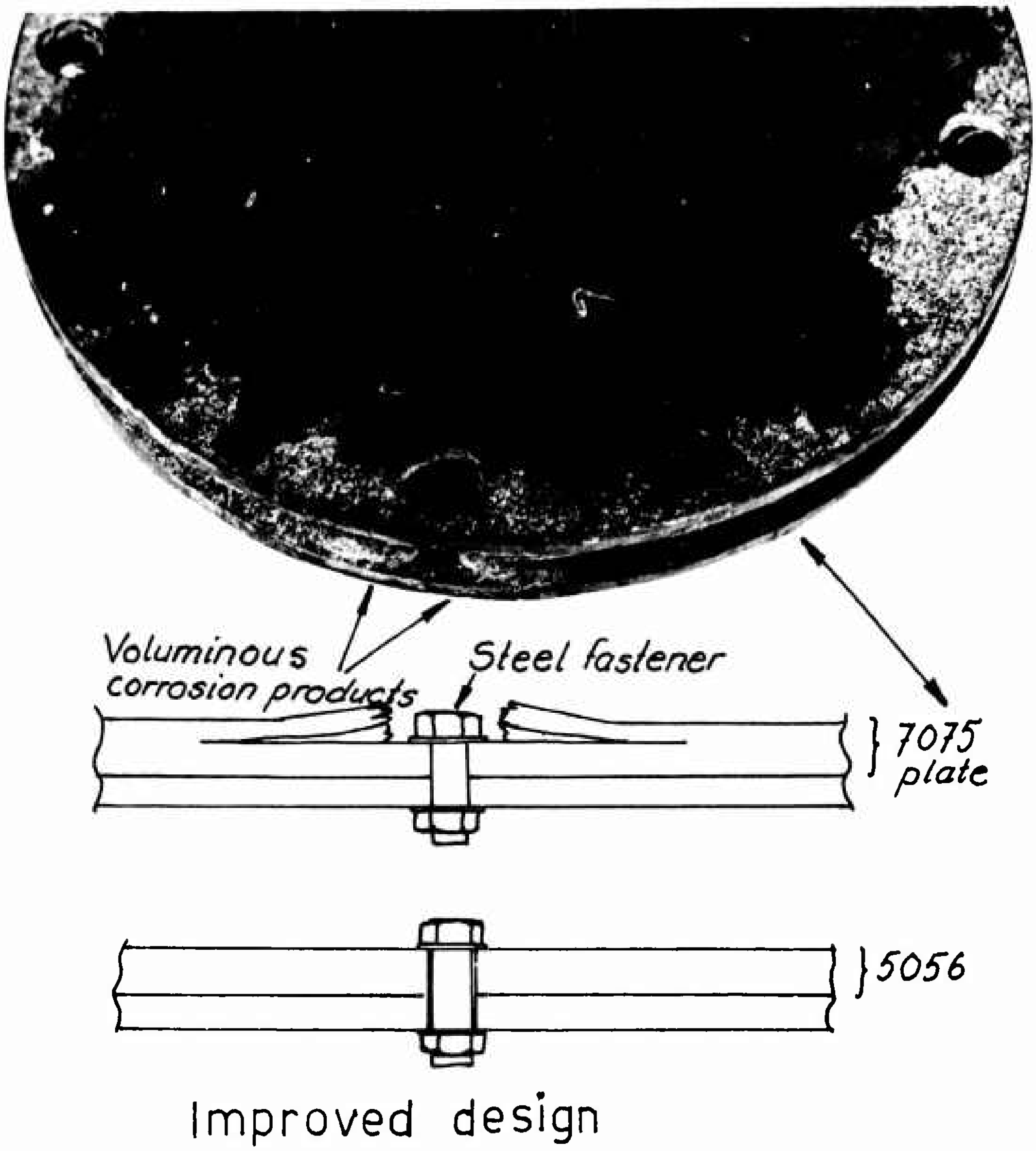

Figure 10. Severe exfoliation of a door exposed to marine atmosphere

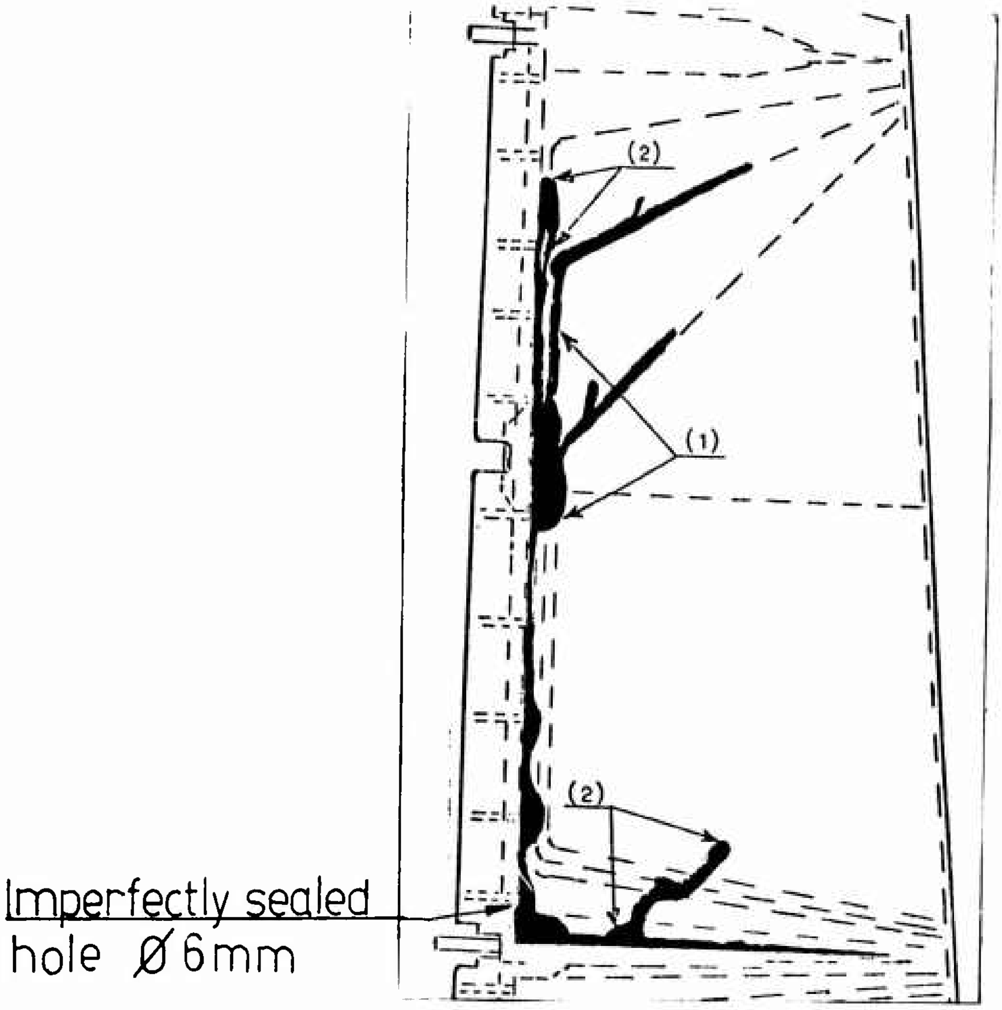

Figure 11. Corroded wing flap. Corroded sandwich area marked in black

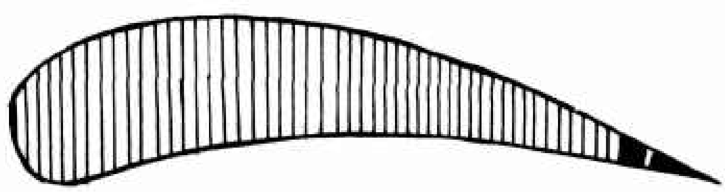

Figure 12. Cross section of a honeycomb construction of suitable design

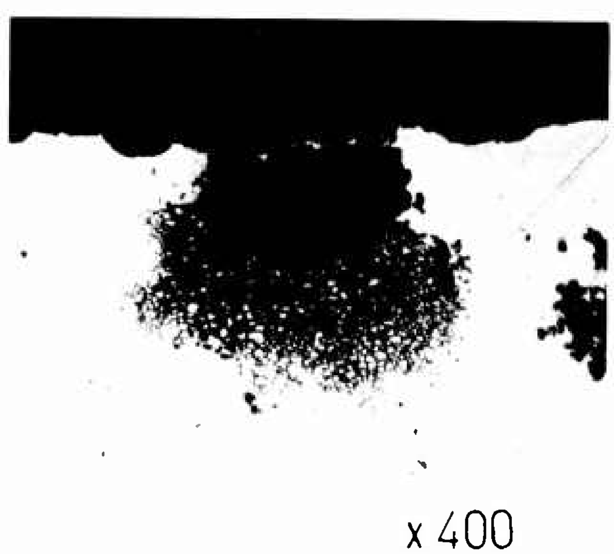

Figure 13. Cross section of a chromic acid anodized forging on an area which

Figure 14. Corrosion of a magnesium casting caused by mechanical damage

U. S. NAVY CORROSION CONTROL MAINTENANCE
by

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The presentation will describe the U. S. Navy Aircraft Corrosion Prevention/Control Maintenance Program.

Identify program elements, present maintenance practices, maintenance control procedures and corrective actions from discovery, resolution and documentation.

Discuss a system of checks and balances which are accomplished through a material condition audit program that assesses the quality of information provided for use by mechanics and the ability of the aircraft operator to maintain the aircraft. The training for personnel involved in the program will also be discussed.

Note: A sample of a detailed Corrosion Control Directive that can be modified to fit any nation's program is provided along with a Basic Corrosion Training Outline.

1. The U. S. Navy has established a program to control corrosion maintenance on naval aircraft which has been very successful. This program is designed to be flexible and grow with need, and is basically controlled by a joint effort of Commander, Naval Air Systems Command and Commander, Naval Air Force, U. S. Atlantic and Pacific Fleets, with technical support provided by the Naval Air Development Center. Program elements are:

a. Command attention;

b. Establishment of training and skill qualification requirements for mechanics;

c. Action to be accomplished at each maintenance level is defined by maintenance/engineering directives;

d. The goals of the program are spelled out in detail;

e. Calendar corrosion corrective intervals are established for each type/model/series (TMS) aircraft by the Fleet Air Force Commanders;

f. Prevention of corrosion is emphasized over corrosion correction;

g. A system of documentation of corrosion maintenance is established;

h. The program and technical manuals are continually updated to reflect the requirement and state-of-the-art procedures to be employed;

i. And last, but not least, a system of checks and balances is provided by the Aircraft Material Audit Program.

The above elements have been incorporated into program directives and technical manuals and implemented in the U. S. Navy.

2. Maintenance in practice, the program functions as follows: Each TMS aircraft has a corrosion corrective interval assigned; it also has an inspection and prevention interval, i.e., 7/14/28/42/56 days, varying with aircraft type and environment, as aircraft corrosion is not flight hour sensitive. Many nations including our FAA base all maintenance on flight hours.

a. The Maintenance Control Coordinator issues a work order to the responsible work center to inspect and apply corrosion prevention in accordance with technical manuals, i.e., application or reapplication of lubricants and corrosion prevention compounds to designated areas of the aircraft as part of the inspection. This action normally occurs at 7 and 14 day intervals.

b. If a corrosion discrepancy is noted during the above inspection, a work order is filled out and remains pending against the aircraft inspected until the aircraft is inducted for corrosion corrective maintenance interval at 28/42/56 days, depending on TMS established interval. When the aircraft is inducted for corrosion correction, all work orders posted against the aircraft are issued to the corrosion work center for corrective action. The work center is normally manned by two or three airframe mechanics, one avionics mechanic and an armament equipment mechanic. In most cases, all discrepancies are cleared in a normal 8-hour day or less. All manhours expended are documented. Work accomplished is provided in narrative form on the Maintenance Action Form and returned to the Maintenance Control Coordinator.

c. Corrosion corrective maintenance is conducted in accordance with technical manuals by trained mechanics and is described in reference (1). When corrosion is discovered that is determined to be beyond the maintenance level capability to correct, assistance is requested from the next higher level of maintenance.

3. Checks and balances are accomplished through a material condition audit program in conjunction with the above described corrosion prevention/control program audits. The program is explained in reference (1).

4. Training for officers should consist of a corrosion familiarization presentation provided by a military officer or civilian engineer employed by the military. Enlisted training should be provided by the military training establishment and include:

a. Introduction to corrosion: Safety; cost

b. Corrosion theory

c. Instruction for corrosion control (ref AGARD Handbook)

d. Preventive maintenance (ref AGARD Handbook)

e. Corrective maintenance (ref AGARD Handbook)

f. Refinishing and paint touchup procedure

g. Aircraft cleaning

h. Emergency procedures

5. The above programs and training are established to control corrosion maintenance of U. S. naval aircraft at sea and ashore and can be adjusted to fit into any military activity of any nation, with modification to fit the nation's military establishment. Provided is a sample draft of a corrosion prevention/control directive that can be used to organize a corrosion control program and basic corrosion training elements.

U. S. Navy
Lessons Learned

1. In summary, many aircraft maintenance schedules are based on flight hours.

2. Corrosion is not flight hour sensitive.

3. Corrosion maintenance must be established on a calendar basis.

4. Command attention is required at all levels to have a successful corrosion prevention/control program.

5. Corrosion prevention must be stressed over corrosion correction.

6. Corrosion prevention/control program must be established and must have some flexibility, controlled by the Commander to meet operational requirements.

7. In order to transfer knowledge contained in technical manuals to a practical application by a mechanic, a training program must be established to ensure the transfer.

Reference (1) contained in AGARD Proceeding 315 G. T. Browne

S A M P L E

Subj: Aircraft, Avionic, Armament and Support Equipment Corrosion Prevention and Control Program

Ref: (a) Technical Manual Aircraft Corrosion Control, AGARD Handbook, Vol --

Encl: (1) Aircraft Corrosion Corrective Maintenance Intervals
(2) Emergency Reclamation Program
(3) Training Programs

1. Purpose. To establish and provide an effective aircraft, avionic armament and support equipment corrosion prevention/control program at applicable echelons of maintenance.

2. Information. Reference (a) provides procedures and direction for the conduct of corrosion prevention and control of aircraft and related equipment. This handbook extends the foregoing directives to include all aeronautical material, including avionic, armament equipment and support equipment, thereby establishing an all-encompassing comprehensive corrosion prevention and control program. "Support equipment," as referred to in this handbook, includes all common/peculiar support equipment and special support equipment utilized in direct or indirect support of commands' aircraft; i.e., special tools, forklifts, fire trucks, crash cranes, weapons handling equipment, engine stands, tie down chains, tow tractors, lifting slings, hydraulic test stands, avionic test/check equipment, preoilers, servicing equipment, nondestructive test equipment, tow bars and other like equipment.

3. Discussion

a. The prevention and control of corrosion on aircraft and related equipment is a command responsibility. Maintaining aircraft and equipment in a high state of mission capability requires that each activity involved establish effective corrosion prevention and control programs to encompass all facets of maintenance. Established programs must be continually assessed for adequacy/effectiveness and adjustments made to increase or decrease program requirements based on the operational environment each activity is experiencing.

b. Each command must place special emphasis on the importance of the Corrosion Prevention/Control Program and lend full support to ensure corrosion prevention and control receives adequate priority for timely accomplishment along with other required maintenance. To prevent excessive out-of-service time, serious damage to aircraft and related equipment, corrosion must be discovered and corrected at its earliest stages of development. Knowledgeable personnel, capable of detecting and correcting corrosion discrepancies, must be available and utilized in every line and shop maintenance activity. Formal training in corrosion prevention and control is a necessity for those maintenance personnel actually performing corrosion arrestment and removal. In-service training for other maintenance personnel to qualify them in corrosion recognition must be accomplished on a continuing basis to ensure that all work center/shop supervisory/ production personnel are capable of detecting corrosion during component processing or inspections prescribed by applicable maintenance instructions/manuals.

c. Corrosion of installed equipments/components, internal corrosion of airframes and support equipment enclosures are often difficult to detect. Normally, the inspection criteria and assigned inspection intervals for these areas is less than those for external inspections; therefore, identifying and correcting corrosion in these areas requires the services of highly trained and motivated personnel. In contrast, corrosion on the exterior of aircraft and equipment is easily detected through visual means and prescribed periodic inspections. Flight and ground crew personnel trained in corrosion recognition will be capable of detecting and reporting external corrosion on a day-to-day basis. Establishment of corrosion control teams, with responsibilities to detect and correct corrosion has, at times, resulted in apathy for reporting corrosion on the part of personnel not assigned to corrosion team billets. This has resulted in most corrosion being detected/reported during scheduled corrosion inspections rather than on a day-to-day basis and has, on occasion, allowed minor corrosion to develop into a major corrosion problem.

d. The corrosion prevention and control program, as set forth in this directive, is designed to incorporate command, middle management, maintenance and flight crew personnel participation. Corrosion recognition and reporting discovered corrosion to Maintenance Control is an "all hands"/everyone's responsibility. The evaluation, removal, arrestment and treatment of corrosion shall be accomplished or supervised by qualified personnel assigned to the squadron's corrosion prevention/control work center, shop maintenance activity's production work centers/avionic armament equipment corrosion work center shops or the activity's corrosion prevention/control coordinator. To achieve and retain an effective program, in-service training and formal schools are to be utilized to ensure that maximum numbers of personnel are capable of detecting, identifying and reporting various forms of corrosion.

4. Action. Activities responsible for aircraft, support equipment, armament equipment and component maintenance under the cognizance of Commander are directed to establish effective programs for the prevention and control of corrosion in connection with day-to-day maintenance as follows:

a. Aircraft Reporting Custodians. Minimum aircraft corrosion corrective maintenance intervals are established in enclosure (1) of this directive. Enclosure (1) is provided to ensure that reported corrosion discrepancies are corrected prior to, but no later than the established interval for each aircraft. Each reporting custodian shall ensure that discovered/reported corrosion discrepancies are corrected prior to the expiration date of established corrective maintenance intervals. Once aircraft are inducted for corrective maintenance, all corrosion discrepancies shall be corrected before aircraft are returned to ready for flight status. Emergency reclamation teams shall be established in accordance with enclosure (2) and reference (a). Corrosion prevention/control program training requirements shall be accomplished in accordance with enclosure (3). Aircraft exposed to fire extinguishing agents or large quantities of saltwater shall be reported.

b. Wing Commanders

(1) Coordinate and monitor corrosion prevention/control and emergency reclamation programs in accordance with this handbook and technical manuals.

(2) Assess the adequacy and effectiveness of subordinate activities' corrosion prevention/control and emergency reclamation programs during command and aircraft material condition inspections.

(3) Ensure that supporting activities maintain adequate stocks of authorized corrosion prevention/control materials.

(4) Continually assess adequacy of supporting activities' facilities and support equipment.

(5) Develop standardized aircraft corrosion prevention/control folders, including aircraft silhouette sheets, for subordinate activities.

c. Ships/Deployed/Commanding Officers

(1) Provide facilities, support equipment, spaces, authorized materials, low pressure air outlets and as much fresh water as operational commitments permit to enhance the successful execution of the embarked air wing, group, squadron or detachment corrosion prevention/control and emergency reclamation programs.

(2) Maintain stock levels of aircraft and support equipment corrosion prevention/control materials consistent with usage or in the absence of usage data, as recommended by the embarked deployed air wing, group, squadron commander or detachment officer in charge. In addition, ensure materials have adequate remaining shelf life prior to stockage or issue.

(3) Ensure compliance with established support equipment corrosion prevention/control maintenance intervals and develop local maintenance requirement directives for equipment that has not been assigned corrosion maintenance criteria or induction interval

d. Stations Commanding Officers

(1) Provide necessary support equipment and facilities for supported activities to conduct an effective corrosion prevention/control and emergency reclamation program; this includes low pressure air and adequate aircraft cleaning facilities.

(2) Ensure compliance with established support equipment and armament equipment corrosion prevention/control maintenance intervals and develop local maintenance requirement directives for equipment that has not been assigned corrosion maintenance criteria or induction interval(s).

(3) Maintain sufficient stocks of authorized aircraft cleaning and corrosion prevention/control materials outlined in reference (a), with adequate remaining shelf life.

e. Commanders of Deployed Units

(1) When deployed, shall be responsible for the coordination and effectiveness of subordinate activities' corrosion prevention/control programs. Special interest shall be placed on aircraft cleaning and judicious use of corrosion preventive materials.

(2) Conduct periodic corrosion prevention/control program spot checks on assigned activities.

(3) Periodically review assigned activities' corrosion prevention/control material stock status and materials remaining shelf life; supporting supply activity assistance as required.

(4) Ensure assigned activities' compliance with enclosures (1) through (3) of this handbook for applicable aircraft.

(5) Manage a corrosion prevention/control material retail issue outlet to ensure equitable distribution of available corrosion prevention/control materials.

f. Squadron Maintenance Activities

(1) The aircraft Division/shops etc officer in charge shall normally be assigned as the corrosion prevention/control officer. However, in activities staffed with sufficient officers, a corrosion prevention/control branch officer may be assigned to the Aircraft Division/shop etc Division. In either case, the officer shall complete the Aircraft Corrosion Prevention/Control training course.

(a) Supervising and coordinating the activity's aircraft, avionic armament equipment and support equipment corrosion prevention/control program.

(b) Ensuring that corrosion prevention/control trained personnel are available in all work centers.

(c) Developing and maintaining squadron instructions/directives or maintenance instructions that outline the activity's corrosion prevention/control, emergency reclamation and reporting aircraft exposed to fire extinguishing agents or large quantities of saltwater programs; other corrosive agents these directives shall assign responsibilities to applicable work centers and establish procedures for the management of each program.

(d) Developing activity's work center/shop corrosion prevention/control and emergency reclamation team training programs.

(e) Providing in-service training to all work centers/shop for corrosion prevention, detection and reporting procedures.

(f) Ensuring that authorized corrosion prevention/control materials, technical publications, directives and equipment are available and that only approved procedures, materials and equipment are utilized.

(g) Reporting defective corrosion prevention/control materials received from supply in accordance with reference (a), when applicable.

(h) Submitting Quality Deficiency Reports in accordance with reference directive.

(i) Ensuring proper corrosion prevention/control documentation in accordance with reference directive.

(j) Ensuring that corrosion prevention/control folders are maintained for each assigned aircraft.

(k) Providing technical advice and rendering assistance to all work centers in matters pertaining to corrosion.

(l) Maintaining a current list of activity's personnel that have completed corrosion prevention/control courses.

(m) Conducting personal inspections of aircraft, avionic equipment, armament equipment (as applicable) and support equipment at frequencies necessary to determine corrosion prevention/control program effectiveness.

(n) Ensuring aircraft/engine preservation procedures are accomplished in accordance with reference directives.

(o) In coordination with division and branch/shop officers, prepare and implement local corrosion maintenance requirement directives applicable to each work center. Frequency of inspections will be determined on the basis of enabling maintenance personnel to detect corrosion in its early stages. Operational environments, the frequency of recurring corrosion, and frequency of visibility of the component/area shall be a prime consideration during maintenance requirement directives. Aircraft without specified corrosion corrective maintenance intervals established in enclosure (1) shall be inspected each 14 days afloat and each 28 days ashore pending Commander's determination of adequate interval(s).

(2) Activities assigned seven or more aircraft shall establish and maintain a permanent corrosion prevention/control work center. To ensure that adequate corrosion prevention/control trained personnel are assigned and utilized within command activities, minimum work center personnel manning is directed as follows:

(a) Work center supervisor - one aviation structural mechanic that has successfully completed aircraft corrosion prevention/control training. The work center supervisor shall be assigned duties as the activity's corrosion prevention/control coordinator and assistant to the aircraft division or corrosion prevention/control branch officer as applicable.

(b) Two aviation structural mechanics rating that have successfully completed aircraft corrosion training course; one shall be a qualified aircraft painter.

(c) One aviation avionics technician rating that is corrosion prevention/control aircraft or avionic equipment corrosion control trained.

(d) One aviation power plant technician rating that is corrosion prevention/control aircraft corrosion control trained.

(e) One aviation armament equipment technician rating that is corrosion prevention/control aircraft corrosion control trained; applies only to activities possessing armament equipment.

(f) Corrosion prevention/control work center augmentation personnel - power plants, airframes, hydraulics, aviators equipment, electronics, electrical/instrument, armament, plane captain, crew chief shops and flight engineer branch maintenance work centers shall have two corrosion prevention/control aircraft or avionic equipment trained augmentation personnel available to the corrosion prevention/control work center. Augment personnel shall be utilized, as required, to ensure that aircraft are thoroughly inspected by knowledgeable personnel during scheduled/unscheduled corrosion inspections. Utilization of the foregoing personnel's services shall be coordinated between the corrosion prevention/control work center supervisor, applicable work center supervisor and Maintenance Control.

(g) Additional personnel - Paragraphs 5f(2)(a) through (f) establish corrosion prevention/control work center minimum personnel manning requirements. However, additional permanent/augmentation personnel may be assigned, as desired, to enhance each activity's corrosion prevention/control program or to support deploying detachments.

(3) Activities assigned two through six aircraft (ashore or afloat) shall designate one aviation structural mechanic rating or above, aircraft corrosion prevention/control trained, as the activity's corrosion prevention/control program coordinator. The

aforementioned program coordinator may be assigned to the activity's airframes work center (or the equivalent) or a separate corrosion prevention/control work center may be established. Additional minimum personnel manning requirements are as follows:

(a) One aviation structural mechanic rating that is a qualified aircraft painter; assigned to airframe work center or corrosion prevention/control work center as applicable.

(b) Augmentation personnel from work centers outlined in paragraph 5f(2)(f); however, one individual is required at each center vice two.

(c) Additional personnel - As outlined in paragraph 5f(2)(g) above.

(4) Activities assigned one aircraft or single aircraft detachments shall designate, as a minimum, one rated aviation structural mechanic, corrosion prevention/control aircraft trained that is also a qualified aircraft painter, as the activity's corrosion prevention/control program coordinator.

(5) Division and branch officers shall:

(a) Coordinate corrosion prevention/control training with the aircraft division or corrosion prevention/control officer. Emphasis shall be placed on authorized aircraft cleaning and judicious use of corrosion preventive materials outlined in reference (a).

(b) Ensure that trained personnel are utilized during the conduct of corrosion maintenance actions and maintenance inspections. Moreover, ensure that QDRs or discrepant material reports are submitted in accordance with reference (a) when applicable.

(c) The flight line division officer shall be responsible for aircraft cleanliness, operational preservation and day-to-day reporting of paint failure or corrosion. The foregoing responsibilities shall be accomplished by ensuring that plane captains, crew chiefs and flight engineers receive corrosion prevention/control training.

(d) The Quality Assurance (QA) Division shall provide local checks and balances:

<u>1</u> Monitor activity's aircraft, avionic equipment, armament equipment (as applicable) and support equipment corrosion prevention/control program to ensure compliance with applicable directives.

<u>2</u> Ensure that all corrosion prevention/control technical publications and other applicable correspondence are current and available.

<u>3</u> Ensure that only authorized procedures for aircraft/avionic equipment cleaning and corrosion treatments are utilized.

<u>4</u> Ensure that only authorized and current shelf life corrosion materials are utilized.

<u>5</u> Continually review incoming corrosion Quality Deficiency Reports and discrepant material reports to ensure that timely corrective action is taken.

<u>6</u> Conduct corrosion prevention/control program quarterly audits and ensure that corrective action is accomplished by divisions and work centers.

<u>7</u> Ensure that the activity's corrosion prevention/control program collateral duty inspector's (CDI) test is adequate and current.

<u>8</u> Monitor activity's aircraft/engine preservation procedures and ensure compliance with established maintenance directives or references as applicable.

<u>9</u> Monitor activity's packaging and preservation procedures.

<u>10</u> Ensure that one rating or above aircraft corrosion prevention/control trained quality assurance representative is assigned to the QA division in activities assigned seven or more aircraft.

<u>11</u> Ensure that one rating or above aircraft corrosion prevention/control trained quality assurance representative is assigned to the QA division in activities assigned two through six aircraft.

(e) Documentation

g. <u>Aircraft Shop Maintenance Activities</u>

(1) Aircraft intermediate maintenance activities shall develop and maintain local corrosion maintenance requirement or maintenance directives for each item of assigned support equipment not previously provided with MRCs or maintenance directives or same technical data outlining corrosion prevention/control inspection frequencies and/or maintenance actions required.

(2) Establish a corrosion prevention/control program for avionic equipment. Aircraft shop maintenance activities airframes division or general maintenance shops division officers were, in the past, assigned responsibilities for implementing and maintaining their activity's overall corrosion prevention/control program. However, the complexity of currently utilized avionic equipment mandates that officers and senior enlisted personnel with avionic equipment training/management backgrounds be assigned responsibilities for implementing and maintaining aircraft shop maintenance activities avionic equipment corrosion prevention/control programs. Therefore, the Airframes shop division or General Maintenance shop division and Avionic Equipment Shop Division Officer shall be assigned responsibilities for implementing/maintaining corrosion prevention/control programs in accordance with reference (a) as applicable (each directly responsible to the aircraft intermediate maintenance activity maintenance officer for the management of their assigned programs). The Airframes Shop Division or General Shop Maintenance Division Officer, Avionic Armament Shop Equipment Division Officer and Support Equipment Shop Division Officer (if designated) shall be assigned as the activity's corrosion prevention/control program officers as applicable. They shall attend the aircraft/avionic equipment/support equipment corrosion prevention/control course, or the equivalent, as applicable. Their duties shall include, but not be limited to:

(a) Developing and maintaining a current activity instruction or maintenance instruction outlining the activity's overall corrosion prevention/control and reclamation programs.

(b) Supervising and coordinating the activity's corrosion prevention/control program.

(c) Ensuring that corrosion prevention and control trained personnel are available in all production work centers.

(d) Developing and maintaining equipment and personnel expertise within the shops to provide corrosion repair assistance to supported activities when skills, tools or equipment are not authorized for aircraft shop maintenance activities.

(e) Developing and maintaining personnel expertise and equipment necessary to ensure rapid corrosion treatment/control for components inducted into shops for emergency reclamation.

(f) Developing and providing in-service training to applicable production work centers for prevention, detection and reporting of corrosion peculiar to each type of assigned support equipment and components.

(g) Ensuring that authorized corrosion prevention/control materials (with adequate remaining shelf life), technical directives, publications and equipment are available within applicable production work centers.

(h) Ensuring that defective material received from supply is reported in accordance with reference directive.

(i) Ensuring proper corrosion prevention/control documentation in accordance with reference directive.

(j) Submitting Quality Deficiency Reports in accordance with reference directives, when applicable.

(k) Ensuring that ultrasonic/water solution component cleaning and drying is not attempted on components and other equipment unless specified.

(3) Personnel manning requirements:

(a) Two corrosion prevention/control aircraft trained E-6's or above assigned to the general maintenance division afloat or airframes division ashore to serve as the activity's airframe/components corrosion prevention/control program experts and coordinators.

(b) Two corrosion prevention/control avionic equipment trained rating or above assigned to the avionic equipment division to serve as the activity's avionic equipment corrosion prevention/control program experts and coordinators.

(c) One corrosion prevention/control aircraft or avionic equipment trained rating or above to be assigned to activity's quality assurance division.

(d) A minimum of one aircraft/avionic equipment corrosion prevention/control (or equivalent) trained (as applicable) rating or above shall be assigned to each shop production work center to serve as the work center's corrosion prevention/control program representative.

(e) Personnel manning requirements outlined in paragraph 5f above apply for aircraft shop maintenance activities assigned aircraft.

AIRCRAFT CORROSION CORRECTIVE MAINTENANCE INTERVALS

Note: The below established intervals shall be complied with in accordance with the basic handbook. Changes/modifications to this enclosure shall be promulgated as required.

1. (Type aircraft) afloat/ashore shall be inducted each 14/28 days. All corrosion discrepancies shall be corrected.

2. (Type aircraft) shall be inducted each 42 days. All corrosion discrepancies shall be corrected.

3. (Type aircraft) shall be inducted each 14 days to correct major corrosion discrepancies. All corrosion discrepancies shall be corrected on alternate 14 day inspections.

4. (Type aircraft) afloat/ashore shall be inducted each 56 days. All corrosion discrepancies shall be corrected.

EMERGENCY RECLAMATION PROGRAM

1. Action

a. Wing commanders shall develop and maintain a priority equipment removal list for each assigned type/model/series aircraft.

b. Aircraft squadron maintenance activities and permanent detachments shall:

(1) Establish an emergency reclamation team composed of corrosion prevention/control trained personnel from all production work centers.

Note: Permanent and augmentation corrosion prevention/control work center personnel may be assigned collateral duty as reclamation team members.

(2) Promulgate and maintain a squadron instruction or maintenance instruction outlining the activity's emergency reclamation program, i.e., safety precautions, team personnel assignments, training, required materials and equipment.

Note: Activity's applicable instruction shall caution reclamation team personnel to ensure that all aircraft/equipment explosive devices have been dearmed and removed (by qualified personnel) prior to initiation of reclamation action.

(3) Ensure availability of materials and equipment outlined in reference directives to enhance rapid decontamination of aircraft and associated equipment.

c. Aircraft shop maintenance activities shall:

(1) Promulgate and maintain a squadron instruction or maintenance instruction outlining the activity's processing procedures for emergency reclamation equipment, work center personnel assignments/duties, team personnel training program, required materials and equipment.

(2) During reclamation actions, assist supported activities by providing expertise and equipment not authorized for aircraft shop maintenance activities.

(3) Ensure availability of material and equipment outlined in reference directives to enhance rapid processing and corrective action for emergency reclamation equipment.

d. Document procedures shall be in accordance with reference directive.

TRAINING PROGRAMS

1. Ensuring high standards of aircraft, avionic equipment and support equipment material readiness is a command responsibility. However, a successful corrosion prevention/control program and optimum material readiness can only be achieved through command awareness/support and adequate numbers of qualified/trained personnel at all cognizant echeclons. Prior to being designated as "qualified," corrosion prevention/control maintenance personnel must complete the courses outlined in paragraphs 3 and 4a(1) below. Completion of the courses outlined in paragraphs 3 and 4a(2) below is required prior to designating an individual as a "qualified" aircraft painter.

2. Officer Familiarization/Indoctrination Training. Wing commanders shall establish a corrosion prevention/control program familiarization/indoctrination briefing and/or training program for personnel currently assigned/subsequently assigned to squadron/shop/detachment billets as follows:

a. Commanding Officer

b. Executive Officer

c. Aircraft Maintenance Officer

d. Aircraft Maintenance/Production Control Officer

e. Aircraft Division Officer

f. Avionics Division Officer

g. Corrosion Prevention/Control Officer

h. Aircraft Maintenance Chief

i. Aircraft Maintenance Control Chief

j. Corrosion team personnel

k. Applicable work center and corrosion team augmentation personnel

3. Enlisted Mechanic Training

a. Personnel that complete any of the below listed courses shall be considered as corrosion prevention/control trained; personnel service record book and training jacket entries are required.

(1) Aircraft training activity, 2-1/2 day, corrosion prevention/control course

(2) Aircraft training activity, instructor supervised, 16 hour, corrosion prevention/control sound-slide course

(3) Representative, 2-1/2 day, on-site corrosion prevention/control course

(4) Avionic equipment course

(5) Representative four-day course equivalent to avionic equipment course

Note: Corrosion prevention/control course completion is a prerequisite for personnel nominated to attend corrosion prevention/control and paint/finish courses.

4. On-the-Job Training

a. Provide courses as follows:

(1) Aircraft corrosion prevention/control, 40-hour course

(2) Aircraft paint, finish and insignia, 80-hour course

b. OJT training quotas shall be restricted for fleet personnel that do not possess the following prerequisites:

(1) Aircraft or avionic equipment training activity corrosion prevention/control course completion (or the equivalent; paragraph 3 above refers) prior to requesting quota to training activity aircraft corrosion prevention/control course

(2) OJT aircraft corrosion prevention/control course completion (or the equivalent) prior to requesting quota for aircraft paint, finish and insignia course

(3) Twelve months remaining on current enlistment

(4) Qualified in accordance with medical requirements and security clearance requirements established for applicable courses; course attendees shall possess copies of current medical evaluation/security clearance when reporting to training activity for training.

BASIC CORROSION TRAINING

1. Introduction to corrosion

   a. What is corrosion?

      Product of electrochemical attack

   b. Recognizing corrosion

2. Corrosion Theory of Aluminum/Alloys

   a. Types of Corrosion

      (1) Galvanic or dissimilar metal corrosion

      (2) Intergranular corrosion

      (3) Pitting

      (4) Exfoliation

      (5) Crevice attack or concentration cell corrosion

      (6) Fretting corrosion

      (7) Stress corrosion cracking

      (8) Corrosion fatigue

      (9) Filiform corrosion

      (10) Microbiological induced corrosion

   b. Causes

      (1) Exposure to Corrosive Environment

         (a) "Moisture," i.e., water, fresh, salt, spray

         (b) Other corrosive materials/chemicals

         (c) Lack of separation between dissimilars

         (d) Poor material selection for construction

         (e) Sand, dirt, etc.

3. Corrosion Preventive Maintenance

   a. Cleaning

   b. Lubrication

   c. Application to corrosion of preventive compounds

   d. Establish a routine by calendar

   e. Use of corrosion compounds on fastovers

4. Corrective Maintenance

   a. Inspect, evaluate and correct.

   b. Remove paint using chemical paint remover approved for use on aircraft surfaces. Do not remove any more paint than required to correct the corrosion problem.

   c. Remove corrosion by mildest means possible.

   d. Inspect the work area using a magnifying glass 5 to 10 X to ensure all corrosion has been removed.

   e. The area shall then be cleaned to a water brake free surface.

   f. A chemical conversion coating shall be applied and allowed time to convert the surface.

   g. The area shall then be primed, sealed and painted as required.

5. When corrosion is discovered in a critical area of an aircraft or corrosion exceeds the limits allowed in the aircraft structure manual, engineering assistance shall be requested.

DESIGN AND MANUFACTURING PRACTICES TO MINIMIZE CORROSION IN AIRCRAFT

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MILITARY WEAPON SYSTEMS FACE TRADEOFFS OF PERFORMANCE, COST OF PRODUCTION AND MAINTENANCE VERSUS LONG TERM DURABILITY AND REDUCED RELIABILITY RESULTING FROM CORROSION. THERE IS A BROAD SET OF REQUIREMENTS PRESENTED TO CONTRACTORS WHICH REPRESENT THE COLLECTIVE WISDOM OF WHAT IS NEEDED FOR DURABILITY. THESE REQUIREMENTS ARE JUDGED TO BE COST EFFECTIVE AND NEAR OPTIMUM IN THIS TRADEOFF OF PERFORMANCE/COST WITH CORROSION RESISTANCE. THESE ARE SET FORTH IN A NUMBER OF DIFFERENT SPECIFICATIONS AND STANDARDS WHICH ARE BEING DISCUSSED IN DETAIL BY OTHERS TODAY.

THE THESIS OF THIS PRESENTATION IS TO SHOW A FEW EXAMPLES OF SOME SPECIFIC DESIGNS, PROCESSES AND MATERIALS WHICH HAVE BEEN FOUND BY ONE MANUFACTURER TO HAVE SIGNIFICANT ADVANTAGES IN THIS TRADEOFF BY THEIR EXCELLENCE OF PROTECTION WITH MINIMUM TRADEOFF PENALTIES. THESE DETAILS OF SUCCESSFUL EXPERIENCES ARE INTENDED TO SET THE STAGE FOR TWO OTHER THESES. THE FIRST IS THAT THE DATA INCORPORATED IN UNITED STATES MILITARY DOCUMENTS, SUCH AS THE REQUIREMENTS IN MIL-F-7179, (PROTECTION OF AEROSPACE WEAPON SYSTEMS), MIL-STD-1568, (MATERIALS AND PROCESSES FOR CORROSION CONTROL), AND THE MATERIALS PORTIONS OF SD-24, (DESIGN AND CONSTRUCTION OF WEAPON SYSTEMS), ARE INDEED AN EXCELLENT BASE FROM WHICH WE CAN BEGIN THE DESIGN OF A WEAPON SYSTEM. BUT IT IS AN ALMOST IMPOSSIBLE SITUATION TO TRY TO SPELL OUT THE DETAILS REQUIRED TO ACTUALLY OBTAIN PERFORMANCE EXCELLENCE IN THE DESIGN TRADEOFFS, OR TO DEFINE THE REQUIRED INTRICATE DETAILS NECESSARY TO ACCOMPLISH OPTIMUM PROTECTION FROM THE PERVASIVE THERMODYNAMICS OF MATERIALS SEEKING LOWER FREE ENERGY STATES.

THE FINAL THOUGHT FROM THIS PAPER IS THE SUGGESTION THAT IN CONJUNCTION WITH OUR BASE OF DETAILED REQUIREMENTS, WITH THE ADDITION OF AN INTELLIGENT SELECTION OF MATERIALS AND MANUFACTURING OPTIONS, WE NEED ONE MORE IMPORTANT FACET. WE NEED VALID TEST METHODS TO TELL US EARLY IN THE EQUIPMENT PRODUCTION CYCLE IF WE HAVE BEEN SUCCESSFUL IN OUR EFFORTS TO PRODUCE DURABLE AND RELIABLE STRUCTURES AND ELECTRONICS.

FASTENERS/FASTENED STRUCTURE

THE PROTECTION OF FASTENERS AND THE STRUCTURAL MATERIALS BEING HELD TOGETHER IS A SITUATION WHICH HAS CHALLENGED US IN MODERN WEAPON SYSTEMS. THE SITUATION OFTEN PRESENTS ITSELF WHEN HIGH STRENGTH METALS, WHICH ARE NOT NECESSARILY IN THE OPTIMUM METALLURGICAL CONDITION FOR STABILITY, ARE TO BE FASTENED IN HIGHLY STRESSED JOINTS. THESE JOINTS THEN MUST OFTEN BE STORED FOR LONG TIME PERIODS ON MISSILE STRUCTURES PRIOR TO THE STRUCTURAL TESTING AND FIRING; OR MAY BE LOADED INTERMITTENTLY, AS IN MISSILE CARRIER STRUCTURES OR AIRCRAFT STRUCTURE, WITH EITHER CONCURRENT OR INTERMITTENT EXPOSURE TO A SEVERE CORROSIVE ENVIRONMENT. IT IS AT THESE CRITICAL JOINTS THAT CORROSION PROBLEMS OFTEN DEVELOP.

REQUIREMENTS AND INNOVATIONS

THE NAVY REQUIRES THAT FASTENERS MEET THE REQUIREMENT OF MIL-F-7179, THAT IMMEDIATE CONTACT OF DISSIMILAR METALS BE AVOIDED IF PRACTICABLE, AND IF ELECTRO-CHEMICALLY "DISSIMILAR" MATERIALS ARE IN CONTACT, THAT THEY BE "INSULATED." WITHOUT SPECIFIC REFERENCE TO FASTENERS, THERE IS A REQUIREMENT THAT ALL CREVICES IN EXTERIOR LOCATIONS BE FILLED OR SEALED WITH AN APPROVED SEALING COMPOUND. THEY ALSO PROVIDE, IN A SEPARATE SECTION, REQUIREMENTS OF MATERIAL, HEAT TREATMENT AND SUSTAINED AND RESIDUAL STRESS LIMITATIONS IN RELATION TO GRAIN FLOW DIRECTION TO MINIMIZE THE POTENTIAL FOR STRESS CORROSION CRACKING OR HYDROGEN EMBRITTLEMENT. FURTHER, MIL-F-7179 HAS A SECTION, 5.10, WHICH ADDRESSES "ATTACHING PARTS" WHEREIN THE REQUIREMENTS OF PAINTING IN DETAIL WHEN DISSIMILAR METALS ARE INVOLVED OR THE FASTENERS ARE INSTALLED IN "EXTERIOR" LOCATIONS, AND REQUIRES THAT ALL HOLES AND COUNTERSINKS THROUGH WHICH FASTENERS SHALL PASS SHALL RECEIVE SURFACE TREATMENTS PRIOR TO ASSEMBLY AND THAT THE FASTENERS TO BE USED IN "EXTERIOR" LOCATIONS BE INSTALLED WITH UNCURED PRIMER OR SEALANT AT THE TIME OF INSTALLATION. FOR WEAPON SYSTEMS ENCOUNTERING THE SEVEREST ENVIRONMENTS, ALL NON-ALUMINUM FASTENERS SHALL ALSO BE OVERCOATED WITH FIVE MILS OF SEALANT AFTER INSTALLATION. THE NUMBER AND DETAIL OF THESE REQUIREMENTS EMPHASIZES THAT WE ARE DEALING WITH A DOGGED AND COSTLY PROBLEM FOR THE MILITARY OPERATING IN SEVERE ENVIRONMENTS. IN SOME CASES, WHEN THAT ENVIRONMENT PERVADES BOTH THE "HEAD" AND NUT END OF THE FASTENERS, ALL THESE COSTLY STEPS FROM A MANUFACTURER'S VIEWPOINT MAY NOT ONLY BE NEEDED, BUT ARE ESSENTIAL TO OBTAIN LOW MAINTENANCE AND RELIABLE PERFORMANCE. ON THE OTHER HAND, FASTENER/ COUNTERSINKS HAVE BEEN MANUFACTURED AND USED IN SEVERE ENVIRONMENTS WITH MUCH LESS COSTLY PROTECTION AND HAVE AN EXCELLENT PERFORMANCE HISTORY.

ALUMINUM AND CADMIUM PLATED STEEL FASTENERS INSTALLED PREDOMINANTLY IN 7000 ALUMINUM STRUCTURE EXPOSED SO THAT SEVERE ENVIRONMENT CONTACTED PREDOMINANTLY ON THE HEAD OF THE FASTENER COUNTERSINK HAVE BEEN PROTECTED BY CHROMATE BRUSH TREATMENT OF THE ALUMINUM COUNTERSINK AREA, INSTALLATION OF THE CHROMATE TREATED OR ANODIZED ALUMINUM FASTENERS OR

CADMIUM PLATED STEEL FASTENERS WITHOUT ANY PRIMER ON THE FASTENER. NO PRIMER OR SEALANT WAS USED AT THE TIME OF FASTENER INSTALLATION IN THE FASTENER HOLE. AFTER INSTALLATION, HOWEVER, FASTENER PATTERNS WERE PROTECTED BY A SPRAY PATTERN OF POLYURETHANE SEALANT AS A PART OF THE OVERALL EXTERIOR FINISH OF THE WEAPON SYSTEM. THUS A PRODUCTIVITY GAIN WITH NO DECREASE IN PROTECTION WAS MADE BY USE OF THE SEALANT OVER-SPRAY IN LIEU OF DETAILED PRIMING OF FASTENERS, INSTALLATION OF THE FASTENER WITH PRIMER OR SEALANT AND OVERCOATING THE NON-ALUMINUM FASTENER WITH FIVE MILS OF POLYSULFIDE SEALANT AS A SEPARATE SEALING STEP.

THE SUCCESS OF THIS SYSTEM MAY BE DUE TO THE SELECTION OF THE POLYURETHANE ELASTOMER FOR NON RUPTURING PROPERTIES UNDER MAXIMUM DAMAGE POTENTIAL AND THE LOW PERMEABILITY OF THE FILM TO WATER AND SODIUM OR CHLORIDE IONS.

TABLE I

FASTENER PROTECTION IN SEVERE ENVIRONMENT

	REQUIREMENTS		MANUFACTURER'S ALTERNATIVE	
	ALUMINUM	STEEL	ALUMINUM	STEEL
COUNTERSINK	CHROMATE TREATMENT OR ANODIZE.	CHROMATE TREATMENT OR ANODIZE.	CHROMATE TREATMENT OR ANODIZE.	CHROMATE TREATMENT OR ANODIZE.
FASTENER DETAIL				
SURFACE TREATMENT	CHROMATE TREATMENT OR ANODIZE.	CADMIUM ELECTROPLATE	CHROMATE TREATMENT OR ANODIZE.	CADMIUM ELECTROPLATE
PRIMER	REQUIRED	REQIRED	NONE	NONE
INSTALLATION SEAL	REQUIRED	REQUIRED	NONE	NONE
OVERCOAT SEAL	NONE	REQUIRED	POLYURETHANE ELASTOMER	POLYURETHANE ELASTOMER.

DISSIMILAR METAL PROTECTION

MIL-STD-1568 REQUIRES THAT DISSIMILAR METAL JOINTS BE PROTECTED AGAINST GALVANIC CORROSION. SD-24 REQUIRES FOR THE NAVY THAT DISSIMILAR METALS BE INSULATED. BOTH DOCUMENTS REFERENCE THE REQUIREMENTS OF MIL-F-7179. MIL-F-7179 ALLOWS DISSIMILAR METALS IN CONTACT, BUT REQUIRES IN THE CASE WHEN MAGNESIUM IS ONE OF THE METALS THAT A TAPE BE USED SO THAT A 1/4 INCH MOISTURE BRIDGING IS REQUIRED TO COMPLETE THE GALVANIC CIRCUIT. POLYSULFIDE SEALANTS ARE ALSO COMMENDED AS GOOD MOISTURE BARRIERS WHEN THE 1/4 INCH GAP IS MAINTAINED. INITIAL EXPERIENCE WITH THESE MATERIALS INDICATED THAT BOTH METHODS PROVIDE QUITE GOOD PROTECTION. IN FACT, ONE WEAPON SYSTEM WAS DESIGNED WITH TAPE AS THE PREFERRED MATERIAL. SINCE THAT TIME, EXAMINATION OF THE PRODUCT HAS MADE IT CLEAR THAT SEALANTS PERFORMED A MUCH SUPERIOR PROTECTION THAN DOES TAPE. THIS HAS RESULTED FROM LONG TERM DAMAGE BY HYDRAULIC FLUIDS TO PRESSURE SENSITIVE TAPE ADHESIVES ALLOWING THE TAPE TO LIFT. COMPLEX CURVATURES REQUIRED DEFORMING THE TAPE IN A LATERAL DIMENSION TO THE DIRECTION OF CALENDERING, IN ORDER TO CONFORM IT SNUGLY TO THE HARDWARE. CREEP-BACK TOWARDS THE ORIGINAL CONFIGURATION LESSENED PROTECTION. SEALANTS HAD NONE OF THESE SHORTCOMINGS. IT MIGHT ALSO BE ADDED THAT POLYSULFIDE SEALANT NOT CONTAINING INHIBITORS EITHER IN THE FORM OF CURING AGENTS OR ADDED SPECIFICALLY FOR CORROSION INHIBITION, GAVE EXCELLENT PROTECTION AS AN INSULATOR OR BARRIER TO PERMEATION.

AS A SPECIAL CASE OF DISSIMILAR METAL PROTECTION, BUSHINGS OF COPPER BEARING ALLOYS SUCH AS BERYLLIUM COPPER OR ALUMINUM BRONZE HAVE BEEN PARTICULARLY TROUBLESOME WHEN INSTALLED IN ALUMINUM LUGS. THIS FACILITATES THE USE OF A PIN TYPE BEARING IN THE SLEEVE, BUT CREATES THE SEVERE DAMAGE POTENTIAL OF NOBLE COPPER METAL IN CONTACT OR NEAR ALUMINUM. WHEN THIS ALUMINUM IS A FORGING, THE LUG STRUCTURE HAS, AS A RULE, EXPOSED VULNERABLE TRANSVERSE OR SHORT TRANSVERSE GRAIN STRUCTURES IN THE VICINITY OF THE COPPER ALLOY. BEST PERFORMANCE HERE HAS RESULTED IN ENCAPSULATING THE COPPER ALLOY IN A THIN NICKEL ELECTROPLATE UNDER CADMIUM ELECTROPLATE APPLIED FOR LUBRICATION AND THE CLOSER COMPATABILITY WITH THE ALUMINUM. OF EQUAL OR GREATER PROTECTION, HOWEVER, RESULTS FROM CHAMFERING THIS HOLE INTO WHICH THE BUSHING IS INSERTED. THIS ALLOWS A GREATER GAP FROM THE EDGE OF THE BUSHING TO THE ALUMINUM LUG WHICH THE ELECTROLYTE MUST BRIDGE, AND WHEN THE JOINT IS LOADED, GIVES A GREATER OPPORTUNITY FOR THE ELASTOMER USED TO FILL THIS CHAMFER TO BE ELONGATED AND RETURN TO THE UNLOADED CONDITION WITHOUT TEARING OR ADHESION LOSS.

COMPATIBLE METAL SURFACES INVOLVING STRESS

MILITARY STANDARD 889 AND THE EARLIER MILITARY STANDARD 33586 HAVE DONE A GOOD JOB OF GIVING GUIDANCE TO DESIGNERS IN SELECTION AND USE OF METALS COMPATIBLE IN DIRECT CONTACT WITH EACH OTHER IN A CORROSIVE ENVIRONMENT. THIS STANDARD ALSO TAKES INTO

CONSIDERATION HOW HIGH CURRENT DENSITIES RESULTING FROM LARGE AREAS OF THE MORE NOBLE CATHODE METALS REACT IN CONTACT WITH SMALLER AREAS OF THE MORE CORRODABLE ANODE METAL. IT ADDS ADDITIONAL PRECAUTIONARY NOTES ABOUT REACTION PRODUCTS OF THE ANODE SUCH AS ZINC HYDROXIDE WHICH IN THEMSELVES CAN BECOME SO ALKALINE AS TO ATTACK ALUMINUM. IT IS EVIDENT THAT THE MANDATORY USE OF THIS DOCUMENT IN THE DESIGN OF MILITARY EQUIPMENT IS A SIGNIFICANT FACTOR IN BUILDING RELIABLE STRUCTURE. BUT AS HIGHER STRENGTH METALS HAVE BECOME MORE COMMONPLACE, IT IS BECOMING EVIDENT THAT ADDITIONAL GUIDANCE TO THAT PROVIDED FOR GLAVANIC DISSIMILARITY IS NEEDED. OR SAID ANOTHER WAY, WE NEED TO LOOK AT GALVANIC DISSIMILARITY BEYOND THE PRIMARY EFFECT OF WHICH METAL IN THE COUPLE IS LOST AND TO CONSIDER THE POTENTIALITY OF BRITTLE FAILURE CAUSED BY DIRECT CONTACT OR FROM SECONDARY EFFECTS OF THE GALVANIC REACTION.

TO ILLUSTRATE, A REVIEW OF SOME OF THE FAILURE PHENOMENA REPORTED IN THE LITERATURE IN RECENT YEARS IS HELPFUL. FAGER AND SPURR[1] AND MEYN[2] REPORT TEST DATA AND REFERENCES SHOWING EMBRITTLEMENT OF A NUMBER OF TITANIUM AND STEEL ALLOYS WHICH IS ATTRIBUTED TO SOLID METAL EMBRITTLEMENT - INITIATING AND SUSTAINING CRACK PROPAGATION CAUSED BY CONTACT WITH CADMIUM AND SILVER. IN 1968 MASTOVOY AND BREYER[3] REPORTED THAT LEAD HAD CAUSED BRITTLE FAILURE IN 4145 STEEL BELOW THE MELTING POINT OF LEAD. PATEL AND TAYLOR[4] SHOWED THAT PH13-8MO AND PH12-9MO CORROSION RESISTANT STEELS HEAT TREATED TO THE 220 KSI STRENGTH LEVEL AND EXPOSED UNDER SUSTAINED TENSILE STRESS IN A WET CHLORIDE CONTAINING ENVIRONMENT IN CONTACT WITH ALUMINUM ALSO EXPERIENCED BRITTLE FAILURE. SERVICE FAILURES OF PH13-8MO AND PH17-4 UNDER THESE CIRCUMSTANCES HAVE ALSO BEEN REPORTED.

LYNN, WARKE AND GORDON[5] HAVE INVESTIGATED A SERIES OF LOW MELTING METALS FOR THEIR EMBRITTLING EFFECT ON STEEL. IN THEIR STUDIES EMBRITTLEMENT BY SURFACE COATINGS OF SOLID ZINC, LEAD, CADMIUM, TIN AND INDIUM WAS SHOWN TO REDUCE TENSILE DUCTILITY. THE THRESHOLD RANGE WAS ROUGHLY THREE QUARTERS OF THE EMBRITTLER ABSOLUTE MELTING TEMPERATURE AND WAS CONTINUOUS UP TO THE MELTING TEMPERATURE. THE LOSS IN DUCTILITY AND FRACTURE STRENGTH OCCURRED WHEN THE 200 KSI 4140 STEEL WAS STRESSED IN TENSION. THIS WORK AND THE RESULTS ALLUDED TO ELSEWHERE IN THIS PAPER SUGGESTS THAT ALL THE METAL COMBINATIONS CAPABLE OF LIQUID METAL EMBRITTLEMENT MAY ALSO BE EMBRITTLED AT TEMPERATURES BELOW THE MELTING POINT OF A LOW MELTING METAL OR ALLOY. COVINGTON[6] GAVE US SEVERAL INSIGHTS INTO THE HAZARDS OF EMBITTLEMENT OF TITANIUM BY DISSIMILAR METAL CONTACT. HE POINTS OUT THAT MODECULAR HYDROGEN WITH A DIAMETER OF 2.12 ANGSTROMS IS NON-EMBRITTLING WHILE ATOMIC HYDROGEN WITH A 1.058 ANGSTROM HAS BEEN SHOWN TO BE EMBRITTLING. THE HYDROGEN ION (H^+) IS ABOUT 10^{-5} ANGSTROM SO IT IS POSTULATED THAT IN THIS FORM THE SURFACE BARRIERS ARE INEFFECTIVE AND THUS THE DANGERS OF EMBRITTLEMENT INCREASED ONE HUNDRED THOUSAND FOLD FROM IONIC HYDROGEN EMANATING FROM CORROSION REACTIONS AT THE TITANIUM SURFACE.

CORROSION REACTIONS GENERATE HYDROGEN IONS WHICH PICK UP ELECTRONS AT CATHODIC AREAS OF THE METAL TO BECOME AN ATOM. IN THE CASE OF TITANIUM, THE ALMOST EVER PRESENT OXIDE FILM DOES NOT CONDUCT ELECTRONS SO THAT THE HYDROGEN ION PROBABLY DIFFUSES THROUGH THE OXIDE FILM TO THE TITANIUM SURFACE WHERE IT BECOMES ATOMIC AND DIFFUSES INTO THE METAL SURFACE IN THAT FORM. THIS MECHANISM SUGGESTS THAT ANODIC MATERIALS IN CONTACT WITH THE TITANIUM WILL GENERATE THE MOST DAMAGING SPECIES OF HYDROGEN, THE ION. IF THE OTHER CONDITIONS NECESSARY FOR EMBRITTLEMENT ARE PRESENT, TENSILE STRESS AND TEMPERATURE, CATASTROPHIC CRACKING IS THE RESULT. AMOUNTS OF IRON AS SMALL AS 0.11 PERCENT CAUSES HYDROGEN EMBRITTLEMENT OF TITANIUM ACCORDING TO COTTON[7]. IN THE WORK BY COVINGTON AND IN EXPERIMENTS CONDUCTED BY COTTON NOT ONLY WAS THE GALVANIC METAL EFFECT OF HYDROGEN GENERATION SHOWN, BUT IN A DRY ATMOSPHERE HYDROGEN INGRESS OCCURRED BECAUSE OF DISCONTINUITY OF THE OXIDE FILM CAUSED BY IRON IN THE PRESENCE OF MOLECULAR HYDROGEN.

A SERIES OF FAILURES OF 4340 STEEL IN THE 260 KSI STRENGTH LEVEL EXPOSED TO A MARINE ATMOSPHERE UNDER HIGH SUSTAINED STRESS LEVELS PRESENTS A GOOD CASE STUDY IN THE COMPLEXITY OF THE PROBLEM FACING DESIGNERS OF THESE STRUCTURES. AT THE TIME OF INITIAL FAILURES, FRACTOGRAPHIC TECHNIQUES WERE NOT KNOWN WHICH WOULD DISTINGUISH BETWEEN STRESS CORROSION CRACKING AND HYDROGEN EMBRITTLE- MENT. SINCE THESE FAILURES OCCURRED MONTHS OR YEARS AFTER THE PARTS WERE IN SERVICE, STRESS CORROSION CRACKING WAS BELIEVED TO BE THE CAUSE FOR FAILURE. AS ELECTRON MICROSCOPIC TECHNIQUES WERE DEVELOPED TO DISTINGUISH BETWEEN SURFACE INITIATED STRESS CORROSION CRACKING AND SUB-SURFACE HYDROGEN INITIATED CRACKS, THE LATTER BECAME SUSPECT ALONG WITH THE POSSIBILITY OF SOLID CADMIUM EMBRITTLEMENT. THESE FAILURES WERE OCCURRING IN MATING PARTS CONNECTED WITH HIGHLY STRESSED TAPERED PINS. IN ORDER TO GIVE ADDITIONAL CORROSION PROTECTION, AFTER THE INITIAL FAILURES SURFACED, CADMIUM WAS ADDED TO THE PIN. THIS COMPOUNDED THE PROBLEM CAUSING A HIGHER FAILURE RATE. THE PERCENTAGES OF FAILURE IN 200 KSI 4340 FOR TWO TORQUE LEVELS IS SHOWN IN TABLE II. THE GREATER DAMAGE OCCURRING WITH HIGH TORQUE AND CADMIUM PRESENT IN 260 KSI STEEL IS SHOWN IN TABLE III. A DETAILED INVESTIGATION SHOWED THAT ALTHOUGH THE CADMIUM EMBRITTLEMENT PHENOMENA CAN BE REPRODUCED IN TEST SPECIMENS, THE TAPERED PIN CONFIGURATION WOULD NOT CAUSE EMBRITTLEMENT IN A DRY ATMOSPHERE AT A 1200 INCH POUND TORQUE AT 77°F. NOMINAL TORQUES OF 480 TO 690 INCH POUNDS RANGE CAUSED FAILURES IN SERVICE WHICH WERE SEEN TO BE HYDROGEN EMBRITTLEMENT. REDUCING THIS TORQUE TO 250-320 INCH POUNDS AND REMOVING THE CADMIUM FROM THE TAPERED PINS RESULTED IN NO CRACKING.

SACRIFICAL COATINGS SUCH AS CADMIUM ARE TRADITIONALLY USED TO PROTECT STEEL FROM STRESS CORROSION CRACKING AND GENERAL CORROSION. THEY ARE CONSIDERED "COMPATIBLE" PER MIL-STD-889. WHEN CONCERN FOR THE PHENOMENA OF SOLID CADMIUM EMBRITTLEMENT AND HYDROGEN EMBRITTLEMENT ARE ADDED TO THE NEED FOR PROTECTION FROM STRESS CORROSION CRACKING AND GENERAL CORROSION, THE COMPLEXITY OF HIGHLY RELIABLE DESIGN BEGINS TO COME INTO FOCUS.

Some of the parameters for good design are fairly clear. For a given alloy, strength levels can be ascertained which are susceptible to hydrogen embrittlement. For the martensitic steels this is well established in 200 KSI range. Threshold values for stress corrosion cracking are also fairly well established. When it is necessary to exceed these strength levels in the alloy, the additional consideration of galvanic potential or temperature at which embrittlement will occur in contact with an adjacent metal must be considered.

The literature does not provide much specific data and this is not going to be easily obtained. Although this data may be extracted from service failure or success histories to some extent, it is probable that an organized test program as well as a service data compilation is necessary to gain the design guide information we need to make reliable high strength steel and titanium parts.

TABLE II
SERVICE FAILURE OF 200 KSI 4340 STEEL

No. in Service	No. Failed	Cadmium in Hole	Torque	Peened	% Failure
1731	1	No	480-690	No	5.7×10^{-3}
790	10	Yes	480-690	No	1.2
2220 (est)	0	No	280-320	No	0

TABLE III
SERVICE FAILURES OF 260 KSI 4340

No. in Service	No. Failed	Cadmium Present	Torque	Peened	% Failure
696	87	Yes	480-690	No	12.5
2132	117	No	480-690	No	5.5
612	0	Yes	280-320	Yes	0
2220 (est)	0	No	280-320	Yes	0

Missiles in Storage

As alluded to earlier in this paper, long term storage has its own technology for durability. When this storage takes place in an essentially vapor tight container, the vapors which can be generated over a five to ten year period are available for direct reaction with other materials. The reaction of cadmium with chlorides emanating from certain polymers is an example which has been noted. In this case, cadmium may sometimes be replaced by tin or nickel for use as a protective electroplate.

An important process for long term torage is sealing the container in a manner to prevent ingress of moisture into what is initially a low moisture content air; or dry inert gas. Elastomeric seals using polysulfides have merit in that they will adhere to a wide spectrum of substrates and have sufficient elongation over a wide temperature range to resist rupture by thermal stresses due to differences in expansion of rocket storage tubes and covers. Polysulfides cannot be used in very high production operations, however, when time to seal and pressure test for leakage is less than an hour. In these cases, flexiblized epoxy or polyurethane elastomer copolymers have been found to be effective.

The Next Big Step

At this point in time, designers of military equipment have a heritage of ground rules stated in their specifications based, as carefully as we have been able, on sound scientific principles. The complexity of the factors which can be brought to bear on the durability of some hardware, in design, manufacturing variables and use, keep us humble, however. As new structural materials become optimized, we will be faced with new unknowns in how to protect them adequately from degradation and may not know where our mistakes in design and manufacture have been made until years of service use. One major shortcoming in the introduction of new materials and processes is that we have lagged in developing test methods which can predict shortcomings in durability resulting from the environment and mechanical stresses the equipment will experience. That should be our next big step.

Conclusions

1. The United States military standards and specifications have given us an excellent baseline requirement upon which we can build durable weapon system structure.

2. There is an opportunity to achieve the durability goals by using good engineering and scientific knowledge by intelligent selection of options or new technology; for example, fastener protection.

3. As highlighted by the interaction of the base material and sustained stress level, there is a need for further knowledge of electrochemically compatible metals.

4. A valid accelerated test for durability that integrates the proper sequence of storage, corrosion environment and mechanical loading offers weapon system cost savings.

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CORROSION CONTROL MAINTENANCE PRACTICES FOR CANADIAN AIRCRAFT

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SUMMARY

The corrosion control program for aircraft of the Canadian Armed Forces was reviewed. Documentation outlining general guidelines and policy was presented along with excerpts from a manual specific to one particular aircraft. The effects of the operational environment on the extent of the corrosion control program for an aircraft were discussed, with Sea King helicopters and CF-104 aircraft serving as examples. The equipment contained in a corrosion-control first-aid kit for CF aircraft was highlighted, along with instructions for its use. The training given to CF aviation tradesmen was also outlined. Finally, the protective coating system selected for all CF aircraft was described and its importance to the overall corrosion control program was noted.

1 GENERAL

General guidelines and policy which are applicable to all aircraft have been prepared and are contained in the following Canadian Forces Technical Orders (CFTO).

1.1 CFTO C-12-010-040/TR-021
Corrosion Control and Precautions Aircraft

This CFTO describes the nature and causes of corrosion. It lays down inspection procedures and outlines the corrosion-prone areas of aircraft. It also includes the corrosion removal techniques, chemical and mechanical, and provides some guidance on the selection of processes and materials to prevent corrosion.

1.2 CFTO C-12-010-010/TP-000
Painting of Aircraft and Aircraft Equipment

In a nutshell, this is the Bible of our aircraft refinishers. It describes all the coating materials used, how they work and how they are applied, describes the necessary equipment, gives the procedures for paint removal, cleaning and preparation of surfaces, and provides some guidance in the selection of coating systems. It also includes a chapter on quality and process control.

1.3 CFTO C-12-010-029/TP-000
Aircraft Cleaning Interior and Exterior

This CFTO describes the materials and procedures to be followed for cleaning the aircraft interior and exterior. The exterior is cleaned with aircraft cleaning compounds qualified to MIL-C-25769 with the assistance of petroleum cleaning solvents for the more stubborn soils.

These general CFTOs are complimented by other manuals specific to each aircraft type that will describe the peculiarities of the particular type such as the corrosion-prone areas and type of corrosion to be expected. Materials used in the construction of the aircraft, preferred corrosion removal techniques and types of inspection to be performed are also included. Excerpts from the corrosion control manual for the CF-18 aircraft are shown in Figure 1, Figure 2, and Table 1.

The corrosion control programs vary greatly with aircraft types, role and environment. As a rule, the Senior Aircraft Maintenance Engineering Officer at each unit is responsible for providing a schedule for inspection, cleaning and corrosion treatment of his assigned aircraft.

This can be illustrated with a few examples:

In the case of the Sea King helicopter which operates from the back of a destroyer and whose mission requires it to stand in the salt water wash in a 40-foot hover above the ocean, we have a very vigorous corrosion control program.

The aircraft is washed completely every day.

A daily corrosion inspection - the aircraft is broken down into ten areas with one different area inspected daily. Corrosion is removed and corrosion preventive compounds are applied as required.

Engine compressors are washed routinely.

In the case of the CF 104 fighter aircraft, tremendous differences have been observed between the aircraft operating in Canada and in Europe. The aircraft operating in Canada are almost corrosion-free, even without a protective coating system, and the corrosion control program at the Canadian base is almost non-existent. However, in Germany, extensive surface corrosion has been encountered, which has led, in some cases, to the removal of wings and engines. The European unit does maintain a very vigorous corrosion control program which includes stripping and repainting aircraft on a regular schedule.

2 CORROSION CONTROL KIT

Each of our flying units has the facilities, materials, equipment, and trained personnel to maintain the protective coating system of the aircraft and to maintain a corrosion control program consistent with the aircraft type and environment.

We have found it necessary to design a first-aid kit that could be taken on small deployment away from units. This kit has been issued in particular to all helicopter units.

The kit consists of selected corrosion removal materials and equipment and of temporary corrosion prevention materials as listed in Table 2. The instructions for use of this kit are shown in Figure 3.

Units have been encouraged to make maximum use of the available Water Displacing Compounds such as the AMLGUARD developed by the US Navy.

3. TRAINING

The CF aviation tradesmen are taught to recognize and identify corrosion at the basic training level. In some cases, this is completed and reinforced by training on specific aircraft types. For example, on the CP 140 aircraft, all the air trades are given two days to cover corrosion-prone areas of the aircraft, types of corrosion to be expected, and reporting and remedial action.

Two trades, the refinisher technician and the metal technician, receive complete training on corrosion removal techniques by chemical and mechanical means.

4. PROTECTIVE COATING SYSTEM

One of the most important elements of our corrosion prevention program is the protective coating system which has been standardized on all our aircraft. This coating consists of a chemical conversion coating on aluminum surfaces (MIL-C-5541) followed by an epoxy polyamide primer (MIL-P-23377) and a two-component polyurethane top coat (CF specification D-12-003-001/SF-000, the American equivalent is MIL-C-83286).

This coating system presents some difficulties which include health precautions during application, the requirements for a surgically clean surface before the application and the difficulty of removal after a decade of baking under the sun.

We feel that this system has served us well and we are very satisfied with it.

Table 1. Location, material and typical problems for corrosion-prone areas of CF-18 cockpit.

IDX NO.	CORROSION PRONE AREA	MATERIAL	TYPE CORROSION
53	Angle	7075-T6 Alclad, Sheet	Surface
54	Splice Plate	7075-T76 Alclad, Sheet	Surface
55	Bonding Strip	Beryllium Copper, Sheet	Surface
56	Angle	7075-T6 Alclad, Sheet	Surface
57	Channel	7075-T6 Alclad, Sheet	Surface
58	Doubler	7075-T6 Alclad, Sheet	Surface
59	Doubler	7075-T6 Alclad, Sheet	Surface
60	Doubler	7075-T6 Alclad, Sheet	Surface
61	Doubler	7075-T6 Alclad, Sheet	Surface
62	Angle	7075-T6 Alclad, Sheet	Surface
63	Doubler	7075-T6 Alclad, Sheet	Surface
64	Channel	7075-T6 Alclad, Sheet	Surface
65	Doubler	7075-T6 Alclad, Sheet	Surface
66	Bracket	7075-T6 Alclad, Sheet	Surface
67	Doubler	7075-T6 Alclad, Sheet	Surface
68	Web	7075-T6 Alclad, Sheet	Pitting
69	Splice Plate	7075-T76 Alclad, Sheet	Surface
70	Doubler	7075-T6 Alclad, Sheet	Surface
71	Cover	7075-T6 Alclad, Sheet	Surface
72	Bulkhead	7075-T7352 Al Aly, Sheet	Surface
73	Former	7075-T7351 Al Aly, Plate	Pitting
74	Former	7075-T7351 Al Aly, Plate	Pitting
75	Skin	7075-T6 Alclad, Sheet	Surface Galvanically accelerated.
76	Former	7075-T7351 Al Aly, Plate	Pitting
77	Former	7075-T7351 Al Aly, Plate	Pitting
78	Bulkhead	7075-T7351 Al Aly, Plate	Pitting
79	Former	7075-T7351 Al Aly, Plate	Pitting
80	Former	7075-T7351 Al Aly, Plate	Pitting
81	Bulkhead	7075-T7352 Al Aly, Forging	Pitting
82	Beam	7075-T73511 Al Aly	Surface

Table 2. Equipment check list for corrosion control first-aid kit.

EQUIPMENT CHECK LIST

L-12-010-000/LC-000 (S49068)

STOCK NUMBER	DESCRIPTION			QTY.
4240-21-808-2765	GOGGLES, INDUSTRIAL			1
5120-00-618-6902	MIRROR INSPECTION			1
5140-21-882-1272	CONTAINER, F SHELL			1
5350-21-814 2530	PAPER ABRASIVE, WET OR DRY NO 280		SH	6
6640-21-116-7992	BOTTLE, SCREW CAP, POLYETHYLENE	(A)		2
6810-21-304-4868	METHYL ETHYL KETONE (MEK)	(B)	CO	1
6850-21-868-6618	CORROSION PREVENTIVE COMPOUND (IPS 3)	(B)	TI	2
7510-21-846-8242	BARRIER TAPE, 2 IN. 3M481		RL	1
7920-21-807-8860	BRUSH, ACID SWABBING			6
7920-21-846-8573	KIMWIPES			1
7920-21-848-4716	SCOTCHBRITE ABRASIVE PAD			6
8030-01-041-1596	CORROSION PREVENTIVE COMPOUND (AMLGUARD)	(B)	CN	2
8415-21-844-4957	GLOVES, DISPOSABLE		PG	1
	NOTES			
	(A) TO BE FILLED WITH WATER/ACID AT USER LEVEL.			
	(B) PROCURE LOCALLY.			

PUBLISHED JUNE 1982

Record of Applicable Technical Directives

None

1. **INTRODUCTION.**

2. The cockpit extends from fuselage station Y204.500 to fuselage station Y326.500 for both fighter and trainer configuration aircraft. Floor levels are at Z108.65, Z105.650, and Z111.650. Structure is of 7075-T7351, 7075-T7352, 7075-T76, 7075-T6, 6061-T6, 2024-T81 alclad, and 7075-T6 aluminum alloy. Finish system is epoxy primer and polyurethane coating.

3. **GENERAL INFORMATION.**

a. All non-clad 7075-T6 material is sulfuric acid anodized.

b. All-T6 aluminum alloy sheet is less than 0.080 inch thick.

c. Types of corrosion expected are pitting and surface.

d. Fasteners are wet installed with polysulfide sealant before application of finish system.

4. **CORROSION PRONE AREAS.** See figure 1. Corrosion prone areas are caused by one or more of the conditions below:

a. Dissimilar metal contact.

b. Water intrusion/entrapment.

c. Metal alloy/type and use.

d. Exposure to corrosive elements.

e. Damaged/worn weather seals.

5. **CORROSION INSPECTION.** (WP005 00). Visually inspect the cockpit and rear cockpit:

a. Floor drain valves for obstructions and correct operation, cockpit valve is located on centerline and rear cockpit valve is located on the left side. b. Canopy weather seal for wear/deterioration; splices, windshield arch area, and canopy sill are suspect areas.

c. Sealant dam at forward corners of canopy at sill for wear/deterioration.

d. Finish system for damage, blisters/bubbles should be opened.

e. Insulation blankets must be kept dry and secure.

6. **CLEANING.** (WP006 00).

7. **STRIPPING.** (WP007 00).

8. **CORROSION REMOVAL.** (WP005 00).

9. **CHEMICAL TREATMENT.** (WP008 00).

10. **FINISH SYSTEM AND MARKINGS.** (WP011 00 and WP012 00).

11. **CLASSIFICATION OF CRITICAL ITEMS/AREAS.** (A1-F18AC-SRM-220, WP001 01).

12. **CORROSION DAMAGE EVALUATION AND LIMITS.** (A1-F18AC-SRM-220, WP001 01).

13. **CORROSION DAMAGE REPAIR.** (WP005 00 and A1-F18AC-SRM-220, WP001 01).

Figure 1. Technical directives applicable to corrosion control in the cockpit area of the CF-18 aircraft.

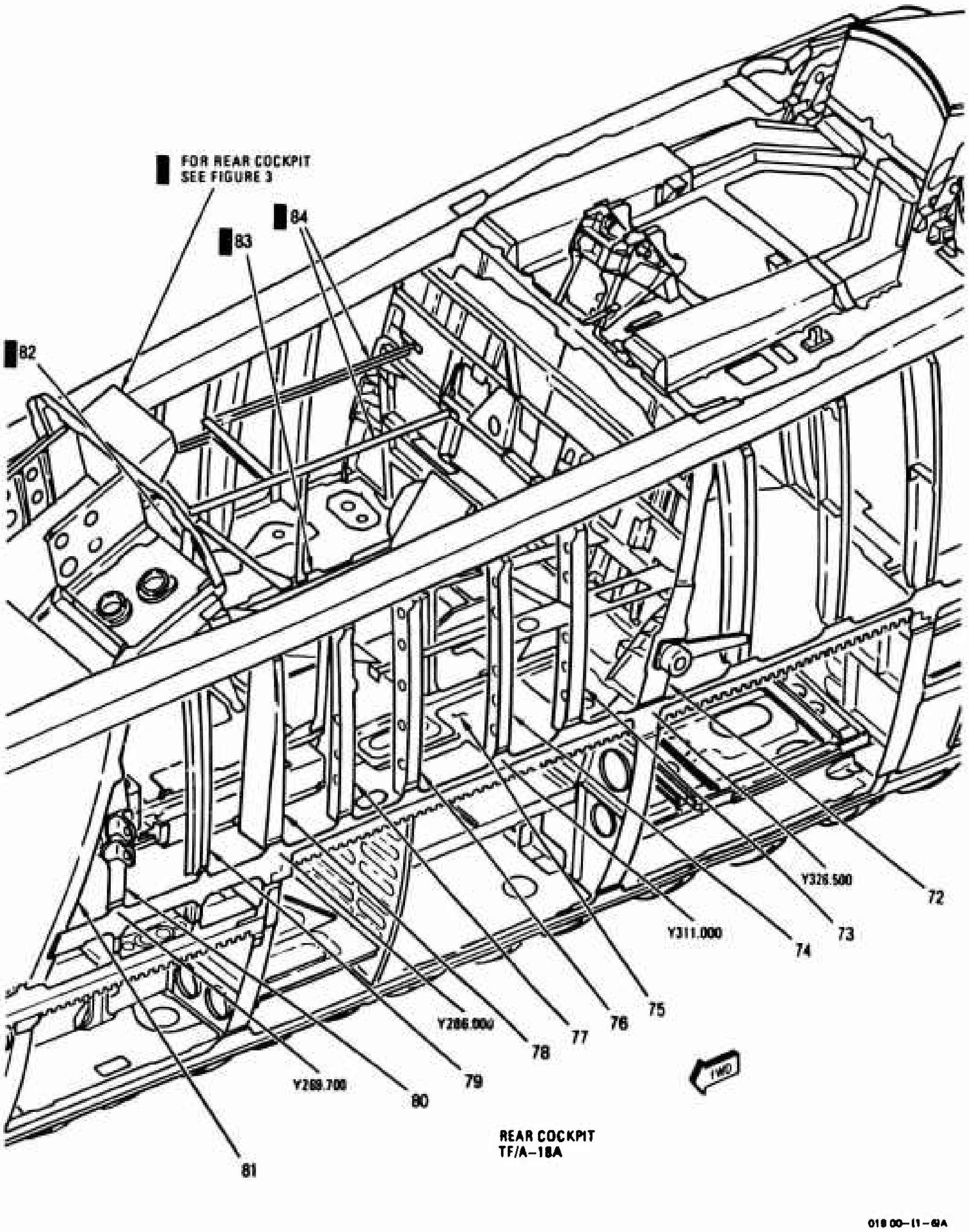

Figure 2. Corrosion-prone areas of CF-18 cockpit. Numb:r at arrows refer to Table 1.

CORROSION CONTROL KIT - FIRST AID - PORTABLE

INSTRUCTIONS FOR USE

1. DEGREASE AFFECTED AREA WITH MEK (ITEM 3)
2. MASK AROUND AFFECTED AREA USING BARRIER TAPE (ITEM 8)
3. REMOVE FLAKING PAINT AND CORROSION USING ABRASIVE PAPER (ITEM 11) OR SCOTCHBRITE PAD (ITEM 10)
4. SCRUB AFFECTED AREA USING BRUSH (ITEM 4) AND CORROSION REMOVING COMPOUND (ITEM 7) KEEPING AREA WET FOR 3 MINUTES
5. FLUSH WITH WATER (ITEM 6) AND WIPE DRY
6. WHERE NO MOVING PARTS ARE INVOLVED APPLY CORROSION PREVENTIVE COMPOUND (ITEM 2) AS PER INSTRUCTIONS ON CONTAINER
7. AROUND MOVING PARTS APPLY CORROSION PREVENTIVE COMPOUND (ITEM 1) AS PER INSTRUCTIONS ON CONTAINER
8. RECORD SPECIFIC LOCATIONS OF ALL TEMPORARY REPAIRS IN A/C LOG SET (FORM CF 336) SO THAT PERMANENT REPAIRS MAY BE CARRIED OUT ON NEXT PERIODIC INSPECTION
9. RESTOCK KIT BEFORE RETURNING TO STORES

CAUTION

ITEM 7 CONTAINS PHOSPHORIC ACID ENSURE RINSING IS COMPLETE AND PROTECT HANDS AND EYES FROM SPLASHING.

Figure 3. Instructions for use of corrosion control kit.

CORROSION RESEARCH IN SUPPORT OF CANADIAN FORCES AIRCRAFT

by

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SUMMARY

Two examples of research projects initiated by the Defence Research Establishment Pacific in direct support of aircraft operators and maintainers in the Canadian Armed Forces, were presented. The first example involved a contract research project at The de Havilland Aircraft of Canada Limited, to investigate the effects of water-displacing corrosion-inhibiting preparations on the fatigue characteristics of structural joints. The initial experimental plan was outlined, and preliminary results were presented. These early results indicated that the preparations did not have a significant effect on the fatigue life of single-strap, riveted butt joints. The second example concerned the prohibition against use of silicon carbide abrasive papers on aluminum in aircraft. Laboratory investigations, including several electrochemical experiments and atmospheric exposure trials, clearly demonstrated that the use of silicon carbide abrasive papers did not increase the severity of corrosion.

1 WATER-DISPLACING CORROSION-INHIBITING COMPOUNDS

1.1 Background

Operators of aircraft in the Canadian Armed Forces routinely use water-displacing corrosion-inhibiting (WDCI) preparations in an effort to reduce and control in-service corrosion. These preparations contain a volatile solvent with a low surface tension that gives them the ability to penetrate between faying surfaces of structural joints, displacing water as they do. Evaporation of this solvent leaves a residue of oily or waxy hydrocarbons that resists subsequent ingress of water.

Laboratory tests conducted at Royal Aircraft Establishment, Farnborough [1,2] and National Aerospace Laboratory in The Netherlands[3] indicated that WDCI preparations could reduce the fatigue life of joints by reducing the load transfer resulting from friction between the joint surfaces. Because of the extensive use of these compounds on Canadian military aircraft, the Defence Research Establishment Pacific (DREP) initiated a contract in 1981 with The de Havilland Aircraft of Canada Limited to undertake a comprehensive investigation of the effects of WDCI compounds on the fatigue characteristics of structural joints.

1.2 Experimental Plan

The investigations initially planned are outlined in Table 1. The total sample population was partitioned into six groups describing various experimental conditions. The fatigue properties to be determined in this plan included fatigue life in air and in salt water and fatigue life in air after pre-exposure in a salt spray chamber. Each group was subdivided by the type of aluminum, surface finish, and the particular WDCI compounds to be used. Groups 5 and 6 were included to demonstrate the effectiveness of the WDCI compounds in reducing corrosion and to determine the subsequent effects on fatigue life.

The test samples were constructed as single strap, riveted, butt joints as shown in Figure 1. Primed specimens were finished with a chromate conversion coating and zinc chromate primer prior to assembly while the remainder of the population was assembled unfinished.

An R3 shaker-lever fatigue machine was constructed in the Structures Research Laboratory at The de Havilland Aircraft of Canada Limited as shown in Figure 2. Fatigue tests in salt water were performed using a watertight compartment around the joint area as shown in Figure 3. The compartment has been designed with a flow rate of 0.925 L/minute.

All samples in the program were subject to constant amplitude loading at frequencies between 25 and 27 Hertz. The sample was always in tension with a minimum to maximum stress ratio in a cycle of 0.1. Two loading cases, resulting in peak stresses of 103 MPa (15000 psi) and 48 MPa (7000 psi) based on gross cross-sectional area, were chosen to be investigated.

1.3 Results and Discussion

Some initial results are presented as a stress level-endurance relationship in Figure 4. The upper set of six groups (see Table 1 for the experimental parameters for each group) was tested at a peak stress of 103 MPa while the lower set was tested at 48 MPa. No statistical analysis has been carried out because of the low number of samples tested within each group so far. However, it does appear that for samples fatigue tested in the same environment (Groups 1 and 3 in air or Groups 2 and 4 in salt water), the application of WDCI compounds has no significant effect on fatigue life.

The majority of failures examined to date have occurred in the butt strap along an end row of rivets with the crack origin materializing on the faying surface of the strap adjacent to one or more rivet holes (Figure 5). Such failures result primarily from stress concentration in the butt strap around the rivet hole due to rivet loading. Under these conditions the addition of WDCI compounds would not be expected to have a significant effect on fatigue life.

The experimental program and results obtained to date have been extracted from a report prepared by P. Bootsma. The remainder of the program is currently under review at The de Havilland Aircraft of Canada Limited in the light of early results. The contract is scheduled for completion in the spring of 1984. The final report on the completed investigation should be available a short time later.

2. THE EFFECTS OF SILICON CARBIDE ABRASIVE PAPERS ON ALUMINUM

2.1 Background

The procedure for repair of corroded areas on aluminum components in Canadian Armed Forces aircraft involves removal of corrosion damage by mechanical abrasion followed by the application of a chemical conversion coating and a subsequent organic finish. The use of silicon carbide abrasive papers in this procedure is specifically forbidden by the technical order on corrosion control [5]. As a result of questions raised by field units, DREP undertook an investigation into the reasons for this prohibition.

A literature survey revealed a study of the pickup of abrasive particles during abrasion of annealed aluminum[6]. However, no direct reference to harmful effects of silicon carbide abrasive papers could be found. We also consulted several aircraft operators who could not specify a reason for the ban but who postulated corrosion problems as the cause. DREP therefore initiated a test program to determine if the use of silicon carbide abrasive papers could increase the susceptibility of aluminum aircraft components to corrosion.

2.2 Experimental Plan, Results and Discussion

Samples of 7075-T6 aluminum were abraded with either aluminum oxide or silicon carbide abrasive papers (320, 400, and 600 grits were used) under identical conditions and then exposed to a marine atmosphere for one month. No appreciable difference in appearance or weight loss was observed between samples abraded with corresponding grits of aluminum oxide or silicon carbide. Additional samples were prepared with grit deliberately imbedded into their surfaces. Exposure tests and examination by scanning electron microscopy revealed no difference in the effect of these grits on the corrosion resistance and appearance of chemical conversion coatings. Furthermore, samples containing imbedded grit passed several paint adhesion tests with no loss of adhesion for either grit.

An electrochemical technique known as Tafel slope determination was used to measure the corrosion rates in sea water of aluminum samples containing imbedded grit. The cathodic Tafel plots for samples imbedded with either 400 grit silicon carbide or 400 grit aluminum oxide are shown in Figure 6. Extrapolation of the linear portion of each curve (near 10^4 nA/cm^2) back to the corrosion potential (E_{corr}) provides a direct measure of the corrosion current. The slope of this line, the Tafel slope, is sensitive to changes in the cathodic reaction mechanism. The measured values of corrosion current and cathodic Tafel slope are shown in Table 2. Since the values for the two grits are identical within experimental error, we can conclude that imbedded silicon carbide does not increase the overall corrosion rate over that for samples imbedded with aluminum oxide.

The potentiodynamic anodic polarization technique was used to determine if imbedded particles of silicon carbide could act as pit initiation sites. The plots for samples imbedded with either 400 grit silicon carbide or 400 grit aluminum oxide and then immersed in deoxygenated sea water are shown in Figure 7. These plots were obtained by scanning the specimen potential away from the corrosion potential (near -1.29 volts in both cases) in the anodic direction. The region of the curves roughly between -1.10 and -0.75 volts in which the current density does not markedly change with changing potential is indicative of the development of a passive (corrosion resistant) film on the specimen surface. Above -0.75 volts the current density increases dramatically. The potential at which this change in behaviour occurs is called the critical pit potential and corresponds to the initiation of pitting on the specimen surface. The dotted line in Figure 7 indicates the corrosion potential of the imbedded sample in aerated sea water. This potential is just below the critical pit potential, indicating that aluminum alloy 7075 is susceptible to pitting in sea water. However, samples imbedded with different grits display virtually identical polarization curves. Thus, imbedded silicon carbide does not increase the susceptibility of aluminum to pitting corrosion.

The validity of the potentiodynamic anodic polarization experiment was tested by deliberately imbedding copper particles (electrolytic dust) in the aluminum surface. The resulting polarization curve is shown in Figure 8. In this case the corrosion potential in aerated sea water is above the critical pit potential so corrosion of the aluminum occurs at a high rate. Thus the technique is indeed sensitive to imbedded materials which can increase the susceptibility to pitting. Silicon carbide is not one of these materials.

2.3 Conclusions

Several electrochemical and atmospheric exposure tests have demonstrated that the use of silicon carbide abrasive papers on aluminum aircraft components does not increase the severity of subsequent corrosion. There is, therefore, no justification for the prohibition of their use if the ban results from concerns about corrosion. A more detailed report on this work is in preparation and should be available soon.

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1. P.H. O'Neill and R.J. Smith. A short study of the effect of a penetrant oil on the fatigue life of a riveted joint. Royal Aircraft Estab. Report TR 73174, Feb. 1984.

2. R.F. Mousley. An effect of corrosion preventative fluids on the fatigue of riveted joints. "The Influence of Environment on Fatigue". I. Mech. E. Conference Publications 1977-4, 1977. pp 131-136.

3. J. Schijve, F.A. Jacobs, and P.J. Tromp. Effect of an anti-corrosion penetrant on the fatigue life in flight-simulation tests on various riveted joints. Natl. Lucht-Ruimtev. Lab. Rep. TR 77103 U, 31 Aug. 1977.

4. P.H. Bootsma, Interim Report No. 1: Fatigue Testing of Aircraft Structures Treated with Water-Displacing Corrosion-Preventative Compounds. The de Havilland Aircraft of Canada Limited. 28 Feb. 1983.

5. "Corrosion Control and Precautions - Aircraft", CFTO C-12-010-040/TR-021, DND Canada, p. 4-8 (1978).

6. R.W. Johnson. A study of the pickup of abrasive particles during abrasion of annealed aluminium on silicon carbide abrasive papers. Wear, 16, p. 351 (1970).

TABLE 1

FATIGUE TEST PLAN

GROUP NO.	TEST	2024-T3 CLAD NO FINISH	2024-T3 CLAD PRIMED	7075-T6 CLAD NO FINISH	7075-T6 CLAD PRIMED
1	Control- Uncorroded, Untreated Test in Air	8	8	8	8
2	Uncorroded, Untreated Test in Salt Water	8	8	8	8
3	Uncorroded, Treated Test in Air	8 LPS-3 8 T-9	8 LPS-3 8 T-9	8 LPS-3 8 T-9	8 LPS-3 8 T-9
4	Uncorroded, Treated Test in Salt Water	8 LPS-3 8 T-9	8 LPS-3 8 T-9	8 LPS-3 8 T-9	8 LPS-3 8 T-9
5	Pre-corroded (2,000 hours With Treatment Test in Air	8 LPS-3 8 T-9	8 LPS-3 9 T-9	8 LPS-3 8 T-9	8 LPS-3 8 T-9
6	Pre-corroded (1,000 hours), With Treatment Test in Air	8	8	8	8
Formerly Group X	Pre-corroded (2,000 hours, Untreated, Test in Air	8	8	8	8
	Total Specimen	80	80	80	80

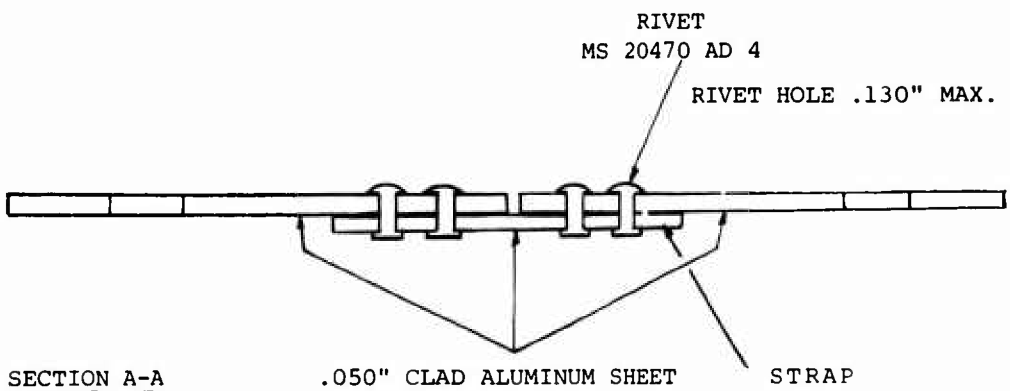
TABLE 2

THE CATHODIC TAFEL CONSTANTS AND CORROSION RATES OF 7075-T6 ALUMINUM IN THE PRESENCE OF IMBEDDED SILICON CARBIDE OR ALUMINUM OXIDE

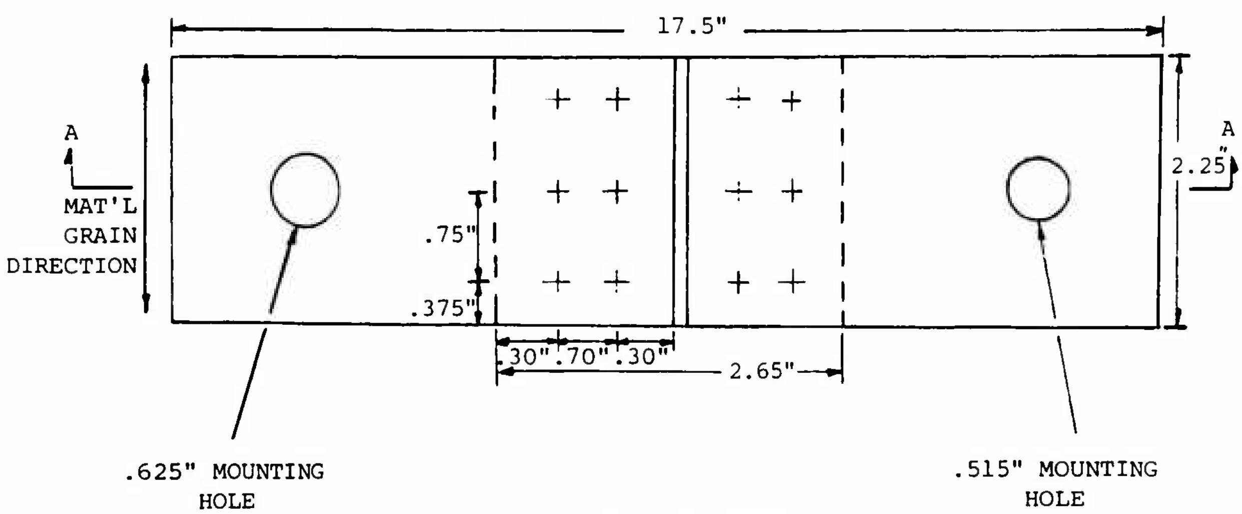
GRIT	CATHODIC TAFEL CONSTANT (volts/decade)	CORROSION CURRENT DENSITY (μamps/cm^2)
SiC	0.498 ± 0.006	5.2 ± 0.7
Al_2O_3	0.496 ± 0.003	5.7 ± 0.5

Corrosion potential = -0.764 volts.

FIGURE 1 - FATIGUE TEST SAMPLE



SECTION A-A



PLAN VIEW ON SAMPLE

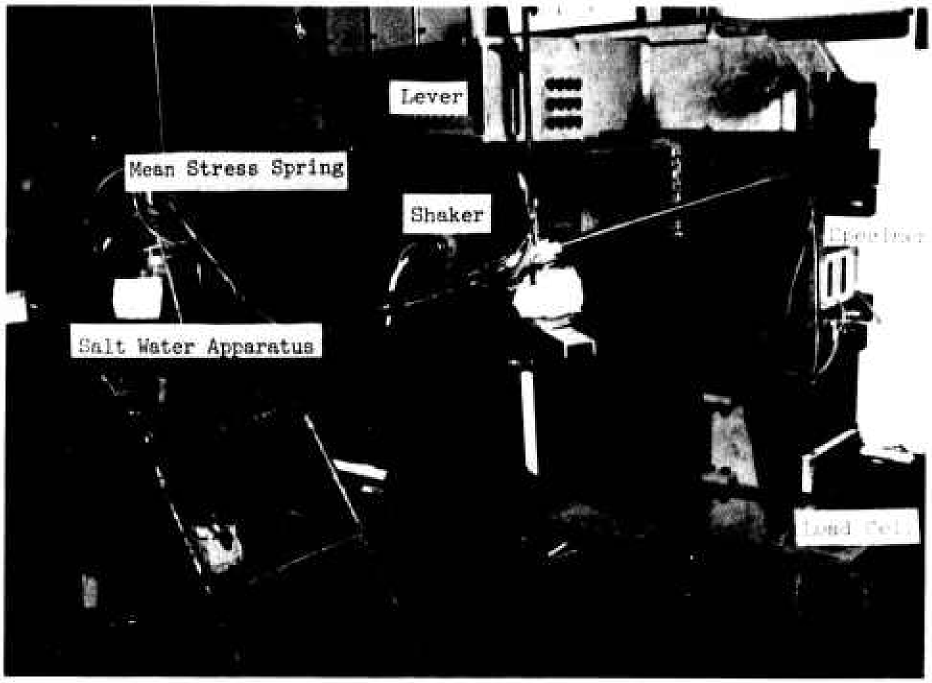


Figure 2. R-3 Shaker-lever fatigue test machine.

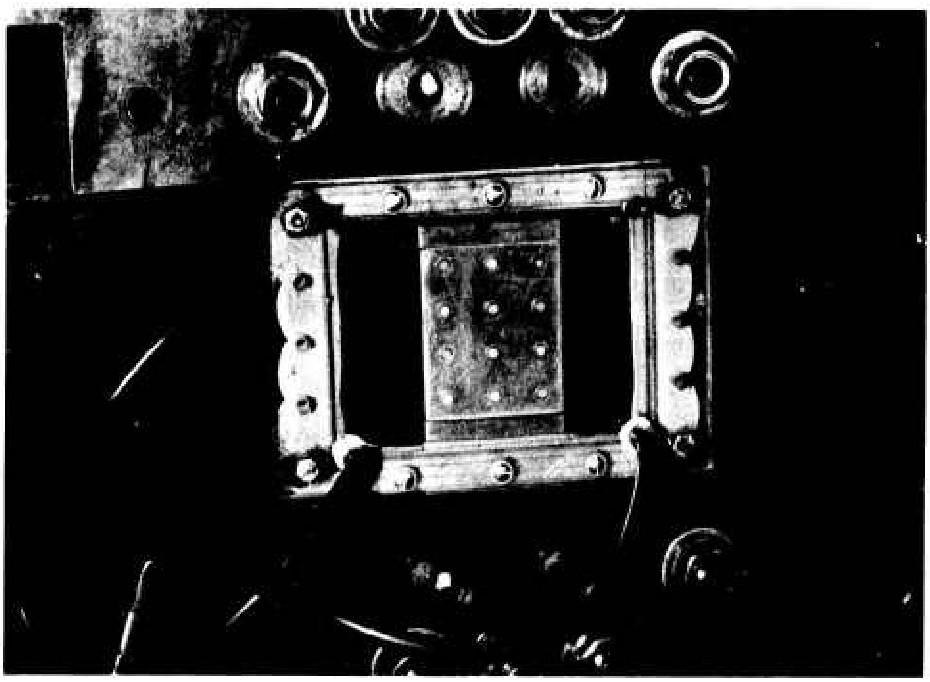


Figure 3. Specimen compartment of fatigue test machine.

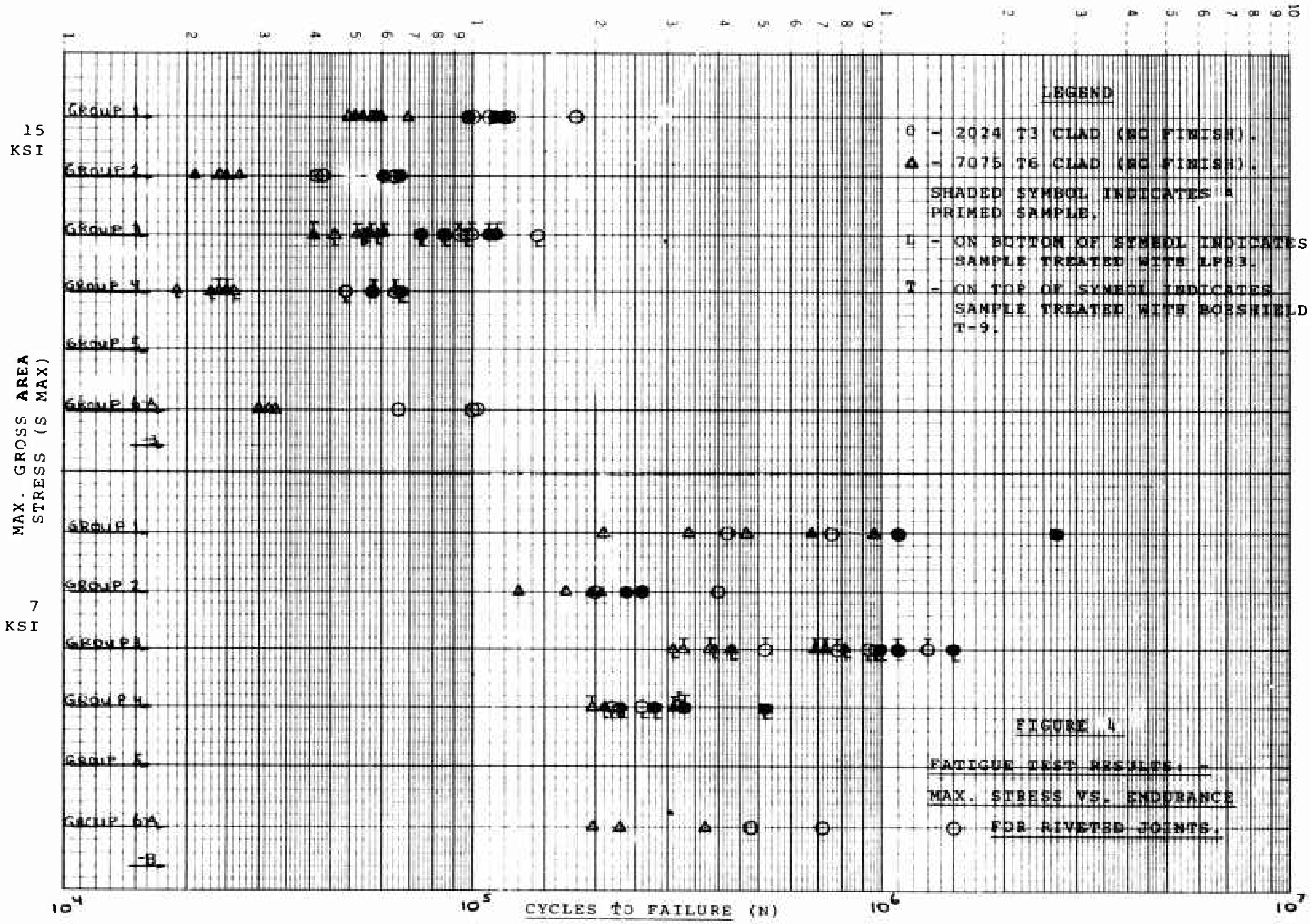


FIGURE 4

FATIGUE TEST RESULTS. - MAX. STRESS VS. ENDURANCE FOR RIVETED JOINTS.

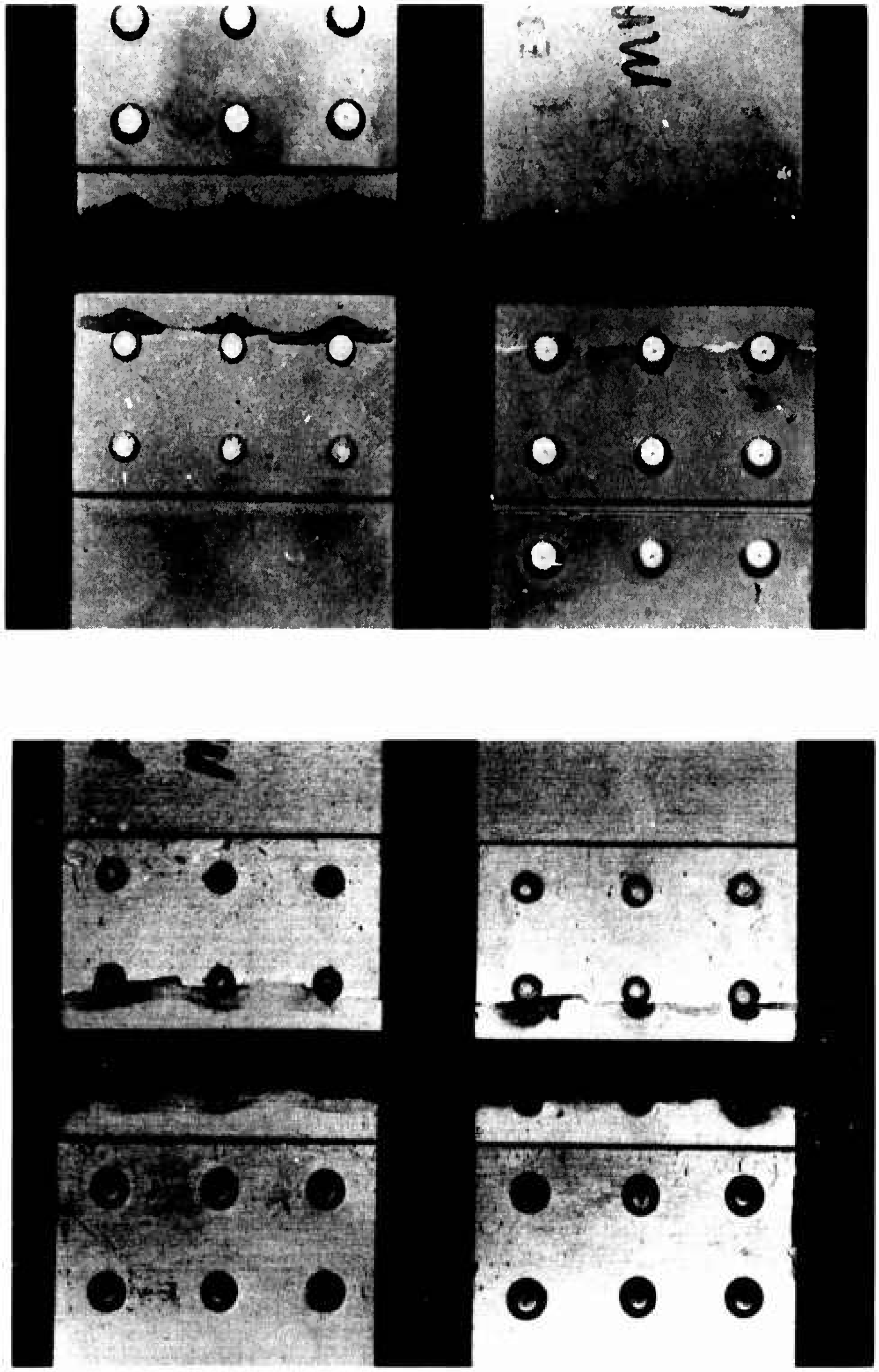


Figure 5. Typical fatigue failures in the butt strap.

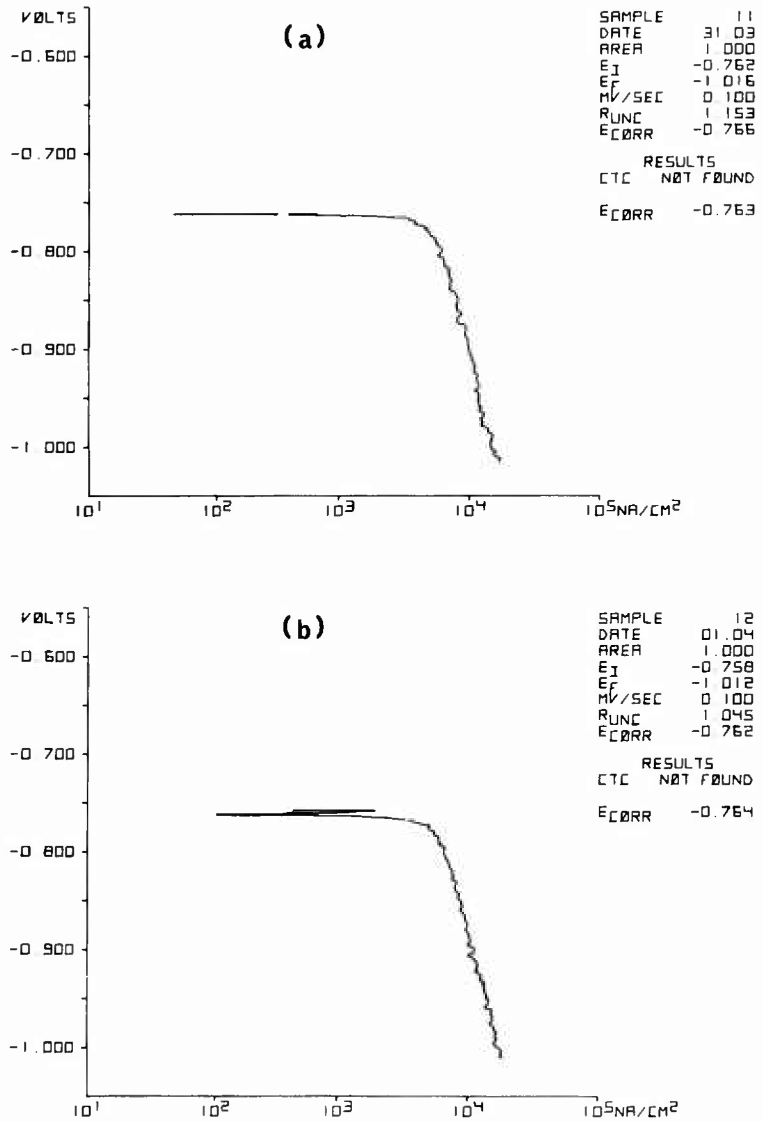
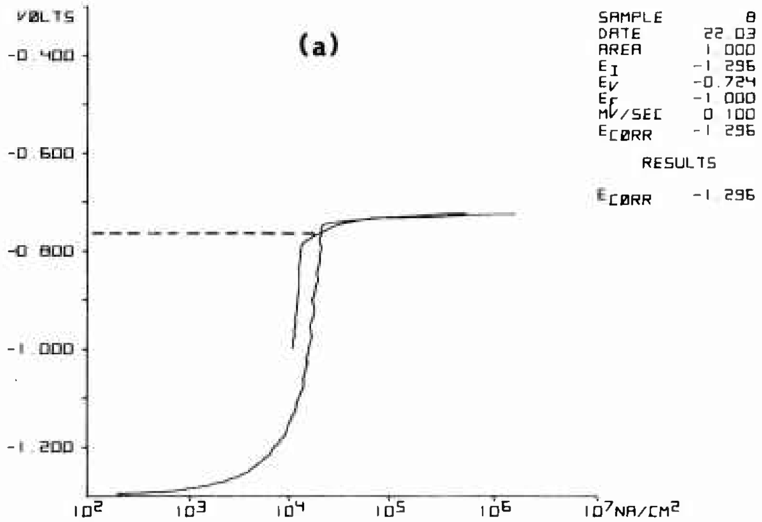


Figure 6. Cathodic Tafel plots for 7075-T6 aluminum in aerated sea water. a) Imbedded with 400 grit silicon carbide. b) Imbedded with 400 grit aluminum oxide.



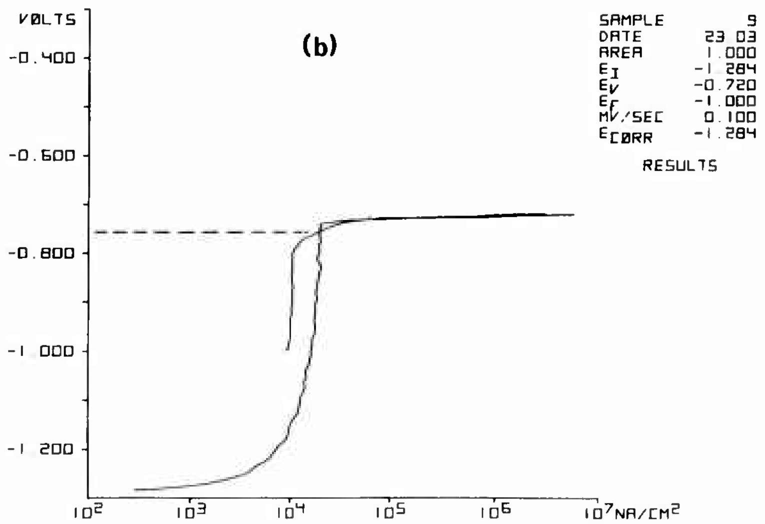


Figure 7. Potentiodynamic anodic polarization curves for 7075-T6 aluminum in deaerated sea water. a) Imbedded with 400 grit silicon carbide. b) Imbedded with 400 grit aluminum oxide. Dotted line indicates the corrosion potential in aerated solution.

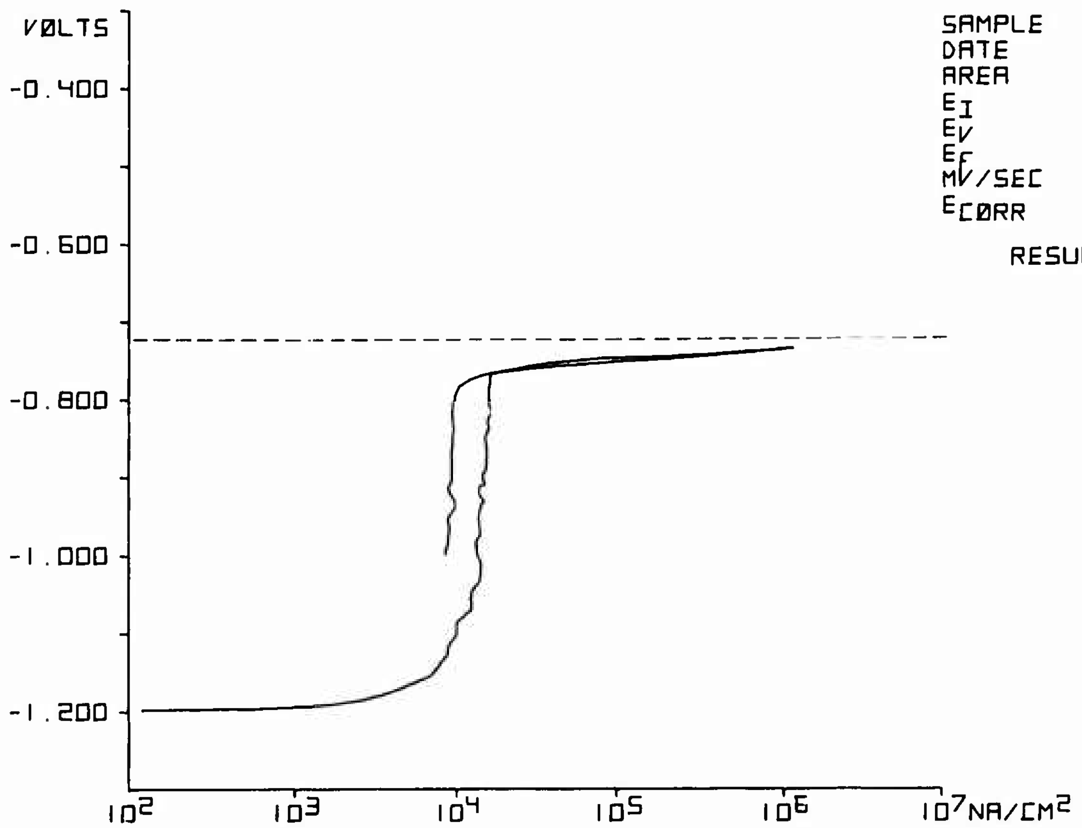


Figure 8. Potentiodynamic anodic polarization curve for 7075-T6 aluminum imbedded with copper particles. The dotted line indicates the corrosion potential in aerated sea water.

METHODOLOGY FOR ASSESSMENT OF CORROSION COSTS

by
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AD-P003 636

INTRODUCTION

Corrosion has a significant impact on the life cycle costs of naval aircraft. Materials, energy, labor and technical expertise that would otherwise be available for alternative uses must be allocated for corrosion control. To help justify the added expense of designing more corrosion resistance in future Navy aircraft and spending more in corrosion research and technology, valid estimates of the magnitude of corrosion costs and the relative distribution of those costs among various aircraft types and aircraft systems are important. While many factors make up the Navy's cost of corrosion for aircraft ownership, the overwhelming one is the effort spent doing maintenance.

MAINTENANCE DATA COLLECTION SYSTEM

The Navy has three levels of aircraft maintenance: organizational, intermediate and depot. The functions of each level are listed in Figure 1. The 3M (Maintenance and Material Management) Data Collection System provides documentation of maintenance. Data is collected and recorded by fleet personnel for the organizational and intermediate levels. The information is transferred from the operational sites to the Navy Maintenance Support Office (NAMSO) where it is used to prepare various types of reports. One of these reports is the monthly 3-M Aviation Corrosion Control/Treatment Report. This report highlights specific Navy/Command segments and is comprised of two basic parts: (1) Individual Aircraft Summaries and (2) Basic Aircraft Model Summaries. The data available is comprehensive and valuable information can be gleaned including such items as: total direct maintenance manhours, manhours and items processed in preventive maintenance and manhours and items processed in corrective maintenance or in the treating of corrosion.

Preventive maintenance includes: aircraft washing, cleaning, surface treating, touch-up painting and inspections. It includes everything that is done to prevent corrosion on aircraft and support equipment where there is presently no corrosion. Corrosion corrective maintenance includes: cleaning, surface treating, priming and painting of corroded items that require no other repair.

There are, however, weaknesses in the data collection system which understate the magnitude of corrosion maintenance. The depot level costs are not addressed. A separate system known as Depot Maintenance Data Collection System, was developed to accumulate this data but has never been fully implemented and little corrosion maintenance data can be extracted. The indirect support costs, those for labor, materials and administration are not accounted for. In addition there is no way to separate the corrosion prevention and treatment manhours spent on items that are repaired due to failures that are attributed to causes other than corrosion. This problem is particularly acute for avionics equipment. For example, it is impossible for an avionic technician at the organizational level to know that corrosion is the cause of a malfunction in a failed WRA (weapon replaceable assembly) because he is not authorized to open the WRA. In this case, he reports the maintenance in accordance with a malfunction code such as: no power out, weak receiver, intermittent transmitter, etc. The failed unit is forwarded to an IMA (intermediate maintenance activity) where a bench technician confirms the malfunction and investigates the cause of the malfunction. If a short in a discrete curcuit component had developed because of corrosion, the bench technician would clean the unit, replace the shorted circuit component and record the action as "remove and replace." The initiating cause of the failure would not be documented.

CORROSION MAINTENANCE DATA

In spite of the limitations in the 3M system, the data that is reported does show that a sizable effort is dedicated to corrosion maintenance. Yearly totals of corrosion maintenance manhours are plotted in Figures 2 through 4, for three types of aircraft. As can be noted, the Navy is spending more manhours each year doing corrosion maintenance with both the preventive and corrective efforts being in long term uptrends. Particularly sharp increases occurred in FY82. In every case preventive maintenance is always the dominant factor.

Several reasons can be put forward to explain these increases. Changes in maintenance policy were made that extended the periods between SDLM (Standard Depot Level Maintenance) for different aircraft. For example, this interval was stretched from 24 to 48 months for the F-14. The policy of performing maintenance at the lowest capable level was enforced more stringently. The organizational and intermediate levels were thus forced to assume more responsibility for corrosion control. The extent and frequency of corrosion inspections were increased. Better training was provided to fleet personnel in the recognition and treating of corrosion. New maintenance manuals were issued and older ones updated. Greater emphasis was placed on conducting and properly documenting corrosion maintenance.

In addition alterations in operational requirements are having their impact. Battle groups deployed to the Indian Ocean during monsoon weather in the summer have encountered unique corrosion control problems. The environmental conditions, listed in Figure 5, are perhaps the harshest experienced by operating aircraft. Under these conditions, the aircraft almost always are covered with a fine film of sand and salt that reappears every 10-15 minutes after being wiped off. Condensation occurring during the very high humidity at night places a corrosive salt solution over the entire aircrafts' exposed surfaces. Continual wipedowns throughout the day by the plane captains have been found to be the best means of combating this severe environment.

Initially many returning aircraft were failing post deployment inspections. One F-14 aircraft inducted for SDLM required 2000 additional manhours of maintenance due to corrosion damage. Since then deployed units were directed to conduct additional corrosion inspections and preventive maintenance including extensive application of water displacing corrosion preventive compounds to all known and suspected corrosion prone areas. Good results have been achieved by these added efforts. Aircraft have been returning from the Indian Ocean in a satisfactory condition from a corrosion standpoint.

There is no direct relationship between corrosion and aircraft usage. Many carrier aircraft average approximately 350 to 400 flight hours per year, or slightly over one flight hour per day. The corrosion processes can be most active during non-operating periods when the aircraft are parked on the flight deck. However, calculating corrosion maintenance manhours per flight hour provides a useful way to compare different kinds of aircraft. The data normalized in this manner are plotted for several aircraft arranged in groupings in Figures 6 and 7. It appears only by coincidence that the A-6E and A-7E exhibit almost identical graphs. Three aircraft, the E-2C, F-14 and S-3A received considerably more maintenance than other aircraft in FY-82. More than eight hours of labor were expended for every flight hour. For the period investigated the S-3A showed the steepest slope rising in the six years, from 1.8 to 8.3 corrosion maintenance manhours per flight hour. Comparing the three large propeller aircraft, in Figure 7, it can be noted that the P-3C, the only non-carrier based aircraft, is given much less maintenance. While it is tempting to attribute the cause to the corrosive conditions of the aircraft carrier environment, the difference in mission profiles is probably a more important factor. The P-3 being a long range patrol aircraft logs many more flight hours per aircraft.

Maintenance expenditures in FY-82 for corrosion for different types of aircraft are listed in Table 1. This list includes most of the aircraft in the Navy's inventory. A labor rate of 19 dollars, obtained through the VAMOSC (Visability and Management of Operating and Support Costs) AIR program was used for these calculations. While admittedly understated for the reasons discussed, the sum for just these aircraft amounts to over 108 million dollars. This number does not include depot maintenance and represents only direct labor expended at the organizational and intermediate levels. Estimates used in the National Bureau of Standards Special Publication[1] "Economic Effects of Metallic Corrosion in the United States" allowed that depots costs and fleet costs were similar and that the cost for materials represents 20 percent of that of labor. If these estimates are applied to the FY-82 endeavor, the cost of corrosion maintenance would exceed 250 million dollars.

Further evidence of the significance of corrosion maintenance is provided in Table 2. Here the percentages of total unscheduled maintenance expended for corrosion are shown. Unscheduled maintenance is that portion taken up by corrective actions and repair. The average for the nine aircraft listed is 11.3 percent.

When properly interrogated the 3M data collection system can yield other useful information. It is historical baseline data against which later reliability or maintenance requirements can be compared after a design change or maintenance change takes place. It is by this use that the effectiveness of corrosion control materials and procedures can be measured. This method would apply to the substitution of corrosion resistant alloys and composites and the use of new coatings, sealants, water displacing corrosion preventive compounds, etc. A quantitative assessment would be made by determining the corrosion maintenance costs for individual parts and components and tracing these costs over several years.

The 3M system, also, can serve to raise appropriate red flags which trigger more detailed engineering investigations necessary to provide the basis for corrective actions and this is, perhaps, its most common use.

REFERENCES

1. National Bureau of Standards Special Publication, "Economic Effects of Metallic Corrosion in the United States," issued May 78.

TABLE I

COST OF AIRCRAFT CORROSION* FY-82

AIRCRAFT	CORROSION MAINTENANCE COST (MILLIONS)
A-6	18.0
A-7	16.8
C-130	2.0
AV-8A	.5
E-2	4.3
F-4	9.6
F-14	12.0
H-2	4.0
H-3	8.4
H-46	7.0
H-53	3.4
P-3	14.9
S-3	7.9
	TOTAL = 108.8

LABOR RATE = $19.

*INCLUDES ONLY ORGANIZATIONAL AND INTERMEDIATE LEVELS OF MAINTENANCE

PORTION OF UNSCHEDULED MAINTENANCE EXPENDED ON CORROSION IN FY-82*

AIRCRAFT	TOTAL MAINTENANCE DMMH/YR (THOUSANDS)	CORROSION MAINTENANCE DMMH/YR (THOUSANDS)	% CORROSION MAINTENANCE
A-6E	1,590	174	11.0
A-7E	1,870	240	12.8
E-2C	397	64	16.1
F-14	1,890	169	8.9
H-2	343	42	12.2
H-3	729	88	12.0
H-46	904	104	11.5
P-3C	1,640	105	6.4
S-3A	1,050	114	10.9
		AVG	11.3

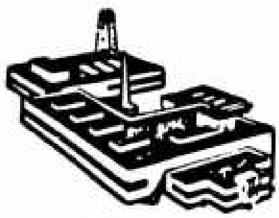
*INCLUDES ONLY ORGANIZATIONAL AND INTERMEDIATE LEVELS OF MAINTENANCE

ORGANIZATIONAL

- (ON EQUIPMENT) INSPECTING, SERVICING, LUBRICATING, ADJUSTING, AND REPLACING PARTS, ASSEMBLIES, AND SUB-ASSEMBLIES

INTERMEDIATE

- (OFF-EQUIPMENT) CALIBRATION, REPAIR OR REPLACEMENT OF DAMAGED OR UNSERVICEABLE PARTS, COMPONENTS, OR ASSEMBLIES



DEPOT

- MAJOR OVERHAUL OR COMPLETE REBUILD OF PARTS, ASSEMBLIES, SUB-ASSEMBLIES, AND END ITEMS INCLUDING THE MANUFACTURE OF PARTS, MODIFICATIONS, TESTING, AND RECLAMATION AS REQUIRED

FIGURE 1. LEVELS OF MAINTENANCE

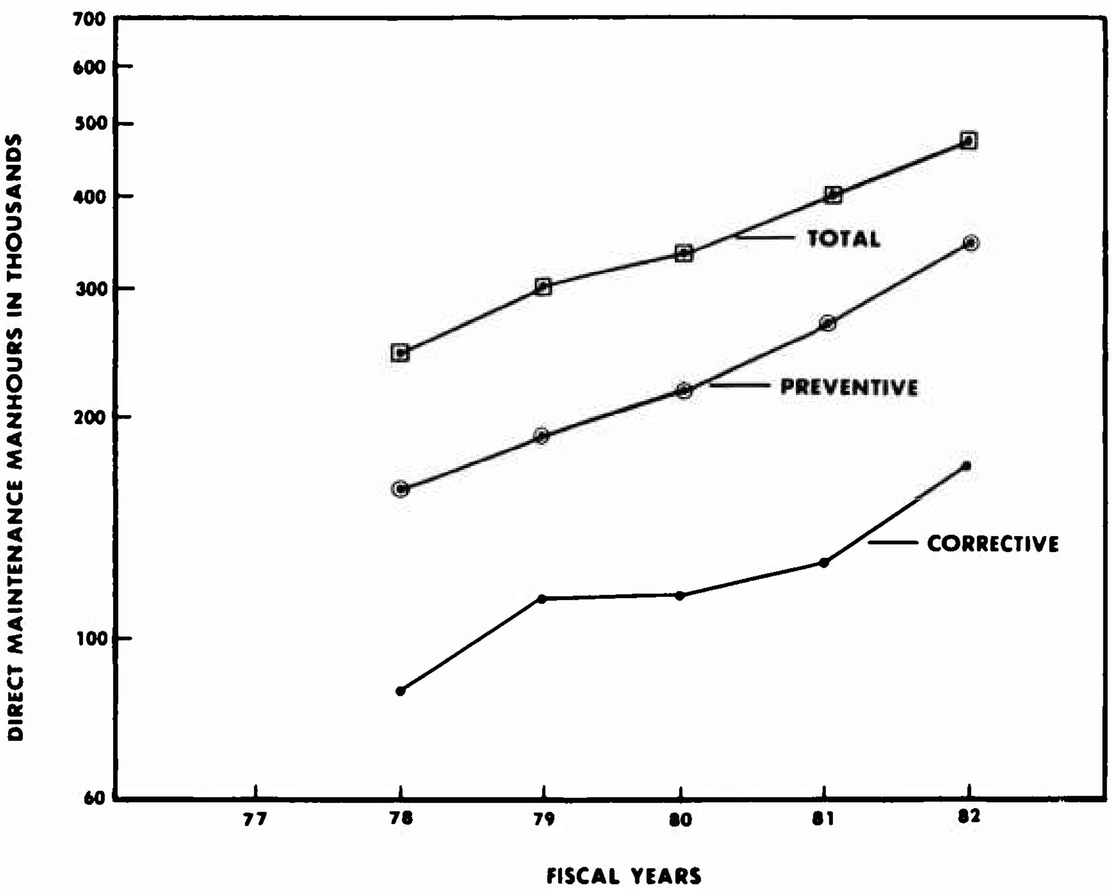


FIGURE 2. CORROSION MAINTENANCE A-6E

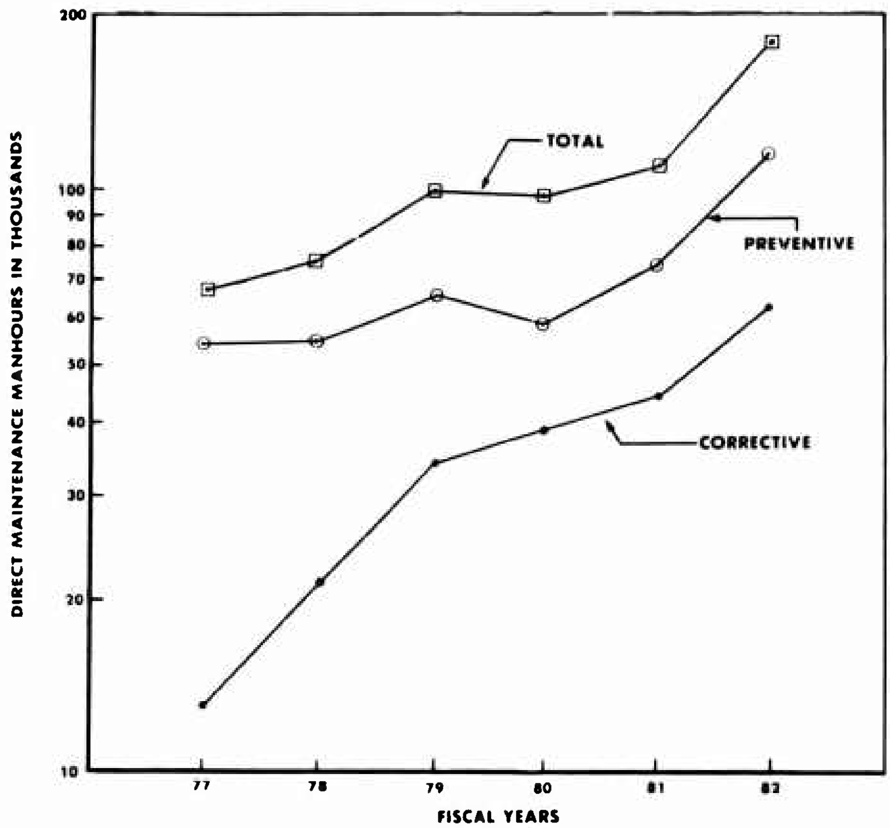


FIGURE 3. CORROSION MAINTENANCE E-2C

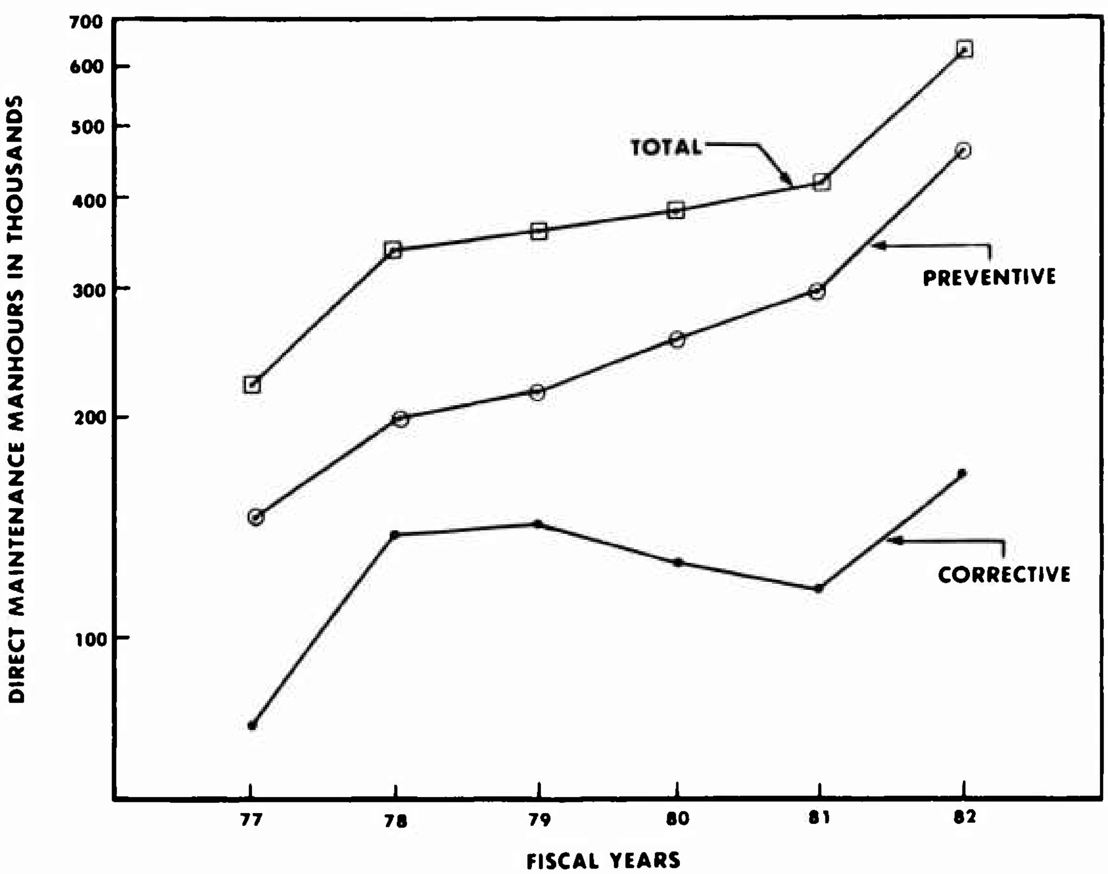


FIGURE 4. CORROSION MAINTENANCE F-14

THE CONTINUOUS SOUTHWEST MONSOON DURING THE MONTHS OF MAY THROUGH AUGUST PRODUCES EXTREMELY HIGH HUMIDITY AND LOW CEILINGS. THE WEATHER DURING THIS PERIOD IS UNCHANGING

OVERCAST - 1000' TO 1500'

WINDS - SOUTHWEST AT 10-20 KNOTS

TEMPERATURE - 80-90°F

R.H. - 70-89% DAY

95-100% NIGHT

CONTINUOUS SALT/PARTICULATE MIST IN THE AIR UP TO 3000'

FIGURE 5. ENVIRONMENTAL CONDITIONS IN INDIAN OCEAN

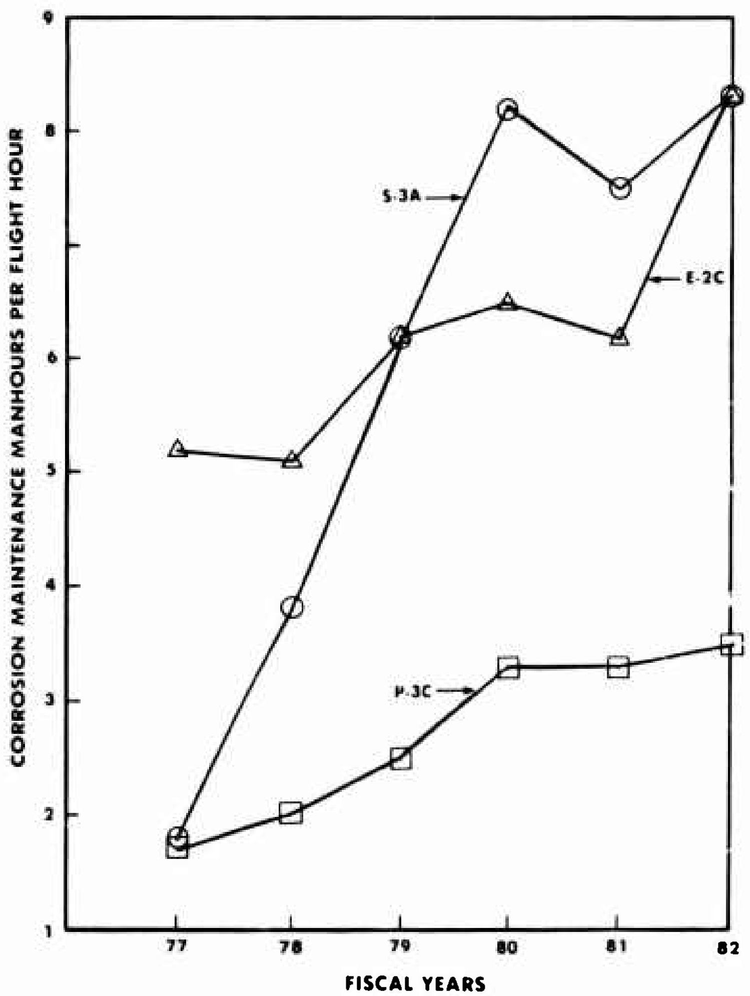


FIGURE 6. CORROSION MAINTENANCE MANHOURS PER FLIGHT HOUR

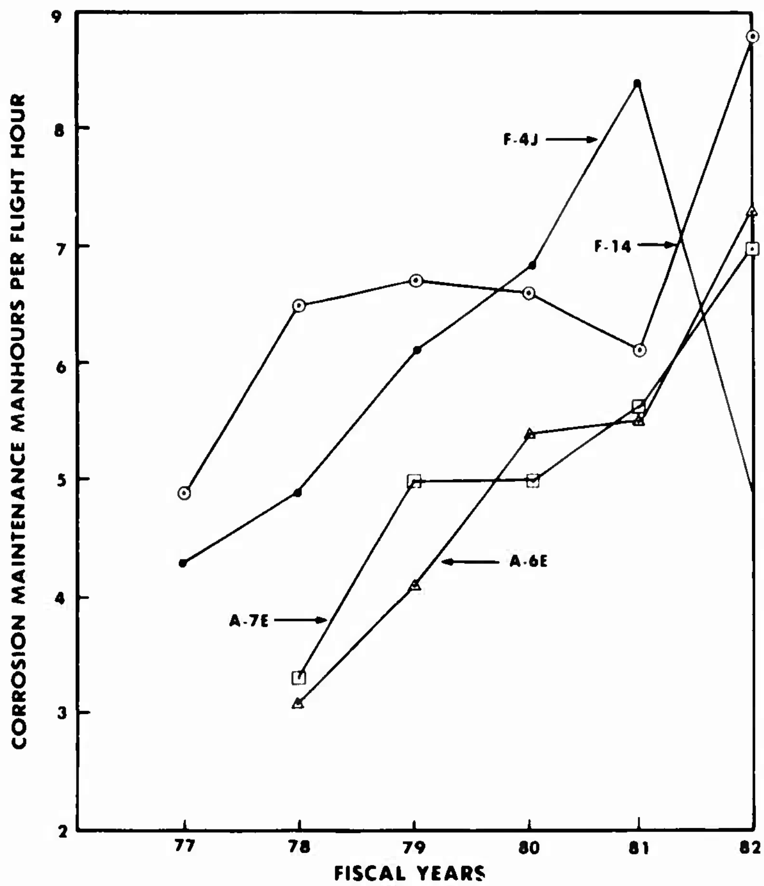


FIGURE 7. CORROSION MAINTENANCE MANHOURS PER FLIGHT HOUR

Cost of Corrosion for Commercial Aviation

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It was explained that due to the difficulty of obtaining accurate corrosion costs, this presentation was more in the nature of a statement rather than a written paper on airline corrosion costs. The intention was to highlight the existence of the International Air Transport Association Document "Guidance Material on Design and Maintenance Against Corrosion of Aircraft Structures" (Doc Gen/2637). This document had been prepared by a working group of several airline members on desirable practices and included an estimate of corrosion costs. These costs were in the process of being updated to 1983 values (based purely on labour escalation costs) since the original figures were derived in 1979.

The relevant section from the document dealing with costs is reproduced as follows:-

"Several IATA Member Airlines have made a preliminary analysis of their corrosion costs based on the annual costs of scheduled maintenance, modification and replacement.

The results of these analysis show the financial cost of the corrosion problem which can be expressed in several ways.

i) Direct cost per flying hour depending on operators and aircraft type (not including maintenance overhead.

1979	1983
$8 – $12	$8 – $20

ii) Percentage of direct airframe maintenance cost between 6% and 8%.

iii) Total annual direct cost for IATA Member Airlines.

$100 M based on 1976 operations and
$200 M based on 1982 operations.

It should be noted that the values represent costs for a range of operators and aircraft types. The lowest value is very conservative and is largely based on one operators actual modification project costs only. The higher value is probably closer to the true cost since it is based upon a breakdown of actual modification, routine maintenance and inspection costs.

Closer examination of these figures reveal that the major component in the cost values associated with corrosion prevention and control is due to labour costs. An additional cost not reflected in the above figures is the unscheduled downtime both at main base and route stations."

It was explained that the original IATA document was in the process of being updated to include information of benefit to the airlines in maintaining the aircraft during its operational life. This updated issue is due to be published in the near future.

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14. Abstract

This publication reports the proceedings of a Workshop held by the Structures and Materials Panel in London, Spring 1983. It contains a number of short presentations made by specialists in the areas of procurement and design specifications, manufacturing and maintenance practice, and costings; both present usage and future prospects are considered. Despite a good level of information interchange, the need for detailed and uniform specification requirements is apparent.

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